Birds and the Built Environment: The Impacts of Architecture, Structures, and Green Spaces on Avian Populations in the United States

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Abstract

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The history of modern bird conservation in the United States built environments starts with the success story of the peregrine falcon in the 1970s. Architecture was crucial to the recovery of this once-endangered bird. Architecture and designed green spaces also have been beneficial to the many other species that have successfully adapted to environments dominated by people. In turn, people have valued the enlivening, beneficial presence of birds in cities, parks, neighborhoods, and farms. This history demonstrates that birds are integral to the built environment. However, the built environment can also cause great harm to birds. Bird building collisions are one of the leading anthropogenic threats to birds, killing 365-998 million birds a year in the United States. Glass, lighting, and landscape elements contribute to this enormous loss. Solar and wind energy sources and infrastructure and communication towers also present significant hazards. These dangers in the built environment will have long term impacts on the overall population of birds in the United States and have contributed to a net loss of 29% of the bird population in North America since 1970. Mitigating the threats facing urban resident birds and migrating bird populations in the built environment depends on a clear understanding of birds as integral and essential to our built environment, a comprehensive assessment of built-environment threats birds face, a balanced approach to implementing effective collision mitigating design strategies, and development of regulations, policies and educational resources related to bird preservation in built environments. Building first on a history of birds and architecture, this thesis seeks to provide designers and architects with knowledge about how birds interact with the built environment, a critical assessment of design

strategies and architecture-specific policies that benefit urban birds, and proposals for making built environments more amenable to birds through design, policy, and education.

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Thank you to "my birds" for teaching me patience, resilience, and that humans must *do better* to protect birds from preventable harm. Their histories, and an unforgettable volunteering experience, inspired me to study birds and the built environment. The following are some of the birds I worked with and how they were injured by anthropogenic hazards: Tussey, a majestic golden-eagle (*Aquila chrysaetos*) lives with injuries from colliding with powerlines. Barbi, a magnificent great-horned owl (*Bubo virginianus*) was injured by a barbed-wire fence. Beautiful Jerudi, a barred owl (*Strix varia*), sweetheart Novia, a barn owl (*Tyto alba*), triumphant Neo, a turkey vulture (*Cathartes aura*), and multiple avian ambassadors were injured by vehicle collisions. Additionally, Alula, a gorgeous red-tailed hawk (*Buteo jamaicensis*) and Millie, a spirited peregrine falcon (*Falco peregrinus*), are powerful representatives of two influential species that symbolize the connection between birds and human civilizations as well as raptors and the built environment. I'm thankful for our four years of building trust together.

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For Chantey, Kestrel, Rachel, Short-Ear, Two-Eye, and all of "my birds."

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INTRODUCTION

Culturally, in western institutions and the English language, we discuss and perceive urban areas as detached or separate from nature, and we seem unable to move beyond this dualist world view.[1] However, central to the idea of ecology is that people and nature are inherently interconnected. They are influenced by each other, and this coupled human-nature system[2] is abundantly present in the built environment. How can birds aid in ending the perceived bifurcation of nature and city as self-contained and different entities? The study of birds that inhabit areas that include wilderness and dense urban spaces provides a tractable means of studying these various systems, and it provides a lens through which to view the world around us.[3] This is particularly true in urban areas, where birds show that nature is as alive in cities as it is beyond their limits.[4] Birds have unique relationships with architecture and built structures, which can be both beneficial and detrimental to them.

Birds have been living in built spaces with humans for millennia. The imagery of birds is found as early as 3200 BCE on the Narmer Pallet from Ancient Egypt[5] and in scenes of conquest on the 2400 BCE Stele of Vultures from Mesopotamia.[6] Birds were portrayed throughout Ancient Egyptian iconography and language even with species-specific details, as seen with the barn owl (*Tyto Alba*)[7] in Figure 1. Bird sightings were first recorded in written form in Vedas, Sanskrit, as early as 1500 BCE.[8] Vultures were integral to death rituals, by performing the ecological service of disposing of the dead, at the Towers of Silence located in present-day Iran dating as early as the 5th century BCE.[9] Peregrine falcons (*Falco peregrinus*) were found nesting on buildings during the Middle Ages, have been spotted perching atop towering cathedrals, and

[1] Ingrid Leman Stefanovic and Stephen Bede Scharper, *The Natural City Re-Envisioning the Built Environment* (Toronto, ON: University of Toronto Press, 2014), 11-12.
[2] Michael L. Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018), 886-7.
[3] Ibid., 8.
[4] Stefanovic and Scharper, *The Natural City Re-Envisioning the Built Environment*, 14.
[5] Hartwig and Melinda, *A Companion to Ancient Egyptian Art* (John Wiley & Sons, 2014), 62.
[6] Ann Clyburn Gunter, *A Companion to Ancient Near Eastern Art* (Hoboken, NJ: Wiley Blackwell, 2019), 292.
[7] Rozenn Bailleul-LeSuer and Anna Ressman, *Between Heaven and Earth: Birds in Ancient Egypt* (Chicago, IL: Oriental Institute of the University of Chicago, 2012), 175.
[8] Morrison, *Ornithology: Foundation, Analysis, and Application*, 892.
[9] Ibid., 897.

were first documented in North American cities in the 1930s.[10] As civilizations documented and recorded the human narrative through time, birds have been included in art and text, observed in our daily lives, incorporated in our rituals, and valued for their services. This relationship with birds has continued into the modern era.

Figure 1. Birds and Ancient Civilizations
Top: Stele of Vultures, Mesopotamia, 2400 BCE, Louvre, Paris.
Bottom Left: Narmer Pallet, Egypt, 3200 BCE, Egyptian Museum, Cairo.
Bottom Right: Head of an Owl (*Tyto alba*), Egypt, 664 BCE.

Pale Male, a light-colored red-tailed hawk (*Buteo jamaicensis*), is a modern-day representative of our relationship with birds in the built environment. The first significant event in Pale Male's life, as recorded by birders in Central Park in New York City, was colliding with a building. Pale Male and his first known partner were documented nesting in Central Park in the early 1990s. After building their nest and laying eggs, local crows had distracted both parents

[10] Clint W. Boal and Cheryl R. Dykstra, *Urban Raptors: Ecology and Conservation of Birds of Prey in Cities* (Seattle, WA: Island Press, 2018), 258-272.

during flight, resulting in building collisions for both birds on separate days. Pale Male returned to the park after observation for a concussion at a New York wildlife rehabilitation center. Unfortunately, his partner was sent to a rehabilitation center in New Jersey and was released but did not return to Central Park.[11]

Pale Male is most famously known for his connection to the people of New York City. Frederic Lilien documented Pale Male's daily life and relationship with the urban residents in *The Legend of Pale Male*. Citizens rallied around in awe of the hawk as he nested on an affluent 5th Avenue apartment building on a 12th-floor cornice. Hundreds of people visited the viewing location in Central Park. The citizens of New York became enthralled with Pale Male's every action, some moved to tears by watching him catch a meal, celebrating each fledgling's first flight, and even yearly Father's Day parties for the hawk. Unfortunately, the residents of the building were not happy with his choice of nesting space that brought crowds to their neighborhood. In 2014, after 15 years and four mates, the building's Co-Op Board dismantled the nest and removed the spikes that held it in place. The citizens were horrified and stood vigil outside of the building. Rallies intensified, chanting lasted day and night as citizens called for the nest to be returned. In just six days, the protesters, along with the New York Audubon Society, who at the time only had three staff members, negotiated with the Co-Op Board. The board hired New York City architect Dan Ionescu to design a permanent nest shown in Figure 2. The designed nest was bolted to the building. Immediately Pale Male and his mate Lola began filling it out with sticks.

Six nesting seasons went by without one viable egg. People began to question if the human-designed nest interfered with nesting. However, after Lola passed away and Pale Male found a new mate, the next breeding season brought viable chicks that fledged. The couple has had 19 additional young by 2020 for a total of 46 young for Pale Male.[12] On April 30th, 2020, Pale Male turned 30 years old.[13] While this advanced age is rare for his species in the wild, an abundance of food, human protection, a personal architect, and luck may have all contributed to

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[11] Marie Winn, *Red-Tails in Love: Pale Male's Story--a True Wildlife Drama in Central Park* (New York, NY: Vintage Departures, 2005), 39-59.

[12] The Legend of Pale Male (Distribber, 2009), https://www.thelegendofpalemale.net/.

[13] "The Legend of Pale Male / New York / Nature Films," The Legend of Pale Male, accessed April 22, 2020, https://www.thelegendofpalemale.net/.

his legendary survival.[14] Pale Male is an avian ambassador for urban birds showing how strong the connection between birds and humans can be in the built environment.

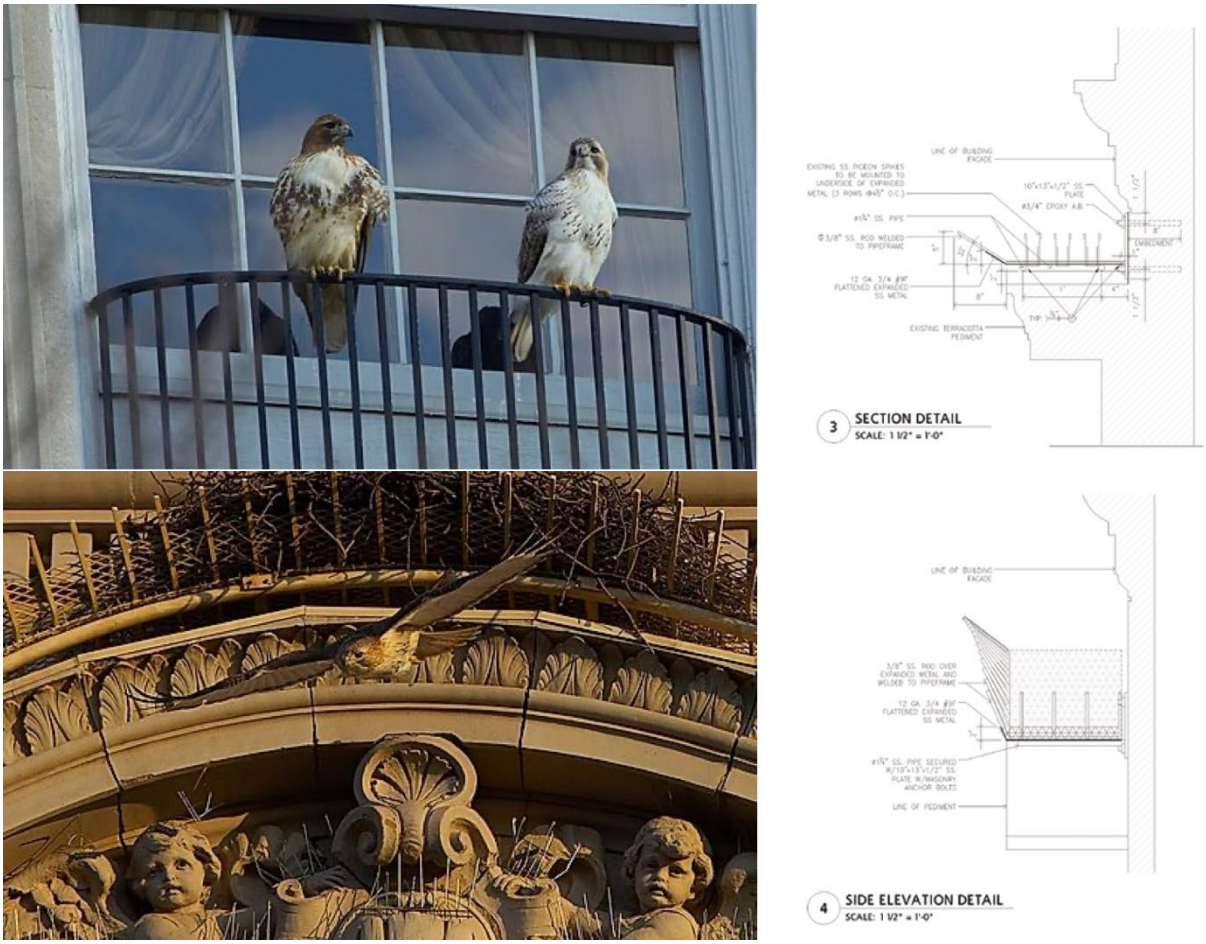

Figure 2. Pale Male with His Mate and Designed Nest
Top left: Pale Male and Lola on a resident's window. Bottom left: Pale Male's architect-designed nest. Right: Detail of Ionescu's nest design.

Birds have economic value as well as cultural and environmental value. Over 53 million people feed birds in the United States, creating a cycle of positive services from humans to birds leading to an increased number of species in areas where feeding is more prevalent.[15] The visibility and accessibility of birds relative to most other wildlife makes bird-watching, ecotourism, and enjoying birds valuable economically. The U.S. Fish and Wildlife Service's 2016 report indicated 45 million Americans actively observed birds around their homes or on

[14] The Legend of Pale Male (Distribber, 2009), https://www.thelegendofpalemale.net/.
[15] Morrison, *Ornithology: Foundation, Analysis, and Application*, 891.

trips.[16] Additionally, they spent over 12 billion dollars on wildlife observing equipment, including bird feeders and binoculars.[17] Birds also provide essential ecological services, including the pest control of insects, small mammals, and weeds; seed dispersal and pollination; scavenging to remove dead carcasses, and nutrient cycling.[18] Although the economic value of birds is hard to measure outside of the poultry industry and the use of feathers in products, it is clear that their value is significant.[19] Great tits (*Parus major*) in the Netherlands were reported to reduce caterpillar damage on a Dutch apple orchard that would cost $44-105 per hectare for professional, human-led, pest removal services. Similarly, a pair of Eurasian jays (G*arrulus glandarius*) are valued between $4,900 and $22,000 over their lifetime for their pest control services.[20]

Urban birds show they are among the most vulnerable wildlife to air, noise, and light pollution. Often birds show signs of environmental stressors of urban life earlier than humans, providing insight into how these stresses affect living beings, including humans. Consequently, birds are indicators of our current environmental conditions. House sparrows (*Passer domesticus*), a globally distributed species that dominate highly urbanized areas, show evidence of increasing oxidative stress[21] due to pollution and poor-quality diets, which could be contributing to their population decrease in European cities over the last few decades.[22] Great tits have been observed singing at a higher frequency to prevent their song from being masked by low-frequency urban noise such as road and air traffic.[23] These changes in vocalizations can interfere with a bird's ability to survive and reproduce.[24] Additionally, along with habitat loss and pollution, bird building collisions have become one of the most significant factors in many

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[16] "2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation," October 2018, https://www.census.gov/library/publications/2018/demo/fhw-16-nat.html.
[17] "2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation."
[18] Morrison, *Ornithology: Foundation, Analysis, and Application*, 891.
[19] Ibid.,891.
[20] Ibid.,891.
[21] Oxidative stress is defined as the occurrence of enzymatic and non-enzymatic antioxidants that cannot fully neutralize the free radicals produced in the cells of living organisms.
[22] Amparo Herrera-Dueñas et al., "The Influence of Urban Environments on Oxidative Stress Balance: A Case Study on the House Sparrow in the Iberian Peninsula," *Frontiers in Ecology and Evolution* 5 (2017).
[23] Hans Slabbekoorn and Margriet Peet, "Birds Sing at a Higher Pitch in Urban Noise," *Nature* 424, no. 6946 (2003): 267-267.
[24] Ondi L. Crino et al., "Effects of Experimentally Elevated Traffic Noise on Nestling White-Crowned Sparrow Stress Physiology, Immune Function and Life History," *The Journal of Experimental Biology* 216, no. 11 (2013), 2055.

avian species' long-term survival.[25] Nearly half of North American migrant birds have declined in numbers by at least 50% since the 1970s,[26] and bird building collisions have likely contributed to this number. A staggering 365 to 988 million birds are killed per year due to bird building collisions alone.[27]

Mitigating environmental stresses and reducing bird building collisions can both be addressed by sustainable architecture. To build sustainably, designers must factor in environmental matters.[28] Some principles of sustainable design that specifically impact birds include designs that coevolve with nature, designs to heal the planet, designs with nature, and understanding that landscapes or green spaces should not be fragmented based on building footprints or boundaries. [29] These principles aid in safeguarding birds from urban threats but do not directly protect resident or migrating birds from casualties caused by structures and buildings. Restorative environmental design, a combination of sustainable design and design focused on human well-being, aims to achieve a harmonious relationship between nature and humans in the built environment by reducing adverse effects of design on nature and human health, while promoting a connection between people and nature.[30] This principle of sustainable design should protect birds in the built environment through collision mitigation. However, birds are rarely a primary focus in restorative environmental design and, as a result, are still in harm's way. Positive environmental impact or biophilic design enhances human well-being by connecting humans and nature through building and landscape design with direct, indirect, or symbolic experience of natural or place-based designs.[31] However, outside of creating space for biodiversity, often overlooked are birds and their relationship to human well-being.[32] When designers open buildings with large walls of glass to increase natural light and connect people

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[25] Ondi L. Crino et al., "Effects of Experimentally Elevated Traffic Noise on Nestling White-Crowned Sparrow Stress Physiology, Immune Function and Life History," *The Journal of Experimental Biology* 216, no. 11 (2013), 2055.

[26] Kenneth V. Rosenberg et al. "Decline of the North American Avifauna." *Science* (New York, N.Y.) 366, no. 6461 (2019): 120-124.

[27] Scott R. Loss et al., "Bird–building Collisions in the United States: Estimates of Annual Mortality and Species Vulnerability," *The Condor* 116, no. 1 (2014): 2.

[28] Stefanovic and Scharper, *The Natural City Re-Envisioning the Built Environment*, 13.

[29] Stephen R. Kellert, *Building for Life : Designing and Understanding the Human-Nature Connection* (Washington, DC: Island Press, 2005), 97.

[30] Ibid., 93.

[31] Kellert, *Building for Life : Designing and Understanding the Human-Nature Connection*, 96.

[32] Giuseppe Carrus et al., "Go Greener, Feel Better? the Positive Effects of Biodiversity on the Well-being of Individuals Visiting Urban and Peri-Urban Green Areas," *Landscape and Urban Planning* 134 (2015): 221-228.

visually with nature, we place birds in harm's way. While recent design movements have striven to connect humans with natural systems in the built environment, "sustainable," "restorative," or "biophilic" principles of sustainable design must not be merely in the interests of humans. They should create built environments in harmony with the natural environment.[33] Architects and designers have been focused on sustainability to preserve the planet, and biophilic design to increase the well-being of our species, but often overlook the negative impacts these designs have on avian species. Structures awarded for their commitment to meeting sustainability standards should not kill birds routinely.[34] Protecting birds through design strategies must be upheld as a vital component of comprehensive sustainable design standards, policies, and education.

Beginning with the modern history of birds in the built environment, chapter one narrates the generally symbiotic relationship between architecture and urban birds as it has unfolded in built environments in the United States. This history begins with the compelling story of the peregrine falcon's return from the brink of extinction that took place on the concrete cliffs of major American cities. Next, this chapter discusses preferences for urban spaces with two examples of urban adaptors the Anna's hummingbird (*Calypte anna*) and the dark-eyed junco (*Junco hyemalis*). The second half of this chapter focuses on the benefits of green urban habitats and food sources to some birds. These habitats include green walls, green roofs, and using native plants in landscapes.

Chapter two examines the threats posed by the built environment for resident and migrating birds. This chapter outlines the specific negative impacts of building design, beginning with a brief overview of structures in the built environment that are hazardous to birds. Energy infrastructure accounts for millions of bird deaths each year in the United States.[35] Solar panels, wind energy, and powerlines all contribute to this loss.[36] Communication towers, transportation, and common structures such as fencing add their unique threats to birds in the built environment.[37] This chapter briefly discusses these significant contributors to bird mortality in

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[33] Kellert, *Building for Life : Designing and Understanding the Human-Nature Connection*, 92.
[34] The U.S. Bank Stadium in Minneapolis, Minnesota as certified LEED Platinum in 2019, the first professional sports stadium to do so. However, its reflective glass facade kills over 100 birds every year.
[35] USAGov. "Migratory Bird Conservation Commission: USAGov." Official Website of the United States Government, https://www.usa.gov/federal-agencies/migratory-bird-conservation-commission.
[36] Ibid.
[37] Ibid.

the built environment and their solutions.[38] However, the focus of this chapter is the threats posed by architecture, lighting, and landscape design primarily in the urban built environment. One of the leading anthropogenic threats local and migrating birds face in the built environment is bird building collisions.[39] Reflective and transparent glass windows and facades cause the most casualties. Lighting also causes significant harm to birds in the built environment through light pollution, lighting that illuminates transparent glass at night, and floodlighting used to illuminate facades. Finally, landscape design, specifically the location of trees, shrubs, and other vegetation, is another influential factor in bird building collisions.

The design solutions outlined in chapter three include efforts to reduce and eliminate bird building collisions, methods used to reduce light pollution and behavior disruptors, and the importance of understanding how avian species interact with built environments.[40] The available glass solutions are evaluated based on their testing methods, limitations, and ability to reduce window collisions in controlled experiments. The section first explains the science behind the most commonly recommended solution by avian conservation organizations to reduce collisions: horizontal and vertical line patterns and frit dot patterns. This is followed by an examination of ultraviolet or UV films and patterns. Next, the chapter addresses the limitations of decals and angled glass. This chapter also addresses glass solutions tested in the American Bird Conservancy's experiments and their threat factor rating system. Next, the chapter presents straightforward methods to prevent light pollution and reduce lighting, followed by a brief section outlining how to mitigate collisions due to landscape design choices. This includes incorporating knowledge beyond design through the understanding of avian behavior, migration patterns, and life histories of local and migrating birds. Finally, this chapter ends with three case studies that provide examples preventative design strategies. [41]

Chapter four compiles current legislation and sustainable design guidelines intended to protect birds in the United States. This chapter begins with a brief history of the acts, policies, and programs that aim to protect bird populations in the built environment. Next, the chapter

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[38] USAGov. "Migratory Bird Conservation Commission: USAGov." Official Website of the United States Government, https://www.usa.gov/federal-agencies/migratory-bird-conservation-commission.

[39] The results of the influence of human beings on nature.

[40] The phrase "bird building collisions" is crucial to use consistently to communicate that window strikes or window collisions are not the only threat facing birds in the built environment. Birds can collide with illuminated structures and materials other than glass.

[41] A life history is the changes through which an organism passes in its development from the primary stage to its natural death.

details sustainable design guidelines that aim to encourage construction of buildings that coexist with local ecosystems, like the Living Building Challenge, or that explicitly incorporate guidelines to protect birds, like LEED's Pilot Credit 55. The last section reviews city and federal policies aimed to reduce bird building collisions. The chapter provides recommendations and revisions to sustainable design guidelines and legislation based on the evaluation of currently available solutions.

Chapter five outlines education strategies to communicate the best available solutions to reduce bird building collisions and to promote the value of birds. First, the important task of communicating these solutions to architects and designers can be achieved by integrating collision mitigating strategies into sustainable design education and college campus policies. Advocating for birds through avian conservation organizations plays a vital role in educating the public about mitigating bird building collisions and the value of urban birds. Finally, aviaries and avian rehabilitation centers connect the public to the personal stories of resident birds fostering stewardship and offering examples of collision mitigation techniques to the public through their buildings.

CHAPTER 1 ADAPTATIONS AND BENEFITS OF THE BUILT ENVIRONMENT

Birds occupy most areas of the built environment, from rural landscapes with few built structures, to small towns with sporadically placed homes between fields, through suburbs with manicured back yards and human-provided food sources, and even dense urban areas where concrete cliffs offer roosting and breeding habitat. Throughout these various spaces of the built environment, some birds have benefited from found or designed habitats and adapted to our diverse landscape modifications. These birds can be identified as urban exploiters or urban adaptors.[42] The abundance of resources birds require (food, water, areas for perching, roosting, and nesting sites) changes with the level of urban development, and individual bird species respond differently to these changes.[43] Urban exploiters, such as American crows (*Corvus Brachyrhynchos*) can exploit and are specifically attracted to heavily developed areas. Urban adaptors, such as dark-eyed juncos (*Junco hyemalis*), can exploit the diverse and abundant resources [44] provided by a moderate to lower level of development.[45] Not all birds can adapt to urban development. Urban avoiders, such as pacific wrens (*Troglodytes pacificus*), avoid areas with even minimal development of the landscape.[46] Often the preferred habitats of urban exploiters and adaptors resemble our general idea of prime habitat. These birds make use of green spaces, but they also challenge our presumptions about proper habitat by nesting on window ledges of high rises, flat gravel roofs, or steel beams, and still successfully fledge offspring. These birds occupy our office buildings and residences with the same right to be there as humans, while also teaching us that overlooked architectural features such as substrate, gravel, or ledges can be prime real estate for birds. In specific cases, they can creatively adapt to altered and constructed environments. This chapter provides examples of how some bird species have benefited from or adapted to our human-centric designs and describes ways design can offer more resources to support these species.

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[42] John M. Marzluff et al., "The Causal Response of Avian Communities to Suburban Development: a Quasi-Experimental, Longitudinal Study," *Urban Ecosystems* 19, no. 4 (April 2015): 1597-1621.
[43] Robert B. Blair, "Land Use and Avian Species Diversity Along an Urban Gradient," *Ecological Applications* 6, no. 2 (1996): 507.
[44] These resources are provided by structural diversity in buildings and vegetation such as increased perching areas or ornamental vegetation.
[45] Blair, "Land Use and Avian Species Diversity Along an Urban Gradient,": 512-3.
[46] Ibid., 514.

THE PEREGRINE FALCON IN URBAN HABITATS

The most well-known narrative of the peregrine falcon (*Falco peregrinus*), takes place in the modern built environment. However, peregrine falcons have nested on buildings as early as the Middle Ages; they have been nesting on Salisbury Cathedral in Wiltshire, England since 1860, and were first documented in North American cities in the 1930s.[47] In the mid-20th century, the role of architecture and the urban environment was a fundamental component to the recovery of the peregrine falcon, a species that until the 1960s was documented to have only 350-400 pairs in the Midwestern and Eastern United States. By the 1960s, peregrine falcons were no longer residents of cities and were rarely seen during the migration season. Their dramatic decline was due to a buildup in the environment of the organochlorines DDE, a byproduct of the pesticide DDT, which was widely applied to croplands. The chemical moved its way up the food chain to the fastest land predator, the peregrine falcon By inhibiting calcium absorption, abnormal reproduction in peregrine falcon led to thin eggshells that broke easily under the weight of the female during incubation.[48] Ultimately this led to nest failure leaving one last breeding pair in the city of Chicago in 1951. In 1972, Rachel Carson made the dangers of DDE to wildlife and humans widely known in her seminal book, *Silent Spring*. The United States banned DDT, and in 1973 peregrine falcons were placed on the U.S. Endangered Species List.[49]

These legal measures helped to protect the remaining pairs of peregrine falcons and organize a recovery effort to protect the species. The Peregrine Fund, then based at Cornell University, developed a program to captively breed and release peregrine falcons. This was eventually taken over by falconers-turned-breeders in the Midwest. Chicago became the center for the release of young falcons through the Chicago Peregrine Program. [50] After over 7,000 captive-bred peregrine falcons were successfully released in North America in the late 1970s, the population increased as the peregrine falcon nested in both remote areas and in built environments, like Chicago, that supported dense human populations near bodies of water. Cities

[47] Clint W. Boal and Cheryl R. Dykstra, *Urban Raptors: Ecology and Conservation of Birds of Prey in Cities* (Seattle, WA: Island Press, 2018), 258-272.
[48] Mary Hennen et al., *The Peregrine Returns: The Art and Architecture of an Urban Raptor Recovery* (Chicago, IL: The University of Chicago Press, 2017), 2-6, 10.
[49] Ibid., 2-6, 10.
[50] Mary Hennen et al., *The Peregrine Returns*, 16-21.

near rivers, lakes, or oceans provide "ample diverse prey, structures with ledges for nests and perches, and open sky to hunt and soar."[51] Cities also offer a habitat with few natural predators.[52] The recovery effort was so successful that peregrine falcons not only started to breed in Illinois but expanded to Indiana, Minnesota, Iowa, Missouri, Ohio, Nebraska, Wisconsin[53] and today, peregrine falcons can be found on both coasts of the United States.

Peregrine falcons are an idyllic example of how some bird species have adapted to the urban environment without needing extensive human support once they have established themselves there. Peregrine falcons now call the urban Midwest canyons of neoclassical buildings, skyscrapers, and modern sustainable buildings in Chicago their year-round habitat, even though the city was not designed with birds in mind (see Figure 3). The first pair to nest in Chicago was in 1987 on the Willis Tower (then called the Sears Tower). Peregrine falcons are typically cliff-dwelling species and use ledges often with gravel substrate as nesting areas. No nest building is required beyond making a small depression in the substrate called a "scrape."[54] In some cases, nests on bare steel beams o have been viable.[55] Buildings along Wacker Street in downtown Chicago, including the Willis Tower, have been continuous nesting sites for pairs of peregrine falcons for over 33 years. The nesting sites along Wacker Street are chosen not for the building's size, but because of the cliff-like ledges, which allow a full 360° view when incubating eggs. These buildings provide a balance between protection and few confining tall walls. Spaces that are more cave than cliff-like also allow nesting high above the city, with little interference from humans. This can be seen in the abandoned historical clock tower in the Central Manufacturing District, which has been occupied by peregrine falcons since 2009.[56] (See Figure 3.)

[51] Boal and Dykstra, *Urban Raptors*, 180-195.
[52] Ibid., 258-272.
[53] Mary Hennen et al., *The Peregrine Returns*, 16-21.
[54] Ibid., 24-6.
[55] Boal and Dykstra, *Urban Raptors*, 180-195.
[56] Mary Hennen et al., *The Peregrine Returns*, 42-6.

Figure 3. Peregrine Falcons (*Falco peregrinus*) on Built Structures
Top: Cliff-like Ledges.
Bottom left: Historical Clock Tower. Bottom Right: Water Intake Crib.

Once suitable nests are established, peregrine falcons have high nest fidelity, meaning they will only choose a new nesting site if breeding is unsuccessful or the site is damaged and unusable. Sites such as a gutter can wash away nests, balcony planters can cause disturbances for both peregrine falcons and humans, and bridges over water could lead fledglings to drown.[57] Protected landmarks are also not ideal places for the peregrine falcon, though as a result of human conflicts rather than ecological unsuitability, particularly when the owners and residents aim to preserve the landmark. For example, when a pair attempted to nest on the historic Powhatan building in Chicago, managers recommended outfitting the roof with a nest box. However, the residents did not want to share their space with the protected falcons, [58] perhaps because of their loud calls and damaging excrement. A compromise was made to allow the pair to complete that year's breeding attempt in the safety of a supplied nest box, but to remove the box 45 days after the young fledged to preclude future attempts. The pair successfully relocated to a site over a mile away. [59]

[57] Mary Hennen et al., *The Peregrine Returns*, 50-2.
[58] Ibid., 107-14.
[59] Ibid., 50-2.

Peregrine falcons also choose unusual or unwanted nesting sites on building types different from those the first breeding pairs chose in the 1970s, such as the water intake cribs shown in Figure 3. Their unique shape mimics rock ledges.[60] Private balconies also can have excellent nesting habitats. Planters with a natural substrate and a covered but not enclosed area on the side of a building produce safe nesting spots. [61] Unfortunately, some building residents may not welcome excretion stains or leftover parts of peregrine meals on or near their buildings. (See Figure 4.)

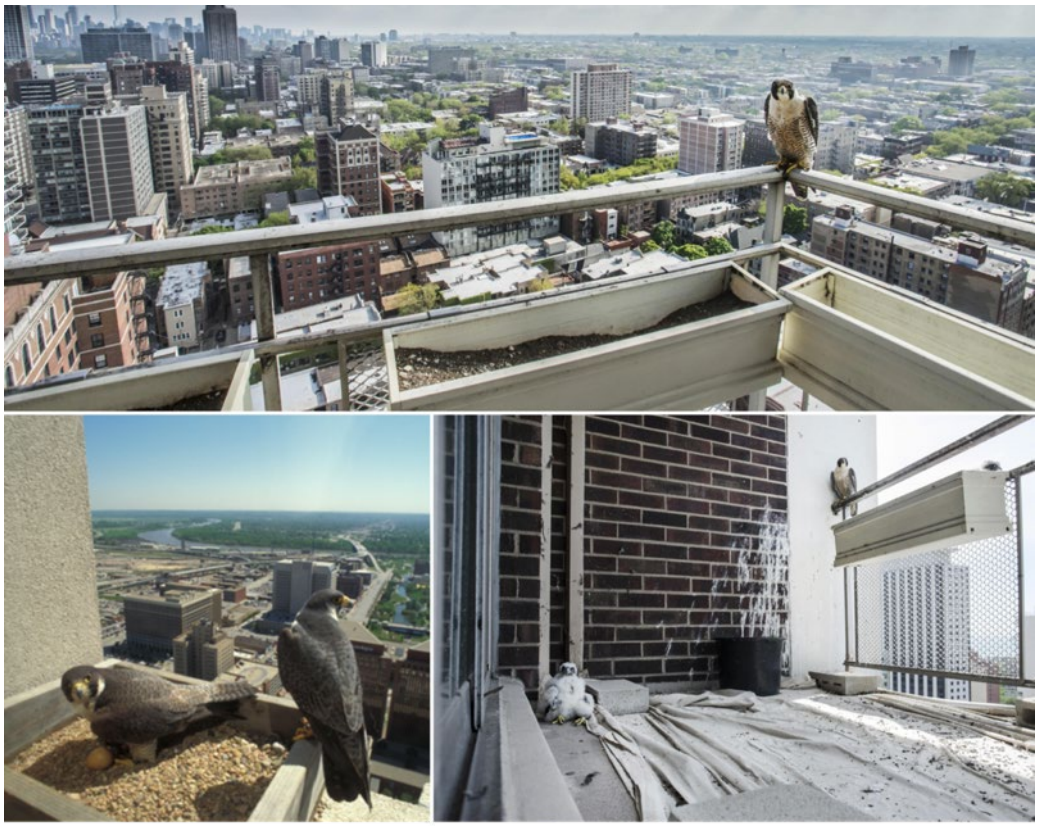

Figure 4. Peregrine Falcons (*Falco peregrinus*) Nesting On Buildings

The presence of the peregrine falcon in urban areas helps to promote conservation efforts. One way this is achieved is through live streams of nests on buildings, which provide comprehensive data from 24-hour monitoring.[62] Since peregrine falcons are protected, their nests cannot be removed, and residents who inadvertently host breeding pairs must wait until the

[60] Mary Hennen et al., *The Peregrine Returns*, 141-55.
[61] Ibid., 141-55.
[62] Boal and Dykstra, *Urban Raptors*, 180-195.

falcons abandon their nests or the chicks fledge.[63] While some residents welcome their new neighbors, mess and all, the addition of a nesting box may be an option for those who are uncomfortable sharing space with a raptor family. Education efforts to inform residents about ecological services peregrines perform, such as pest control, could help further persuade them to allow nesting.

A survey in 2017, indicated that all but seven US states are home to the peregrine falcon, and their urban habitats vary from small towns to metropolises.[64] Even some peregrine falcons that were released in remote areas eventually migrated to cities, becoming many of the urban peregrine falcons that occupy cities on the West Coast of North America.[65] Designing for peregrine falcons helps further conservation efforts and provides desired ecosystem services. Scientists have designed nest trays and integrated pea gravel onto ledges to provide adequate nesting substrate for peregrine falcons.[66] In a study of 87 urban nests in eastern North America, human-made nest ledges and gravel-lined trays or boxes had almost three times the total number of young fledge than those without human-made additions. Several building and bridge managers have investigated how to attract peregrine falcons to control starling and pigeon populations. They have suggested the presence of peregrine falcon has lessened maintenance costs.[67] The species has shown they are capable of adapting to architecture that mimics their natural habitat. Little additional designed space is needed to help make their urban habitat more successful. However, it is important to remember peregrine falcon nesting requirements when designing new buildings as not inadvertently to remove their preferred habitat space.

Examples of how some birds have adapted to urban and suburban spaces are often clearly displayed by raptors or "birds of prey" through their visible interactions with architecture and modified urban landscapes. However, a preference for urban and suburban spaces, and some birds' ability to adapt to their resources, is not exclusive to raptors. Some hummingbirds like the Anna's hummingbird (*Calypte anna*) and passerines, or songbirds, like the dark-eyed junco, have also adapted to the built environment.

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[63] Mary Hennen et al., *The Peregrine Returns*, 142-145.
[64] Boal and Dykstra, *Urban Raptors*, 180-195.
[65] Ibid.
[66] Ibid.
[67] Ibid.

ADAPTING TO PERI-URBAN AND SUBURBAN SPACES

As humans modify the landscape and contribute to climate change, some animal populations are forced to move to new habitats and modify their behaviors in response to these new ecological and evolutionary pressures.[68] Birds need to respond to environmental changes as quickly as humans cause them.[69] Some birds can adapt to these changes and benefit from the resources provided by peri-urban and suburban spaces like the Anna's hummingbird and the dark-eyed junco (see Figures 5 and 6).

The Anna's hummingbird's traditional winter range was the Pacific slope of northern Baja California and north to the San Francisco Bay area of California. Since the mid-1930s, the species' winter range has been expanding and now extends as far north as Vancouver Island in British Columbia and inward towards southern Arizona and West Texas.[70] To understand what could account for this range expansion, Greig et al. (2017) examined how climate, housing density, and supplementary feeding data predicted winter occupancy of Anna's hummingbirds over a 17 year (1997-2013) period across the West Coast. They found that over this timespan, Anna's hummingbirds were able to become residents in urban and suburban areas they previously migrated out of during the winter. Housing density and human-modified habitat predicted colonization in the expanded range but not in their historical range.[71] These urban areas allow the species to survive colder thermal limits, in part due to local heat retention or the "heat island effect". In addition, while warmer winters supported this shift, they found that it was primarily supplemental food in the form of non-native flowers and nectar feeders, that best modeled this change in winter occupancy.[72] These findings suggest that the Anna's hummingbird's winter range expansion is due to the species' ability to utilize urbanization,

[68] Emma I. Greig et al., "Winter Range Expansion of a Hummingbird Is Associated with Urbanization and Supplementary Feeding," *Proceedings of the Royal Society B: Biological Sciences* 284, no. 1852 (2017): 1.; Ellen Ketterson, "Journey of the Juncos: Migration and Adaptation in Our Changing World," *Bird Academy, Cornell University* (October 7, 2019).
[69] Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[70] Clark and Russell. Anna's Hummingbird (CALYPTE ANNA), version 1.0. In Birds of the World (A. F. Poole, Editor). (2020) Cornell Lab of Ornithology, Ithaca, NY, USA.
[71] Greig et al., "Winter Range Expansion of a Hummingbird Is Associated with Urbanization and Supplementary Feeding,"(2017): 5.
[72] Ibid., 6-7.

cultivated urban and suburban exotic plants,[73] and supplementary feeding through human-provided feeders.[74] The nectar feeders demonstrate the connection between human modifications of the environment, human behaviors, and the adaptation and support of a species. Through land modification and resource availability, humans have altered the distribution of the Anna's hummingbird and potentially the species' migratory behavior.[75]

Figure 5. Female Anna's Hummingbird (*Calypte anna*)

The dark-eyed junco is one of the most recognizable passerines in North America.[76] This common and abundant species is found from northern Alaska to northern Mexico.[77] The dark-eyed junco is known as the "snowbird" for its ground foraging winter flocks often observed around suburban feeders. This species is located throughout the built environment in backyards, edges of parks and modified landscapes, farms, and rural roadsides in addition to their ancestral mountain breeding habitat.[78] The dark-eyed junco's ability to adapt to peri-urban and suburban settings has provided essential ecological research of avian evolution and migration. In the

[73] Greig et al., "Winter Range Expansion of a Hummingbird Is Associated with Urbanization and Supplementary Feeding,"(2017): 6-7.
[74] Ibid., 1-6.
[75] Ibid., 1.
[76] Nolan et al. Dark-eyed Junco (JUNCO HYEMALIS), version 1.0. In Birds of the World (A. F. Poole and F. B. Gill, Editors). (2020) Cornell Lab of Ornithology, Ithaca, NY, USA.
[77] Ibid.
[78] Ibid.

1980s, a small population of dark-eyed juncos successfully colonized the campus of the University of California in the coastal city of San Diego, California.[79] This "city" or "coastal" population had twice as long of a breeding season than their ancestral "mountain" populations and fledged twice as many young.[80] The dark-eyed juncos in San Diego ceased migrating and were breeding in the city, which offered a milder climate and reliable food sources.[81]

Figure 6. Female Slate-Colored Dark-Eyed Junco (*Junco hyemalis*)

Studies demonstrating how this population adapted to urban environments include significant biological and behavioral changes over a few decades. Yeh's 2004 study found that city dark-eyed juncos exhibited a change in plumage rather quickly. They showed less white coloring on the tails, more brown coloring on the crown, and a slightly shorter wing length.[82] City juncos were also found to be less aggressive,[83] showed fewer signs of stress when handled,

[79] Pamela J. Yeh and Trevor D. Price, "Adaptive Phenotypic Plasticity and the Successful Colonization of a Novel Environment," *The American Naturalist* 164, no. 4 (2004): 531.
[80] Yeh and Price, "Adaptive Phenotypic Plasticity and the Successful Colonization of a Novel Environment," (2004): 531.; Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[81] Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).; Yeh and Price, "Adaptive Phenotypic Plasticity and the Successful Colonization of a Novel Environment," (2004).
[82] Pamela J. Yeh, "Rapid Evolution Of A Sexually Selected Trait Following Population Establishment In A Novel Habitat," *Evolution* 58, no. 1 (2004).; Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[83] Melissa M. Newman, Pamela J. Yeh, and Trevor D. Price, "Reduced Territorial Responses in Dark-Eyed Juncos Following Population Establishment in a Climatically Mild Environment," *Animal Behaviour* 71, no. 4 (2006): 893-899

were calmer, and allowed a closer approach to humans than mountain juncos.[84] Additionally, compared to mountain juncos, city juncos had fewer extra-pair fertilizations,[85] males tended to young more often,[86] and they sang at a higher pitch to be heard over the background noise of the urban environment.[87] These observed changes in urban or city juncos show the species' ability to quickly adapt to the rapid modification of the environment while at the same time illustrating how anthropogenic changes to the landscape and climate can dramatically impact avian species.

The Anna's hummingbird and dark-eyed junco have adapted to land modifications and resources available in peri-urban and suburban areas. The dark-eyed junco was observed nesting in vines on the University of California, San Diego campus,[88] and hummingbirds visit the green wall of the Sam Cuddleback Assembly Wing in San Francisco, California.[89] The built environment can offer additional habitat space and vital resources for these urban adaptors and other bird species by incorporating green walls and green roofs into building designs and using native plants in urban and suburban green spaces.

GREEN WALLS AND ROOFS AS HABITAT

Green walls have been used on buildings for over 2000 years, with the earliest vertical gardens being attributed to Mediterranean cities.[90] Traditionally, green walls use self-adhering plants rooted in the ground, planters that spread along vertical surfaces of structures, or they use plants that drape down from planters on parapets, sills, or balconies. Contemporary green walls, or living walls, grow from systems installed directly onto building walls. They typically are intricate systems with regulated water and other optimized growing variables that are installed onto building facades. While traditional and contemporary systems can vary dramatically

[84] Jonathan W. Atwell et al., "Boldness Behavior and Stress Physiology in a Novel Urban Environment Suggest Rapid Correlated Evolutionary Adaptation," *Behavioral Ecology* 23, no. 5 (2012): 960-969.; Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[85] Jonathan W. Atwell et al., "Hormonal, Behavioral, and Life-History Traits Exhibit Correlated Shifts in Relation to Population Establishment in a Novel Environment," *The American Naturalist* 184, no. 6 (2014).
[86] Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[87] Gonçalo C. Cardoso and Jonathan W. Atwell, "On the Relation between Loudness and the Increased Song Frequency of Urban Birds," *Animal Behaviour* 82, no. 4 (2011).
[88] Ketterson, "Journey of the Juncos," *Bird Academy, Cornell University* (October 7, 2019).
[89] Greenroofs, "Drew School Sam Cuddleback III Assembly Wing Vertical Garden," Greenroofs.com, 2020, https://www.greenroofs.com/projects/drew-school-sam-cuddleback-iii-assembly-wing-vertical-garden.
[90] Manfred Kohler, "Green Facades – A View Back and Some Visions," *Urban Ecosyst* 11, (2008): 423.

regarding the plants used and how they are maintained, both systems can provide valuable green space that improves the aesthetics, building integrity, and health and wellbeing of human occupants.[91] Green walls in the urban environment benefit humans by providing insulation and helping to remove particulates and carbon dioxide from the air.[92] While clinging plants, such as ivy, can be destructive to brick and mortar surfaces, they have been shown to protect walls through temperature and humidity regulation while also helping to reduce storm-water flows.[93] In addition, green walls have been shown to reduce noise pollution and light pollution in urban environments. In addition to the human benefits, these kinds of green spaces can also offer significant habitats to native plants, insects, and birds.

A 2013 study by Chiquet et al., found that self-adhering, green walls indicated immense value to resident avian populations by providing shelter, refuge, and food sources. [94] They monitored 27 green walls and 27 bare walls in Staffordshire, UK during summer and winter months. They found that birds used the upper half the green walls consistently, with no variation between season. There was also an increase of birds on the roofs of buildings with green walls together with surrounding vegetation, in comparison to the bare control walls. The walls in the study ranged in size from 2 m to 6 m high. On each of the green walls, 100% of the surface was covered with vegetation. The walls were surveyed for five months over two seasons: Summer (July and August) and Winter (January, February, March). They observed 83 individual birds comprising nine species, with some arriving in mixed flocks that were more than double the number in flocks found on bare walls.[95] Birds on green walls were more abundant in the morning than evening but showed no difference in numbers throughout the day on the bare walls. The preference for morning indicates insectivorous birds used the green wall for a food source at a time in the day when insects are least active and easier to prey upon.[96] Seasons did not affect the abundance of birds compared to bare walls, but more birds were found on green walls in the winter than in the summer and were associated with evergreen plants more strongly than with deciduous plants in the winter. This study indicated the foliage provides important shelter,

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[91] Manfred Kohler, "Green Facades – A View Back and Some Visions," *Urban Ecosyst* 11, (2008): 423.
[92] Caroline Chiquet et al., "Birds and the Urban Environment: The Value of Green Walls," *Urban Ecosystems* 16, no. 3 (2013): 453-459.
[93] Ibid.
[94] Ibid.
[95] Ibid.
[96] Ibid.

refuge, and nesting space. Evergreen plant species can also produce food for birds in the winter months. No significant difference in birds present on evergreen or deciduous green walls was reported in the summer months.[97]

Green walls can provide a range of resources for urban and migrating birds that either complement existing land-based green areas or offset an absence of such resources.[98] For humans, plants provide increased well-being, health benefits, and recreational benefits as well as various ecosystem services.[99] The benefits of plants, and the increased biodiversity they offer, are typically more visible to humans on green walls than on green roofs or even some land-based green spaces. In this case, green walls can work in combination with green roofs to create larger biodiverse habitat areas in dense urban areas where space for green areas is limited. This design element could be especially beneficial in areas that do not provide people with connections to green spaces or natural areas, particularly if used on walls that face windows where people work and live.[100] An example of a green wall is seen in Figure 7.

Figure 7. Green Wall on the Sam Cuddleback III Assembly Wing, San Francisco, CA

Much like green walls, green roofs are an old technology rooted in the vernacular architecture of many cultures across the globe. In the Middle Ages, green roofs were used at some Benedictine Monasteries, and 20th-century architects incorporated green roofs into their celebrated designs. Le Corbusier listed green roofs as one of his five points of architecture and

[97] Chiquet et al., "Birds and the Urban Environment: The Value of Green Walls,": 453-459.
[98] Ibid.
[99] Ibid.
[100] Ibid.

Frank Lloyd Wright used green roofs as a way to integrate architecture into the natural landscape. Modern green roofs flourished in Europe after the Second World War as countries like Germany aimed to rebuild greener cities.[101] By the 1960s, Germany, particularly Berlin, began to standardize the green roofs we see most commonly today, and by 1970 the standard plants used were *Sedums*. These succulents are tolerant of harsh conditions and can absorb water. By the 1980s, the green roof's ability to store water and reduced runoff became one of the main purposes for incorporating them into building designs.[102]

Today, two types of green roofs are found across Europe and North America: intensive and extensive green roofs. Intensive roofs are formal gardens that require a deep, flat soil layer to plant larger vegetation like shrubs or trees. Extensive green roofs have shallow soil levels and can adapt to roofs with slopes up to 40 degrees. Pre-grown *Sedum* mats are often rolled out onto roof membranes to create an extensive green roof instantly. However, mats offer little biomass limiting the diversity of organisms that can live in them. However, using a substrate material with seeded or planted sedums can offer more biodiversity by allowing species to colonize as the green roof develops.[103] To avoid birds prematurely visiting the space and destroying the young plants, the use of seeding or plugs as the starting vegetation can mitigate this issue.[104]

Green roofs can provide habitat for urban and migrating birds by offering food, water, cover, and space while at the same time benefiting human wellbeing by adding vital green space. However, a green roof's benefit to birds depends on its design, vegetation, and maintenance. [105] When attracting birds to green roofs, food is the most important benefit, so they should be maintained as habitat for invertebrates that birds eat. Birds use green roofs more often in urban areas than in the suburbs, since they are an essential food resource where food may be scarce otherwise.[106] Seed and fruit-bearing plants on roofs are also important food sources, as are food-bearing street trees. In some cases, green roofs could provide coverage to protect birds from predators or weather, particularly when birds use roofs as nesting areas.[107] A wide variety of

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[101] R. Fernandez-Canero and P. Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review," *Journal of Animal and Veterinary Advances* 9, no. 15 (January 2010): 2041.
[102] Dusty Gedge and Kadas Gyongyver, "Green Roofs and Biodiversity," *Biologist* 52, no. 3 (July 2005): 160-2.
[103] Gedge and Gyongyver, "Green Roofs and Biodiversity,": 160-2.
[104] Bowes, Judy, and Matthew J Eckess. Green Roof Planting. Personal, March 1, 2020.
[105] Fernandez-Canero and Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review,": 2043, 2045.
[106] Ibid.
[107] Ibid.

birds can nest on green roofs; these include birds that would typically prefer cliffs, open grasslands, or stony substrate as nesting habitats.[108] Providing water is crucial to attracting birds to green roofs. Some birds can drink the water from planted succulents or benefit from water retaining substrates, and some species can still nest and breed successfully without supplemental irrigation.[109] However, the most attractive designs incorporate supplemental irrigation or small areas of water like a pond or fountain. While green roof space is limited by the roof space available, it is essential to understand the size and habitat needed by the bird species a design is aiming to attract. Not all rooftops will be large enough to accommodate species with extensive space needs or large populations of species. Adding green walls can increase the available habitat. [110] Building height and species mobility contribute to attracting birds to green roofs. While taller buildings may provide sites of respite for migrating birds, resident birds may not be as likely to nest on the same building.[111]

While design tactics can be used to attract birds to green roofs, few studies explain how to promote nesting on green roofs or have observed species of birds that do. Green roofs using extensive amounts of *sedum* can provide habitat for many urban adapters, but attention to habitat design on intensive roofs can create space for vulnerable species. While green roofs do not fully replace land lost to urbanization and other types of habitat destruction, species have been found to return to dense urban areas with the introduction of green roofs. The Waterfowl and Wetland Trust in the United Kingdom designed their green roof to provide space for mallards (Anas platyrhynchos) to nest. Species of skylarks, finches, and thrushes also have successfully nested on the roof.[112] Gedge and Kadas explained in their 2005 article that green roofs can be useful tools for conservationists. For example, they report that the London Biodiversity Partnership is working with developers to create green roofs to promote urban occupation by the black redstart (Phoenicurus ochruros), the UK's rarest breeding bird (50-100 breeding pairs). To mimic this species' preferred habitat and provide a safe space for breeding, the developers designed "brown roofs" with little vegetation and increased substrate.[113] In the United States, The Ford Motor

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[108] Fernandez-Canero and Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review,": 2043, 2045.
[109] Ibid.
[110] Ibid.
[111] Ibid.
[112] Ibid.
[113] Gedge and Gyongyver, "Green Roofs and Biodiversity,": 163.

Company's River Rouge Assembly Plant in Dearborn, Michigan is home to two nesting species, the olive-sided flycatcher (Contopus cooperi) and the killdeer (*Charadrius vociferous*; see Figure 8). Killdeer also have been found nesting on the green roofs at the O'Hare International Airport in Chicago. The city of Portland, Oregon, has listed over eight species using their green roofs.[114] Furthermore, the Jacob Javits Convention Center in New York City listed 29 identified species in 2018, including the Eastern bluebird (Sialia sialis) and red-tailed hawk (Buteo jamaicensis), and over 100 herring gull (Larus argentatus) nests were recorded in 2019 (see Figure 9).[115] It is evident in these few examples that various species can be attracted to green roofs, and their addition to urban areas can lead to significant improvement of habitat for birds. However, more design elements may be needed to provide adequate nesting habitat. Artificial nesting boxes, for example, can be incorporated onto green roofs to entice cavity-nesting species to inhabit the area. They can be placed on poles or in plants on roofs with a thicker substrate and must be oriented away from direct sunlight.[116] With the correct design components (water, food, space, and cover), green roofs can provide habitat for urban birds or refuge to migrating birds. Green roofs can also be designed as a space for particular bird species as part of broader conservation efforts while at the same time meeting sustainability goals that protect all species.

[114] Fernandez-Canero and Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review,": 2044-5.
[115] "An Unconventional Oasis: Sustainability Report 2019" (Jacob Javits Convention Center , 2019), https://issuu.com/javitscenter/docs/8725_javits_sustainabilityreport201).
[116] Fernandez-Canero and Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review,": 2047.

Much like green walls, green roofs can provide biodiverse green space for birds while also increasing overall well-being for humans.[117] Since the public cannot occupy some green roofs outside of a guided tour, they offer an undisturbed habitat for nesting birds increasing local urban biodiversity. Even without access to the public, they can be viewed from adjacent buildings or from floors allowing the occupants to have a visual connection with nature providing psychological benefits such as stress recovery and improved concentration.[118] Additional sustainable benefits include insulating properties and storing or controlling water runoff. The Jacob Javits Convention Center's green roof cooled the exterior roof surface by 31%, reduced the heat flux into the building by 46%, and collects, on average, 77% of rainfall-runoff.

Figure 8. Ford Rouge Factory Green Roof Habitat, Dearborn, MI
Species: olive-sided flycatcher (*Contopus cooperi*) and killdeer (*Charadrius vociferous*).

[117] Stephen R. Kellert, Judith Heerwagen, and Martin Mador, *Elements of Biophilic Design: the Theory, Science, and Practice of Bringing Buildings to Life* (Hoboken: Wiley, 2008).
[118] Ibid.

Figure 9. Jacob Javits Convention Center Green Roof Habitat, NYC, NY
Featuring herring gull (*Larus argentatus*) nests.

Green walls and green roofs can provide an additional design element that urban and suburban landscapes often lack but which are beneficial to bird populations: native plants. Native plants are often particularly helpful for insectivorous bird species, many of which are declining or no longer observed in urban areas.[119] In residential areas of Washington D.C., Narango et al.'s 2018 study found that the overuse of nonnative plants in residential and urban areas may contribute to the Carolina chickadees' (*Poecile carolinensis*) decline by decreasing the abundance of native plants that support critical food resources. This can cause Carolina chickadees to alter their typical diets of 90% insects and spiders and 10% seeds and fruit[120], which results in the production of fewer young and lower reproductive success.[121] Areas with

[119] Desirée L. Narango et al., "Nonnative Plants Reduce Population Growth of an Insectivorous Bird," *Proceedings of the National Academy of Sciences* 115, no. 45 (2018): 11549-11552.
[120] Mostrom, A. M., L. Curry, and B. Lohr. "Carolina Chickadee (Poecile carolinensis), Version 1.0." Ithaca, NY, 2020. Carolina Chickadee.
[121] Narango et al., "Nonnative Plants Reduce Population Growth of an Insectivorous Bird,": 11549-11552.

vegetation consisting of less than 70% of native plants can create a population sink that is unable to sustain population growth. These results were not seen in areas with more than 70% native plants. Narango et al. suggest that to support insectivorous bird species, plants in urban and suburban areas should consist of no more than 30% nonnative species. Not only do nonnatives plants impact the quality of food, but they also affect the quality of habitat and nesting area for birds, which can impact breeding success. The widespread use of nonnative plants by designers and residents essentially has created a "food desert" for native insects. This reduces the number of birds in urban spaces, including birds that are considered urban adaptors.[122] Narango et al. recommend that habitat restoration should be curated to support viable and sustainable food webs rather than incorporating native plants indiscriminately.[123]

Since 1970, habitat loss has been the single largest contributor to the 2.9 billion net decline of birds in the United States.[124] A frequently suggested way to reduce habitat loss is to stop building and expanding the built environment into formerly wildland areas. Given that the world's human population size will continue to grow,[125] continued expansion into wildland areas is inevitable. However, green or living walls and green rooftops are design strategies that can bring back some of the vital lost habitats many resident and migrating species depend on for survival. These spaces can be further improved by using native plants, which promote traditional ecological food webs.

This chapter began with an example of how some bird species can thrive in built environments not explicitly designed for birds through exploiting or adapting to the available resources. Peregrine falcons made an astonishing comeback on minimally designed and often forgotten ledges of office buildings, abandoned clocks, water intake cribs, and bare steel bridge beams. They adapted to the built habitat because, while humans often see cities as void of nature, peregrine falcons used buildings as cliffs and rock outcrops, natural elements they prefer. The Anna's hummingbird and dark-eyed junco demonstrated that while birds like the peregrine

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[122] Narango et al., "Nonnative Plants Reduce Population Growth of an Insectivorous Bird,": 11549-11552.
[123] Ibid.
[124] Kenneth V. Rosenberg et al. "Decline of the North American Avifauna." *Science* (New York, N.Y.) 366, no. 6461 (2019): 120–24.
[125] United Nations, Department of Economic and Social Affairs, Population Division (2019). World Population Prospects 2019: Highlights (ST/ESA/SER.A/423).

falcon can thrive in dense urban areas, some birds are able to quickly adapt to the resources provided by suburban and peri-urban spaces.

Through green walls and green roofs, design can curate nesting spaces, and provide plentiful insects and berries, vital water sources, and protection from predators and the elements. Green or living walls and green roofs are beneficial for birds, buildings, and humans. In many cases, the level of adaptation required of birds to nest on rooftops or walls is minimal. The incorporation of these green elements on structures is also minimal. For buildings without these green structures, surrounding green spaces that include at least 70% of native plants can be especially beneficial to birds that rely on the food source they support. By examining how specific species have benefitted from the built environment and adapt to our built structures, we begin to see how birds interact with the built environment. It is important to remember that each bird species behaves differently to spaces we design for them or for ourselves. The study of how birds adapt to or benefit from designed space provides knowledge of how to support avian species in urban, peri-urban, and suburban spaces while promoting a connection to nature through providing space to encourage their presence in built environments.

CHAPTER 2 NEGATIVE IMPACTS OF ARCHITECTURE AND THE BUILT ENVIRONMENT

Despite the ability of some birds to adapt to or to exploit the built environment, the infrastructure needed to support modern humans can often be devastating to their populations. Along with habitat loss and pollution, dangers in the built environment are significant factors in many avian species' long-term survival.[126] These dangers include energy infrastructure, communication towers, transpiration, and common structures such as fences, which kill up to 400 million birds a year in the United States. While this estimate is shocking, architecture, lighting, and landscape design all contribute to bird building collisions that are estimated to kill up to one billion birds each year in the United States.[127] Since the 1970s, nearly half of North American migratory birds have declined in numbers by at least 50%.[128]

This chapter begins with a brief review of the many dangerous structures that birds face in the built environment; it then focuses on glass, lighting, and landscape design. By understanding why bird deaths occur in the built environment, we can evaluate currently proposed solutions and develop the most effective solutions to mitigate these deaths.

DANGEROUS STRUCTURES IN THE BUILT ENVIRONMENT

Wind turbines are often vilified as one of the deadliest types of structures for birds in the built environment. However, the U.S. Fish & Wildlife Service's Migratory Bird Program estimates less than one million birds die each year due to collisions with wind turbines.[129] In contrast, between 8 and 57 million birds die from electrocution on powerlines or collisions with them.[130] Solar and oil-based energy production also kill many birds each year, but reliable

[126] Kenneth V. Rosenberg et al. "Decline of the North American Avifauna." *Science* (New York, N.Y.) 366, no. 6461 (2019): 120-124.
[127] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City." *PLoS ONE* 14, no. 11 (2019).
[128] Rosenberg et al. "Decline of the North American Avifauna.": 120-124.
[129] U.S. Fish & Wildlife Service. "Wind Turbines," U.S. Fish & Wildlife Service - Department of the Interior, accessed March 1, 2020, https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/wind-turbines.php
[130] U.S. Fish & Wildlife Service. "Electric Utility Lines," U.S. Fish & Wildlife Service - Department of the Interior, accessed March 8, 2020, https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/electric-utility-lines.php.

estimates of these deaths for the United States are not available. This suggests that the current total estimates of 9-58 million birds killed by energy infrastructure are low. Of transportation-related deaths, airplane strikes tend to receive the most attention, since they have led to human casualties. However, they account for less than .0002% of bird fatalities from all transportation threats. Roadways, particularly collisions with vehicles cause far more bird deaths than airplane strikes. Communication towers kill 6.8 million birds a year due to their height and behavior-disrupting lights.[131] Finally, common structures like fences and pipes killed over 13,000 birds in the state of New Mexico in one year.[132] Little research has been done on these causes of bird deaths in other areas, so this understudied threat is likely to be grossly underrepresented. The estimates currently available (shown in figure 10) suggest that structures other than buildings kill 104-405 million birds each year. This is an area in need of significant research, so future design strategies can be implemented to mitigate these large numbers of bird fatalities.

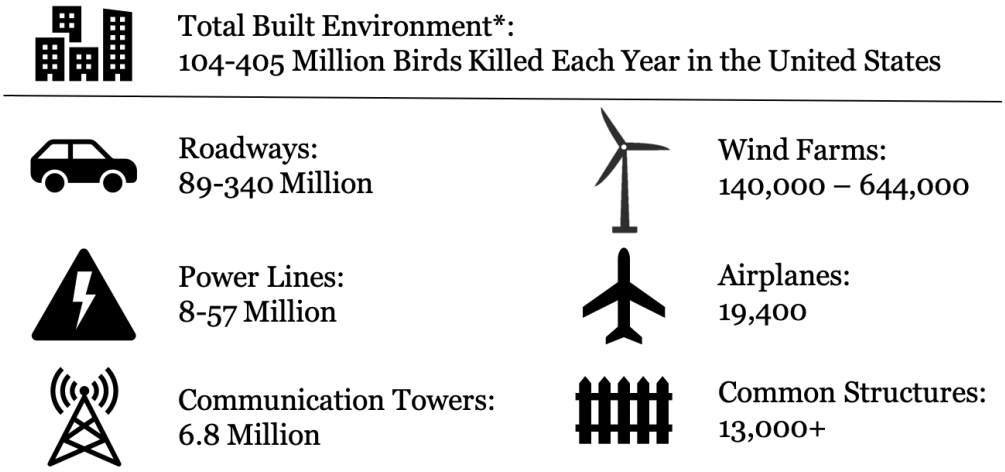

Figure 10. Dangers of the Built Environment

The total impact of energy sources and infrastructure on birds is complex, since structures for renewable energy cause large numbers of bird fatalities while also reducing the pollution and habitat destruction caused by the fossil fuel industries. The EIA reported in 2017 that 8% of the total United States energy carrying capacity was wind energy. The Department of Energy has set

[131] U.S. Fish & Wildlife Service. "Communication Towers," U.S. Fish & Wildlife Service - Department of the Interior, accessed March 2, 2020, https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/communication-towers.php.

[132] Michael L. Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 27056-71.

goals for increasing this to 20% of the nation's energy by 2030 by building wind energy infrastructure in all 50 states. The effects of wind farms on birds are still being studied. Monopole wind turbines kill 250,000 birds each year in the U.S., as reported by Loss et al. in 2014. This number is predicted to climb as the numbers of turbines increase and as larger turbines come on line. There are over 200 documented species of birds killed by wind turbines, comprising mostly passerines but including birds of prey, such as the golden eagle (*Aquila chrysaetos*). Regionally, casualties are highest in California and mountainous regions in the east[133], whereas temporally, birds are most at risk during migration, particularly at night.[134] In the west, raptors are the primary casualties, whereas in central and eastern US, migrating Neotropical songbirds collide with wind turbines most frequently.[135] Beston et al. reported in their 2016 study that birds of prey such as the golden eagle and ferruginous hawk (Buteo regalis) are expected to experience declines in population due to wind farms.[136]

Solar energy is expected to grow faster than any other energy source, and most of this will happen in the Southwest of the United States.[137] Its growth threatens a variety of bird species.[138] Water birds can perceive the reflective or mirrored surfaces of solar panels as one large body of water. They then can collide with them in an attempt to land or when foraging in flight for surface insects. Their hot, mirrored surfaces can also be deadly if birds attempt to land on them. Flying near the light concentration towers of solar power facilities can fatally burn or singe birds as well.[139]

Powerlines are also a sizeable threat to birds through habitat fragmentation but can be fatal when encountered directly. Electrocution and collisions with transmission lines are common causes of death. Loss et al. estimated in 2014 that 8-57 million birds die from powerline collisions, and 1-11 million birds die from electrocution each year. Powerlines affect many

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[133] Scott R. Loss et al., "Bird–building Collisions in the United States: Estimates of Annual Mortality and Species Vulnerability," *The Condor* 116, no. 1 (2014): 8-23.
[134] U.S. Fish & Wildlife Service. “Wind Turbines.”
[135] Michael L. Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 26824-40.
[136] Ibid.; Wind energy can also indirectly impact birds due to loss or modification of habitat.
[137] Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 26855-74.
[138] Ibid.
[139] Michael L. Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): 26-8.

species of birds, because they are very hard to see and are often in locations where birds frequently travel. They are even less visible in poor weather conditions or darkness.[140] Additionally, collisions with powerlines and electrocutions from transformers or wires have negatively impacted recovery efforts of the golden eagle in the Western United States and the Ridgway's hawk (*Buteo ridgwayi*) in the Dominican Republic.[141]

We often hear of fossil fuels as harmful to birds because of the pollution they produce, but their extraction also impacts birds' habitats. The extraction of oil and natural gas alters habitat to the point that some species have been reported to avoid conventional sites with oil rigs used for extraction and unconventional sites which may use fracking instead of traditional oil rigs.[142] Some species may even be actively attracted to extraction sites as is the case with synanthropic (human-adapted) species. In Pennsylvania, oil and gas sites altered entire communities of breeding forest birds.[143] In 2006, it was estimated that one half to one million birds drowned throughout the United States at open pits and tanks that dispose of oil by-products, and more than 1,000 birds have died from being attracted to and burned at flares created through combustions at the energy sites. An unknown number of birds collide with structures lit at night on oil and gas sites.[144] Future studies of the impact of the oil and natural gas industry on birds will focus on the new extraction processes through oil sands and fracking.[145]

Structures in the built environment, such as communication towers, kill over 6.8 million birds each year in the United States. The first documented case of birds colliding with communication towers was in 1949; on some nights thousands were recorded.[146] In 1998, three towers killed 5,000-10,000 birds in a single night in western Kansas.[147] A more recent observation by Longcore et al. in 2013 indicated that 6.8 million birds of 350 different species, mostly long-distance migrants, collide with communication towers each year in the United

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[140] U.S. Fish & Wildlife Service. "Electric Utility Lines."
[141] James F. Dwyer et al., "Retrofitting Power Poles to Prevent Electrocution of Translocated Ridgway's HaFwks (Buteo Ridgwayi)," *The Journal of Caribbean Ornithology* 32 (2019): 4-10.
[142] "Conventional Oil vs. Unconventional Oil," Keystone Energy Tools, May 26, 2020, https://www.keystoneenergytools.com/conventional-oil-vs-unconventional-oil/).; Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 26904-20
[143] Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 26904-20
[144] Ibid.
[145] Ibid.
[146] Ibid, para. 27026-45.
[147] U.S. Fish & Wildlife Service. "Electric Utility Lines."

States. Longcore et al. documented high species-level mortality rates in some species. The yellow rail (*Coturnicops noveboracensis*) loses 9% of its population each year through collisions with communication towers, and 8.9% of all Swainson's warblers (*Limnothlypis swainsonii*) die by colliding with communication towers each year in the United States.[148] While flashing and non-flashing lights can cause disorientation or attract birds to the towers, height can increase fatalities.[149] Supporting guy wires, heights over 350 feet, and placement of towers along migratory paths and ridgelines also increase mortality rates.[150]

Collisions with vehicles kill 89-340 million birds each year.[151] Ground-nesting or dwelling birds, fruit-eating birds, water birds, and even birds of prey are drawn to roadways and killed each year. Examples of ground-dwelling birds include turkeys and pheasants that cannot quickly maneuver away from vehicles [152] Water birds often collide with vehicles as the wind currents carry them into traffic on bridges. Owls that fly at the same height as vehicles and hunt at night also are vulnerable.[153] Birds can also be drawn to roads because of carcasses of road-killed animals, as with corvids or vultures. Hawks and eagles can be attracted to rodents along the roads that may be feeding on scraps of food or fruit-bearing plants.[154] In addition to vehicles, airplanes kill over 19,000 birds a year due to strikes. While the strikes can happen at any time, they often occur at low altitudes during takeoff and landing. Because these strikes have caused plane crashes and over 250 human deaths, they are very consequential, even though the relative numbers of birds killed by planes are small.[155]

Other structures in the built environment can be inconspicuous but still deadly to birds. In Oklahoma, Wolfe et al. studied bird mortality caused by wire fences in 2009. They found one bird killed for every mile of the fence. After marking the fence with small white clips, no fatalities were reported. Open metal and PVC pipes used as signposts or ventilation for toilets

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[148] Travis Longcore et al., "Avian Mortality at Communication Towers in the United States and Canada: Which Species, How Many, and Where?" *Biological Conservation* 158 (2013): 410-419.
[149] Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 27026-45.
[150] U.S. Fish & Wildlife Service. "Communication Towers."
[151] U.S. Fish & Wildlife Service. "Road Vehicles," U.S. Fish & Wildlife Service - Department of the Interior, accessed March 3, 2020, https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/road-vehicles.php.
[152] Ibid.
[153] Ibid.
[154] Ibid.
[155] U.S. Fish & Wildlife Service. "Communication Towers."

can be attractive but deadly nesting cavities for birds. The birds often become trapped and die in the pipes.[156] A 2014 study in New Mexico found that out of 100 pipes, 24 had dead birds, 61% being the western bluebird (*Sialia mexicana*), a cavity nester. The same study estimated that 13,580 birds die in New Mexico each year due to uncovered pipes.[157] There is an urgent need for a comprehensive evaluation of the dangers that birds face, how this impacts conservation efforts, and the effectiveness of the solutions currently available.

Current solutions to the danger birds face in the built environment fall into two categories: immediate solutions and future solutions. Immediate solutions can be implemented if the public is made aware of capping or placing screens over open pipes and marking fencing. However, most solutions require further study to provide viable options to reduce bird deaths. One main area of the built environment that needs future study to understand how to reduce bird deaths is energy infrastructure. Once wind turbines or solar panels are installed, few mitigation techniques can be implemented. Monitoring can be helpful if it triggers mechanisms for protecting birds and for devising long-term solutions. Wind turbines in Wyoming are monitored manually or with heat-detecting cameras for birds such as the golden eagle. The turbines can be manually or automatedly stopped so the birds can safely fly by the turbines. Additionally, one study tested turbine lighting but found that it did not reduce or increase impacts.[158] Thoughtful placement of wind turbines and solar panels away from vulnerable species of birds or their paths of movement is one of the most effective solutions for reducing bird deaths currently being used. A few studies propose solutions for preventing electrocution on distributing poles or preventing collisions with power lines. Correctly retrofitting transformers and energized wires, shown in Figure 11, are proven to reduce the number of electrocutions effectively.[159] Additional tactics

[156] Morrison, *Ornithology: Foundation, Analysis, and Application* (Baltimore, MD: Johns Hopkins University Press, 2018): para. 27056-95.
[157] Ibid.
[158] U.S. Fish & Wildlife Service. "Wind Turbines."
[159] James F. Dwyer et al., "Retrofitting Power Poles to Prevent Electrocution of Translocated Ridgway's Hawks (Buteo Ridgwayi)," *The Journal of Caribbean Ornithology* 32 (2019): 4-10.

proven effective at reducing collisions are common-sense solutions, such as marking lines, removing grounding wires, and burying lines when possible.[160]

Fig. 2. Correctly retrofitted power poles. (A) Three-phase pole with all energized wires covered. (B) Three-phase pole with all energized wires covered and a supplemental perch (the supplemental perch alone would not correctly retrofit the pole). (C) Transformers correctly retrofitted with bushing covers and jumper covers on energized components (the uncovered bushings and jumpers are not energized). (D–F) A Ridgway's Hawk moving from (D) concrete pole top, through (E) the air gap between the grounded pole top and the energized wire, to (F) perching on a conductor cover preventing contact with the energized wire.

Figure 11. Wind Farm Monitoring and Retrofitted Power Poles
Power Poles Caption by Dwyer et al., 2019.

Adding lights on communication towers is one way to reduce their impact on birds; however, lights should not be strobing lights or red lights, as they can cause disorientation, attraction, or disrupted behaviors like migration. Other solutions include careful placement such as selecting already degraded areas, avoiding areas near wetlands, refuges, migratory routes, ridgelines, coastal areas, breeding areas, or key habitats of concern. Reducing tower heights to less than 199 feet and using free-standing towers, to avoid guy wires, can also reduce deaths.[161]

Animal bridges that allow for safe passage of animals across busy roadways are especially helpful to birds of prey that are often hit by vehicles when hunting smaller prey. The

[160] U.S. Fish & Wildlife Service. "Electric Utility Lines."
[161] U.S. Fish & Wildlife Service. "Communication Towers."

smaller prey may reroute to the animal bridge away from deadly roadways. However, until constructed, immediate solutions include barriers such as low fences or diversion poles along bridges and removal of food sources from roadways.[162] Additionally, understanding how species interact with infrastructure such as roadways can help reduce collisions by providing information to the public and local municipalities to prevent vulnerable species from being hit by vehicles. Current strategies to reduce airplane strikes include modifying flight schedules when possible and bird removal[163] or hazing. Site management such as removing attractive bird habitats is also used to prevent airplane strikes.[164] However, reducing habitat space should be a last resort. Strategically placing green roofs at airports could lead birds to safe spaces away from airplane flight paths as has proven to be true at the large-scale green roofs located at O'Hare International Airport in Chicago.[165]

Common structures such as oil pits, fencing, and open pipes can be remedied easily with large covers, markers, and pipe caps. However, unlike the solutions for these common structures, most dangers that pose a threat to birds in the built environment need more research not only to understand how to mitigate the dangers, but also to understand more clearly how birds interact with the built environment.

BIRD BUILDING COLLISIONS

One of the leading anthropogenic threats local and migrating birds face in the built environment is collisions with buildings.[166] A 2014 estimate provided by Loss et al. indicated a staggering range of 365 to 988 million bird deaths a year in the United States directly caused by building collisions.[167] This estimate is broken down into three building types: commercial

[162] U.S. Fish & Wildlife Service. "Road Vehicles."
[163] This includes lethal removal and capture and release.
[164] U.S. Fish & Wildlife Service. "Aircraft," U.S. Fish & Wildlife Service - Department of the Interior, accessed March 2, 2020, https://www.fws.gov/birds/bird-enthusiasts/threats-to-birds/collisions/aircrafts.php.
[165] R. Fernandez-Canero and P. Gonzalez-Redondo, "Green Roofs as a Habitat for Birds: A Review," *Journal of Animal and Veterinary Advances* 9, no. 15 (January 2010): 2045.
[166] The phrase *bird building collisions* communicates that window strikes are not the only threat facing birds in the built environment.
[167] Loss et al., "Bird–building Collisions in the United States: Estimates of Annual Mortality and Species Vulnerability,": 2.

buildings (4-11 stories tall) account for about 60% of the yearly collisions,[168] residential buildings (1-3 stories tall) about 40% and skyscrapers less than 1% or 500,000 collisions a year.[169] These are the immediate fatalities, but fatalities are not the only repercussions of collisions with buildings. Non-fatal collisions can lead to subsequent deaths, impair behaviors, make birds easier prey, and cause the inability to complete migration and reproduce.[170]

Building elements that most strongly affect the likelihood of collisions include types of glass used, lighting, and design of surrounding landscapes. Reflective and transparent glass windows and facades are the leading cause of bird building collisions.[171] Transparent glass is dangerous when birds cannot perceive it as a solid impediment, but instead see it as a clear passageway. Glass that reflects green spaces, clear flyways, and open skies is just as deadly because it appears to be free of obstruction, offering a clear flight path.[172] Similarly, floodlighting used as a safety measure to make large buildings visible, like the Washington Monument[173] and the One Moody Plaza Tower, has the negative impact of attracting migrating birds or birds that are pursuing food sources to the light. Landscape design is the third design factor that influences bird building collisions. Trees, shrubs, and other vegetation can be dangerous if reflected in the glass, lie behind transparent glass, or when they appear as food sources and attract birds towards the transparent or reflective glass.

Buildings are often designed with large panes of glass to create an illusion of a continuous connection with the landscape outside. This is driven by our desire to find balance with nature and utilize the healing benefits. However, designers must be aware of how our structures interact with and impact various aspects of the environment. And they should mitigate the negative effects of some seemingly sustainable features, such as green spaces near or behind transparent glass.

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[168] This does not account for buildings like U.S. Bank Stadium that fall into the category of commercial buildings based on the building's height of six stories but has a large footprint and extensive use of glass.

[169] Loss et al., "Bird–building Collisions in the United States: Estimates of Annual Mortality and Species Vulnerability,": 2.

[170] Ibid.

[171] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009).; Daniel Klem and Peter G. Saenger, "Evaluating the Effectiveness of Select Visual Signals to Prevent Bird-Window Collisions," *The Wilson Journal of Ornithology* 125, no. 2 (2013).

[172] Reflective glass includes tinted windows. (Schneider et al., 2018)

[173] The Washington Monument was made visible to pilots in 1930 using floodlights that caused 300 bird building collisions on a clear night and 500 bird building collisions on an overcast night during migration season.

How birds see the city is dramatically different from how humans do. Instead of moving forward and assessing the pathway ahead as humans do, most birds assess danger behind and to the sides. If they are startled by something in their peripheral vision, they can become disoriented and shift any remaining frontal focus away from obstacles straight ahead. Even the windows and mirrored walls a bird has already accounted for in its flight path can become dangerous when a bird is disoriented. Additionally, some birds' high-resolution sight may be concentrated laterally instead of straight ahead decreasing their ability to see fine details.[174] If this glass is not clearly marked, it can be deadly. Most birds travel quickly, between twenty and thirty miles per hour, making many collisions with buildings fatal.[175] Examples of reflective and transparent glass can be seen in Figures 12 and 13.

Figure 12. Examples of Reflective Glass
Top Left: U.S. Bank Stadium. Bottom Left: Population Health Facility, University of Washington. Right: 4th and Vine Street Office Building, Seattle, WA

[174] Martin Rössler, Erwin Nemeth, and Alexander Bruckner, "Glass Pane Markings to Prevent Bird-Window Collisions: Less Can Be More," *Biologia* 70, no. 4 (2015): 540.
[175] Ibid.

Figure 13. Examples of Transparent Glass
Upper Left: UW Link Light Rail Station, University of Washington. Lower Left: PACCAR Hall, University of Washington. Upper Right: Ford Foundation Building Atrium, New York City. Lower Right: U.S. Bank Stadium.

The data from the 2019 study of the U.S. Bank Stadium and 20 other buildings in downtown Minneapolis, Minnesota, by Loss et al., shows that the four buildings with the highest bird building collision casualties had the largest glass area. Three out of the four of these buildings also had the highest proportion of vegetation within 50 m (see figures in Appendix 1). The study's findings indicate that a high proportion of vegetation and a lower proportion of glass is just as deadly as a high proportion of glass and a lower proportion of vegetation. This makes it clear that understanding how the landscape impacts design materials is crucial to mitigating bird building collisions. This study also found that increased glass area, proportion lighted[176], and vegetation within 50 m of buildings correlated with an increased number of species that collide with the buildings.[177] When viewed by season, the data for the four top buildings indicate that spring fatalities increased with an increased proportion of lit building surface and vegetation at

[176] Proportion lighted is defined in Loss et al.'s 2019 study as the proportion of the façade that is lit compared to the portion that is not lit by artificial light.
[177] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 15.

50 m and 100 m. In the fall, increased glass area and vegetation within 100 m increased collisions.[178] Increased glass, building height, and nearby vegetation cause confusion especially with unbroken glass reflections and transparent spaces. Increased glass almost always means increased light emission at night that attracts nocturnal migrants.[179] The dangers associated with light and landscape may seem minimal but are vastly magnified when coupled with reflective or transparent glass in designed spaces.

As with global environmental changes caused by greenhouse gas emissions and destruction of habitat, artificial light introduces large-scale, preventable dangers to the environment. Artificial light has been shown to have adverse effects on birds.[180] It can disturb circadian rhythms, causing birds to sing earlier before dawn or at night, and disturb the timing of migration, leading to early or late breeding.[181] Artificial light from street lights has a significant negative effect on ground breeding birds,[182] and light cues can disturb their migration, egg-laying, and quality of diet. Artificial light also disrupts foraging and feeding patterns, reproduction, predator-prey balance, communication between birds, and can be mistaken for celestial guides used by birds during migration. This is especially true during overcast conditions.[183] However, an additional light source, polarized light is believed to aid birds during migration. Polarized light is emitted from dark surfaces like buildings, solar panels, and roads.[184] Birds may use this light to guide migration routes by calibrating their magnetic compass to polarized light patterns in the sky at twilight.[185] According to a 2020 study by Lao et al., unlike artificial light, polarized light was not found to result in bird building collisions.[186]

The Central and Eastern areas of the United States have the highest species richness of migration rages in the world and also a higher amount of light pollution located in these

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[178] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 12.
[179] Ibid., 18.
[180] Catherine Rich and Travis Longcore, *Ecological Consequences of Artificial Night Lighting* (Washington, DC: Island Press, 2006): 100-05.
[181] Ibid., 115-6.
[182] Ibid., 129-30.
[183] Ibid., 414-5.
[184] Sirena Lao et al., "The Influence of Artificial Light At Night and Polarized Light On Bird-Building Collisions," *Biological Conservation* 241 (2020): 2.
[185] Ibid.
[186] Ibid., 5.

migration passageways.[187] Short distance migrants spend their full annual cycle in bright regions of North America and occupy higher levels of light pollution than long-distance migrants.[188] These areas of light pollution are greater in temperate regions where urbanization is widespread. This leads to higher migrant stopover at green spaces in urban and peri-urban areas.[189] The effects of light pollution during migration make some species more susceptible to building collisions, especially nocturnal migrants.[190]

In addition to behavioral impacts and light pollution, artificial light emitted from structures can attract birds to buildings, particularly if the light is near reflective materials or illuminates solid facades. Insects gather at these solid facades causing insectivorous birds to collide with the building. When light is near or behind reflective or transparent materials, it also can act as a beacon, as with solid surfaces. However, it has an added danger of presenting the illusion of open space and birds fly into the windows thinking they can navigate through the lit, open space.

This beacon effect was recently observed in October 2019 at the NASCAR Hall of Fame in Charlotte, North Carolina. The Carolina Waterfowl Rescue group reported that 310 chimney swifts (*Chaetura pelagica*) hit the large glass façade of the building. They reported that about 100 swifts had died on impact and they were rehabilitating about another 100. Researchers believe the migrating birds were resting at night and were disturbed, which attracted them to the lit façade.[191] Videos circulated on social media and news outlets reported the "mysterious" event of birds "killing themselves" as a bizarre one-off.[192] When considering the location, however, it seems evident that this isolated event was indicative of a widespread problem. This beacon of light illuminates the large glass façade and light spreads out across the concrete plaza like the morning sun across a landscape. The buildings behind the beacon are dark or sparsely lit, further consolidating the light emitting from the NASCAR Hall of Fame seen in Figure 14. Artificial

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[187] Sergio A. Cabrera-Cruz, Jaclyn A. Smolinsky, and Jeffrey J. Buler, "Light Pollution Is Greatest within Migration Passage Areas for Nocturnally-Migrating Birds around the World," *Scientific Reports* 8, no. 1 (2018): 2.
[188] Ibid.
[189] Ibid., 5.
[190] Ibid.
[191] Amanda Watts and Eric Levenson, "Over 300 Migrating Birds Smashed into Charlotte's NASCAR Building," https://www.cnn.com/2019/10/16/us/birds-nascar-building-trnd/index.html (Accessed November 1st, 2019).
[192] Gary Gastelu, "The Big One? 300 Birds Mysteriously Crash into NASCAR Hall of Fame," https://www.foxnews.com/auto/the-big-one-300-birds-mysteriously-crash-into-nascar-hall-of-fame (Accessed November 1st, 2019).

light emitting from buildings correlates with increased bird building collisions.[193] The lighted area of a building is a better predictor of bird building collisions than the percentage of glass, amount of glass used, or the size of the panes.[194] While increased use of glass and light does influence bird building collisions, this finding supports turning lights off at night will effectively reduce bird building collisions caused by artificial light radiating from inside of a building like at the NASCAR Hall of Fame.[195]

Figure 14. NASCAR Hall of Fame at Night, Charlotte, NC

Brightly lit structures and floodlighting can also capture birds at night, leading to an estimated 4-50 million fatalities a year in the US.[196] These lights, which include lighted buildings, floodlights, and spotlights can attract hundreds of bird species that migrate at night. While straightforward evidence shows how artificial light attracts birds at night, studies have suggested that flying into artificial light disrupts visual references, causing spatial disorientation. Birds' flight paths can be shifted by their reaction to the light source. The glow from cities on the horizon can also influence the orientation of migratory birds, especially immature birds that

[193] Sirena Lao et al., "The Influence of Artificial Light At Night and Polarized Light On Bird-Building Collisions," *Biological Conservation* 241 (2020): 5.
[194] Ibid.
[195] Ibid., 6.
[196] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 117.

orient themselves towards the city instead of along their proper flight paths.[197] Being captured by artificial light can also affect migrating birds' energy stores, delay arrival at breeding or wintering grounds, and contribute to collisions with glass.[198] Very bright light sources can also visually stun the birds. F.J. Vergeijen argues strongly for the use of the word "capture," in reference to the way birds are drawn to light, which is more descriptive than "attract,"[199] as birds captured by lights can encircle them for hours.[200] Once a bird is captured by light at night it often will not leave that zone. The birds can collide with each other, exhaust themselves, or become vulnerable to predators.[201] An example of capturing is shown in Figure 15. Evans Ogden's 2002 report for the Canadian based Fatal Light Awareness Program (FLAP), demonstrated that artificial light emissions have a significant impact on birds and lead to increased numbers of bird deaths. The report monitored sixteen buildings in Toronto, Canada ranging in height from 8 to 72 stories. While height did not have a significant impact on bird mortality, total building light emissions did. The study concluded that an increased number of birds captured by the light would lead to more deaths. The results of the 2019 study by Loss et al. that included U.S. Bank Stadium, a large building with a large glass façade, further supports the conclusion that the

[197] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 68-9.
[198] Ibid., 71.
[199] Ibid., 68-9.
[200] Ibid., 97-8.
[201] Ibid., 117.

amount of light emitted proportional to the building's surface lead to increased bird building collisions.[202]

Figure 15. Birds Captured by World Trade Center Memorial Lights

As human populations increase so does the use of artificial lights, to a point where it is hard to find land that is not illuminated or influenced by artificial lighting. In 1981, the term *photo pollution* was devised to describe situations when artificial light adversely affects wildlife.[203] At the Washington Monument in Washington D.C., shown in Figure 16, the first incidents of bird building collisions caused by artificial light were recorded in the 1930s.[204] The monument had first used a red light to indicate its location for aircraft but was not monitored for bird building collisions. After the installation of floodlighting to illuminate the entire structure, the building killed 300 birds in one night during migration season. During an overcast night, over 500 birds were killed.[205] Details of recent building collisions or measures to reduce or turn off

[202] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City."
[203] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 67-8.
[204] Robert Overing, "High Mortality at the Washington Monument," The Auk 55, no. 4 (1938), 679.
[205] Ibid.

the floodlighting at the Washington Monument are not available. This information is also not included in Lights Out DC's yearly bird collision statistics gathered from the DC area.[206] Most recently, in May 2017, the dangers of floodlighting were observed at One Moody Plaza in Galveston, Texas. The floodlighting at this building killed 395 migrating birds in one night. The birds were attracted to and collided with the surface illuminated by twenty white floodlights (see Figure 16).[207] These and many other examples demonstrate that illuminating chimneys, buildings, bridges, and monuments with floodlighting contributes significantly to migrating bird fatalities.[208]

Figure 16. Dangerous Floodlights: One Moody Plaza and The Washington Monument
Left: One Moody Plaza with flood lights on (top) and off (bottom). Right: The Washington Monument showing a floodlit structure and two red warning lights.
pollution, a floodlit structure, and two red warning lights.

[206] The American Bird Conservancy suggests that building collisions are no longer an issue for the Washington Monument as it is now surrounded by various sources of light creating a larger area of light pollution expanding beyond the Washington Monument.
[207] Purbita Saha, "Lights Out for the Texas Skyscraper That Caused Hundreds of Songbird Deaths," Audubon, July 2, 2019, https://www.audubon.org/news/lights-out-texas-skyscraper-caused-hundreds-songbird-deaths).
[208] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 74.

Communication towers and ceilometers have also been factors in large numbers of fatalities for migrating birds.[209] Bird collisions with these structures are more closely related to the intensity and color of light as well as constant or strobing patterns than to the structures' materials or landscaping.[210] From the study of ceilometers, researchers discovered that a bird's ability to see wavelengths in the light spectrum differs from humans. This is indicated by the increased nonlinear flight behavior near a tower with white strobing light and the tower with a red light compared to a control with no light.[211] These findings indicated that birds become disoriented by red lights or steady light sources but in different ways. Red lights can disorient birds during migration mimicking the rising and setting sun on the horizon. While steady beaning white lights, as previously stated, can capture birds or attract them to solid surfaces. Birds are less strongly affected by strobing or white to blue wavelengths of lights.[212]

While the dangers of artificial light on wildlife and in combination with built structures are well known, landscape features can lead birds to dangerous areas resulting in bird building collisions. A 2015 study of Bryant Park located in New York City shows that urban parks provide stopover habitat for migrant birds but can lead to collisions.[213] Light emitting from the buildings surrounding the park increased the number of collisions but so did the surrounding landscape. The buildings surrounding Bryant Park are lined with trees and the landscape includes flowers and shrubs often reflected in the glass of the buildings. The study found the more glass used in the building's façade, the more it reflected the vegetation, increasing collisions.[214] These findings were also reported in Argentina by Rebolo-Ifran et al. in 2019.[215] Buildings located in a landcover matrix with tall vegetation reflected in the windows caused more collisions than buildings surrounded by urban landscapes.[216] The study also showed that as urbanization

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[209] A ceilometer measures the height of a cloud ceiling or cloud base using a laser or light source.
[210] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 76-84.
[211] Ibid.
[212] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 76-84.
[213] Kaitlyn L. Parkins et al. "Light, Glass, and Bird Building Collisions in an Urban Park." *Northeastern Naturalist* 22, no. 1 (2015): 84-91.
[214] Ibid.
[215] Most cited research on the topic of bird building collisions is from North America. Argentina is home to 10% of the world's biodiversity, indicating the urgency to research the issue of bird building collisions and available solutions beyond North America.
[216] Natalia Rebolo-Ifrán, Agustina Di Virgilio, and Sergio A. Lambertucci, "Drivers of Bird-Window Collisions in Southern South America: a Two-Scale Assessment Applying Citizen Science," *Scientific Reports* 9, no. 1 (2019).

increased collisions decreased.[217] The effects of light on collisions can often be mitigated by turning off the lights. However, eliminating natural landscapes in urban or built environments is not a logical solution. The solution requires a balance between landscape and protecting birds from collisions.

The 2015 interdisciplinary article by Carrus et al. states that in people "natural settings are, more consistently than others, capable of promoting psychological well-being by reducing psychophysical stress, inducing positive emotions, and facilitating the renewal of cognitive resources." This is based on the Biophilia Hypothesis that "human beings evolved in natural environments and developed an innate tendency to respond positively to natural settings." The findings of their study indicate that "biodiversity increases the psychological benefits associated with the 'green' experience."[218] This result is still compatible with an evolutionary perspective, as biodiversity plays a fundamental role in life support and ecosystem continuity, and the natural quality of a place is positively linked to preferences expressed by users.[219] This study associates the increase of green areas in cities as beneficial to human well-being. While the biodiversity discussed in this study primarily included species of birds and insects,[220] this is still a human-based perception of nature. Understanding how birds interact with green spaces and their locations can lead to design solutions aimed at mitigating collisions.

Green rooftops create a centering experience for humans and provide much needed clean air and contribute to well-being. However, positioning them on buildings that also incorporate reflective or transparent glass, enclosed areas where natural or human-made perches attract birds, can be deadly for birds. Transparent windows giving people the benefit of viewing the green roof are often not detectable by birds trying to enter this space. This is especially dangerous for birds seeking trees and shrubs in green spaces enclosed in glass, because the green space may attract

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[217] Natalia Rebolo-Ifrán, Agustina Di Virgilio, and Sergio A. Lambertucci, "Drivers of Bird-Window Collisions in Southern South America: a Two-Scale Assessment Applying Citizen Science," *Scientific Reports* 9, no. 1 (2019).
[218] Giuseppe Carrus et al., "Go Greener, Feel Better? the Positive Effects of Biodiversity on the Well-being of Individuals Visiting Urban and Peri-Urban Green Areas," *Landscape and Urban Planning* 134 (2015): 221-228.
[219] Ibid.
[220] Juliette Bailly et al., "Negative Impact of Urban Habitat on Immunity in the Great Tit Parus Major," *Oecologia* 182, no. 4 (2016), 1053-1062.

birds to a building, they may not otherwise encounter.[221] Additionally, landscape and green spaces near glass structures increase bird building collisions.

Loss et al.'s 2019 study of the U.S. Bank Stadium and 20 downtown Minneapolis, Minnesota buildings demonstrates the dangers of landscape features near buildings. The location is immediately west of the Mississippi River, which, as the largest river system in North America, is part of a vital migration passageway.[222] This study is the first to include a multi-use stadium, the U.S. Bank Stadium, in monitoring bird building collision. Stadiums tend to be large, lit at night, and designed with large glass facades, all dangerous design choices for birds.[223] They often are illuminated internally or externally during spring and/or fall migration periods.[224] The surface of the stadium building is 37% highly reflective glass and includes 6,000 square meters of uninterrupted glass on the northwest façade facing an open landscape with trees and lawn. LED lighting is used inside, outside, directed into the stadium and in ground-based lighting (see Figure 17).[225] Additionally, the landscape that surrounds the stadium, and the urban downtown area, increase collisions. These landscapes include forests, deciduous woodlands, lakes, wetlands, croplands, and limited grassland.[226] This study also documented the species killed by collisions. The top five species with the most fatalities, were the common yellowthroat (*Geothlypis trichas*), ovenbird (*Seiurus aurocapilla*), Tennessee warbler (*Leiothlypis peregrina*), Nashville warbler (*Leiothlypis ruficapilla*), and white-throated sparrow (*Zonotrichia albicollis*). Species are depicted in Figure 18. These are all migratory songbirds that travel primarily at night. This similarity among the top five species could be due to the fact that the study did not monitor for collisions outside of four migration seasons. A study from 2018 by Schneider et al. monitored the Virginia Tech Corporate Research Center year-round. The results of the study showed that outside of migration seasons, breeding season (July)

[221] C. J. Eakin et al., "Avian Response to Green Roofs in Urban Landscapes in the Midwestern USA," *Wildlife Society Bulletin* 39, no. 3 (2015), 574-582.
[222] Ibid.
[223] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 1.
[224] Ibid., 2.
[225] Ibid. 2.
[226] Ibid.

had the next highest number of fatalities. The resident species, American robin (*Turdus migratorius*), made up the majority of the casualties.[227]

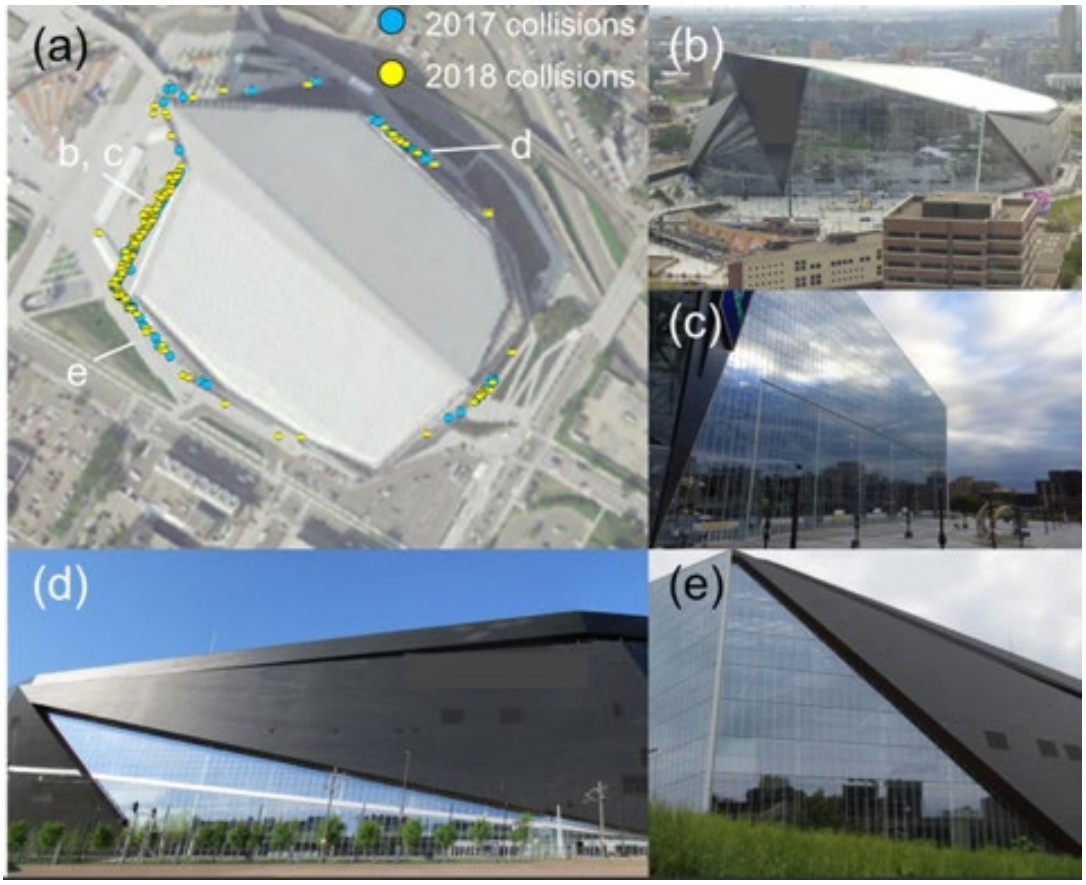

Figure 17. U.S. Bank Stadium, Minneapolis, MN
Bird collisions at U.S. Bank Stadium. (a) Locations of 229 bird collisions observed during monitoring at U.S. Bank Stadium in downtown Minneapolis, Minnesota, USA, 2017–2018; (b, c) the largest unbroken span of glass (~6,000 m^2) where 52% of all collisions at the stadium occurred; (d) a glass surface on the northeast façade where 11% of collisions occurred; (e) a glass surface on the southwest façade where 17% of collisions occurred.
(Caption by Loss et al., 2019)

The landscape surrounding the 21 buildings in the downtown area helped attract birds to the area contributing to the frequency of bird building collisions. This study monitored bird collisions over four migration seasons. It quantified how design features of the building influence fatalities caused by bird building collisions including height, area of glass, area of light, the proportion of light emitted at night, footprint and the surrounding vegetation at a 50 m and 100 m

[227] Rebecca M. Schneider et al., "Year-Round Monitoring Reveals Prevalence of Fatal Bird-Window Collisions at the Virginia Tech Corporate Research Center," *PeerJ* 6 (2018): 13.

buffer.[228] Surrounding vegetation is included in the features that could potentially increase collisions by attracting birds to the landscape surrounding a building. In 2018, Schneider et al., found that increased lawn area and trees within 50 m of a building increased collisions.[229]

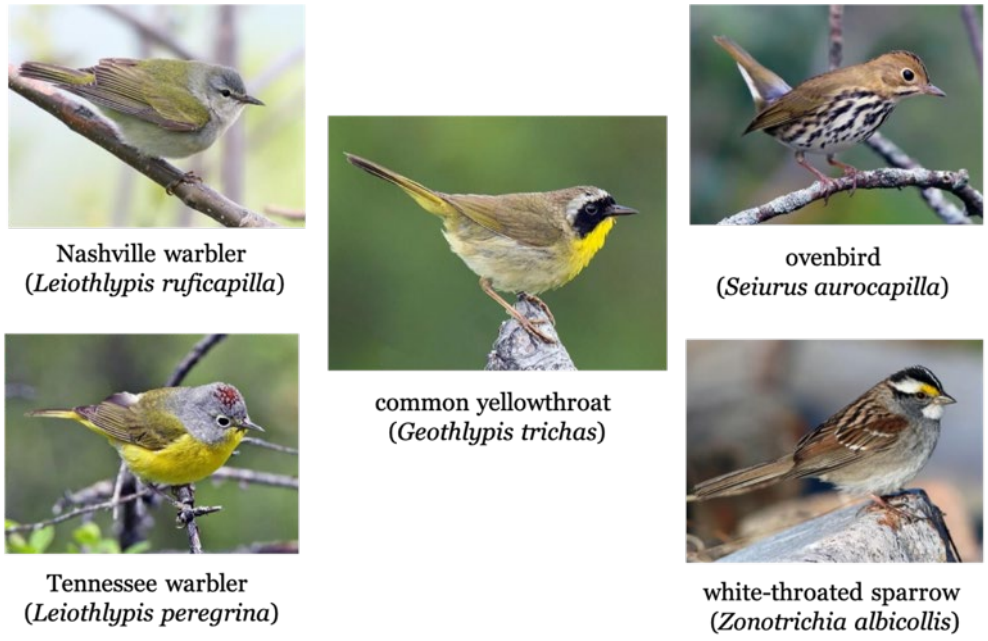

Figure 18. Five Species with the Highest Number of Fatalities

The four most fatal buildings in Minneapolis, in terms of overall collision number, had 79-216 fatalities a year with 111 fatalities from the U.S. Bank Stadium alone. (For comparison: Loss et al.'s 2014 study estimated that U.S. high rises kill 5-77 birds a year). The design features that cause the high numbers of collisions among these four buildings include large amounts of glass reflecting surrounding vegetation. But these design features did not necessarily contribute to bird building collisions at typical building types in the downtown area. However, both types of buildings do show that an increased proportion of lighted glass increases overall fatalities in the spring. There is also an increase in the number of different species colliding with buildings in the spring.[230] The Minnesota Audubon Society and concerned citizens approached the U.S. Bank

[228] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 1.
[229] Rebecca M. Schneider et al., "Year-Round Monitoring Reveals Prevalence of Fatal Bird-Window Collisions at the Virginia Tech Corporate Research Center," *PeerJ* 6 (2018): 7.
[230] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 16-17.

Stadium in 2012 and 2013 about the collisions. The building owner's inaction led to Loss et al.'s 2019 study.[231]

Overall fatalities of all species were correlated with glass area, the amount of light emitted proportional to the building's surface, and vegetation within 100 m. Although vegetation within 100 m was important year-round, in the spring, fatalities were also correlated with proportional light, while in the fall glass area played a more significant role. When broken down by the top species impacted, glass had a greater effect on white-throated sparrows and ovenbirds. The Nashville warbler collided with buildings that were the tallest, had the largest footprint and vegetation within 50 m of the building. The common yellowthroat was found to be attracted to vegetation near buildings beyond the 50 m buffer. The 100 m vegetation buffer was the highest indicator of predicted common yellowthroat deaths. However, for the Tennessee warbler, none of the tested variables explained why they collided with the buildings based on the design aspects monitored.[232]

When considering the life history of these five species, we can understand the impact of the surrounding landscape of the downtown buildings and birds vulnerable to collisions vary in their familiarity with urban space, preferred habitat, migration, food sources, and size. The white-throated sparrow prefers coniferous and deciduous forest habitat.[233] During migration, they can be found along the edges of woodlots, thickets, or weedy fields, as well as backyards, city parks, and green spaces in the suburbs, so low vegetation reflected in building glass is a significant danger to them.[234] Ovenbirds prefer mature forests in the summer. In the winter they do not require mature forests but will avoid open fields and cultivated areas. During migration, ovenbirds migrate in large numbers during storm fronts and are reported being killed by towers and tall buildings in their path where lit glass windows become dangerous beacons in overcast

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[231] Alisa Opar, "Minnesota's Newest Sports Stadiums Take Very Different Approaches to Bird Safety," Audubon, October 24, 2018, https://www.audubon.org/news/minnesotas-newest-sports-stadiums-take-very-different-approaches-bird-safety).

[232] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 16.

[233] Coniferous trees are cone bearing trees that retain their leaves or needles. Deciduous trees drop their leaves or needles in early to late autumn.

[234] Falls and Kopachena (2020). White-throated Sparrow (*Zonotrichia albicollis*), version 1.0. In Birds of the World (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA.

conditions.[235] The Nashville warbler prefers mixed open forest areas with shrubs and undergrowth, forest edges, bogs, abandoned fields and mountain pastures.[236] Open areas that surround downtown Minneapolis could account for these birds' attraction to green spaces within 50 m of downtown buildings. Their life history does not account for why they were most susceptible to larger (in footprint and height) buildings. However, some species are more susceptible to collisions with glass. Sabo et al. suggest in a 2016 article that resident birds can learn to avoid collisions with glass; therefore, migrant birds more susceptible to collisions.[237] The Tennessee warbler spends most of its time in high trees and migration is spent passing between the boreal forests of Canada and Central America, preferring most types of forest or woodlands.[238] No design features were directly attributed to their high number of fatalities other than the significant fact that the buildings monitored are located in a high migration area. The common yellowthroat is found most often in low tangled vegetation near marshes and wetlands. They are also attracted to low-growing grasses and low trees or bushes in back yards.[239] The

[235] This is not unlike the effect the Washington Monument had on hundreds of birds that collided with the lit structure during overcast nights in 1930.
[236] Lowther and Williams (2020). Nashville Warbler (*Leiothlypis ruficapilla*), version 1.0. In Birds of the World (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA.
[237] Ann M. Sabo et al., "Local Avian Density Influences Risk of Mortality from Window Strikes," *PeerJ* 4 (2016): 1,9.
[238] Rimmer and McFarland (2020). Tennessee Warbler (*Leiothlypis peregrina*), version 1.0. In Birds of the World (A. F. Poole, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA.
[239] Guzy and Ritchison (2020). Common Yellowthroat (Geothlypis trichas), version 1.0. In Birds of the World (P. G. Rodewald, Editor). Cornell Lab of Ornithology, Ithaca, NY, USA.

landscape surrounding the U.S. Bank Stadium, shown in Figure 19, includes low growing grass and trees, which may have contributed yellowthroat mortality during migration.

Figure 19. Landscape Surrounding the U.S. Bank Stadium

The overall findings were that four of the 21 buildings accounted for over half the total collisions during the study. These buildings showed a positive correlation between building strikes and a large amount of glass as well as the presence of surrounding vegetation. Additionally, the, factors that influence bird building collisions on the 17 other buildings varied with season (specifically between spring and fall migration) varied by species and varied with the proportion and area of light emitted from the buildings at night. These findings support the argument that building-specific and species-specific bird protecting designs, especially regarding landscape features, could be more effective than applying identical designs solutions to all sizes of downtown buildings.[240] Loss et al. suggest focusing on the buildings with the largest fatalities first when considering bird protecting designs, as well as increasing research on the effectiveness of design solutions for these buildings.[241]

[240] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 1.
[241] Ibid., 17.

Anthropogenic dangers are a primary source of bird fatalities in the built environment contributing to the loss of 3 billion net birds since 1970 in North America. This includes infrastructure like powerlines, energy infrastructure including wind and solar farms, roadways, and communication towers. Mitigating environmental stresses, preventing loss of habitat, and reducing direct hazards that contribute to bird building collisions must all be considered to attain truly sustainable buildings. Designers and architects who intend to design sustainably must include consideration of the threat facing birds in sustainable and environmentally friendly design. To do so, all architects and designers should be aware of five design or location features that most negatively impact birds: reflective and transparent glass, lit structures and light pollution, green spaces and water sources within 100 m of built structures, building location relative to migration passageways, and how bird species interact with these four features. The information gathered in this chapter makes it clear that solutions will not be provided by a single expert or the findings of one study. In order to develop effective mitigation strategies to bird building collisions, understanding how birds interact with the built environment as a whole and on a species level is crucial.

CHAPTER 3 PREVENTING BIRD BUILDING COLLISIONS WITH DESIGN SOLUTIONS

Finding effective design options to eliminate bird building collisions is challenging because few case studies and primary source materials address these solutions. Additionally, this information is widely scattered among studies and organizations, making it difficult to compare data and evaluate the most effective solutions for reducing collisions. Based on the available primary source material such as experiments, monitoring studies, and case studies, this chapter identifies the current best practices. It consolidates this information to evaluate the effectiveness and limitations of collision prevention strategies. The mitigation strategies outlined in this chapter begin with glass solutions followed by lighting and landscape solutions.

Collision mitigation techniques focus primarily on window collisions, as transparent and reflective glass are the most dangerous elements of the built environment leading to bird deaths. However, lighting design, landscape design, and avian behavior can increase or decrease the likelihood of window collisions. Among the three primary mitigation design strategies in this chapter, lighting solutions and the effect of artificial light on urban wildlife are the most well studied. Extensive experiments testing light mitigation strategies demonstrate that complicated solutions are not required to provide successful outcomes. Simply turning out the lights at night during migration seasons can significantly reduce bird building collisions. This chapter also examines the additional mitigation strategies available to reduce the negative impact of artificial light on birds in built environments. Studies show that a clear and direct way to reduce bird fatalities using landscape design strategies is to reduce reflections of vegetation in glass that is not treated with collision deterrence methods. Additional solutions for preventing bird building collisions through landscape design rely heavily on understanding avian behavior and life history.

GLASS SOLUTIONS

Effective design solutions for preventing birds from colliding with building glass must signal to a bird that it cannot fly through the glass. These designs aim to protect the birds from fatal head-on collisions as well as injury from diverting too late. Usually, this involves the

application of patterns on exterior glass surfaces, such as opaque or translucent lines, dots, triangles, or other shapes. These must be big enough and grouped closely enough to make the glass visible as a solid to flying birds, in enough time for them to avoid colliding with it. The following experiments test various glass treatments.

An initial leader in the research on window collisions solutions, Daniel Klem published three studies in 1990, 2009, and 2013 providing the foundation of the most commonly used window collision mitigation techniques including frit dots, lines, and ultraviolet patterns.[242] Today, these solutions are widely promoted by the Audubon Society and American Bird Conservancy. However, a detailed evaluation of the results of Klem's experiments shows that some popular solutions, such as spaced lines and ultraviolet patterns, do not consistently prevent collisions and require further study. Additionally, the testing methods used in the three studies have limitations that may impact the test results.

Klem's experiments use two methods of testing. The flight tunnel tests require a dark-eyed junco (*Junco hyemalis*) or white-throated sparrow (*Zonotrichia albicollis*) to fly towards a control pane of transparent glass or a glass pane with and collision deterrence pattern or film. The open field experiments use wood-framed picture windows in a mowed field facing a forest allowing wild birds to come in contact with the windows (see Figure 20). A feeder was placed one meter from a pane of glass in the test and was randomly rotated to a different window each day.[243] The flight tunnel test limitation is that no reflections of vegetation or the sky can be projected onto the glass. The open-field test allows birds to fly around the structures and do no replicate buildings. Additionally, the published studies do not have images of the patterns or comprehensive charts of the results, so their findings can be challenging to interpret. Figures 21 through 24 below recreate some of these data and patterns based on the details from Klem's

[242] "Collisions Between Birds and Windows: Mortality and Prevention." (1990); "Preventing Bird–Window Collisions." (2009); and "Evaluating the Effectiveness of Select Visual Signals to Prevent Bird-Window Collisions" (2012).

[243] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009): 314-321.

studies. (Charts of the results of Klem's 2009 and 2013 experiments can be found in Appendix 2.)

Figure 20. Klem's Open Field Experiment

In Klem's 1990 experiment, he tested collision preventing window patterns with dark-eyed juncos. These patterns consisted of vertical or horizontal cloth strips with a width of 2.5 cm creating line or mesh patterns shown in Figure 21.[244] These experiments are the basis of the widely used "2 by 4" rule promoted in bird-safe guidelines[245] by the Audubon Society and American Bird Conservancy. This rule advises that lines, decals, or dots be spaced two inches horizontally or four inches vertically apart. This is based on Klem's tests with cloth strips on transparent glass spaced at 5 cm horizontally and 10 cm apart vertically. These two experiments prevented collisions by 100% when compared to the clear glass control for dark-eyed juncos. Vertical lines spaced at 10 cm were tested in a flight tunnel by Rossler et al. in 2015 and reduced

[244] Daniel Klem, "Collisions Between Birds and Windows: Mortality and Prevention." 1990. *Journal of Field Ornithology* 61 (1). Association of Field Ornithologists, Inc.: 120–28.

[245] The terms bird-safe and bird-friendly are not defined by data indicating the building or structure is free of collisions. Most of the time, they indicate the use of any collision mitigation strategies.

collisions by 94%.[246] Shepard et al. also tested 10 cm horizontal lines four years later in the same flight tunnel as Rossler et al. and had the same result: collisions reduced by 94%.[247] The lines were spaced based on this species' wingspan of 18-25 cm because it is thought birds will not try to fly through spaces too narrow or may harm their wings.[248] However, the results of the experiment seem counterintuitive: for example, if birds avoided the 10 cm spaced lines because the obstacles were too close together to fly through, spacing them at 5 cm should have resulted in collisions reduced by 100% but they were only reduced by 75%. Klem's experiment also tested transparent glass covered with cloth strips to create a mesh leaving 13 cm openings from corner to corner. This method reduced collisions by 100% even though the open space was larger than the 10 cm vertical lines. Rossler et al. tested a grid pattern spaced 10 cm vertically and 13 cm

[246] Martin Rössler, Erwin Nemeth, and Alexander Bruckner, "Glass Pane Markings to Prevent Bird-Window Collisions: Less Can Be More," *Biologia* 70, no. 4 (2015): 537-540.
[247] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 7-8.
[248] The American Bird Conservancy has now updated this rule to two inches by two inches or 5 cm by 5 cm to accommodate birds with smaller wingspans like hummingbirds. However, the Anna's hummingbird's (*Calypte anna*) wingspan is 12 cm.

horizontally with 95% of the collisions reduced.[249] It is unclear if the spacing or the pattern successfully reduced collisions in the mesh experiments.

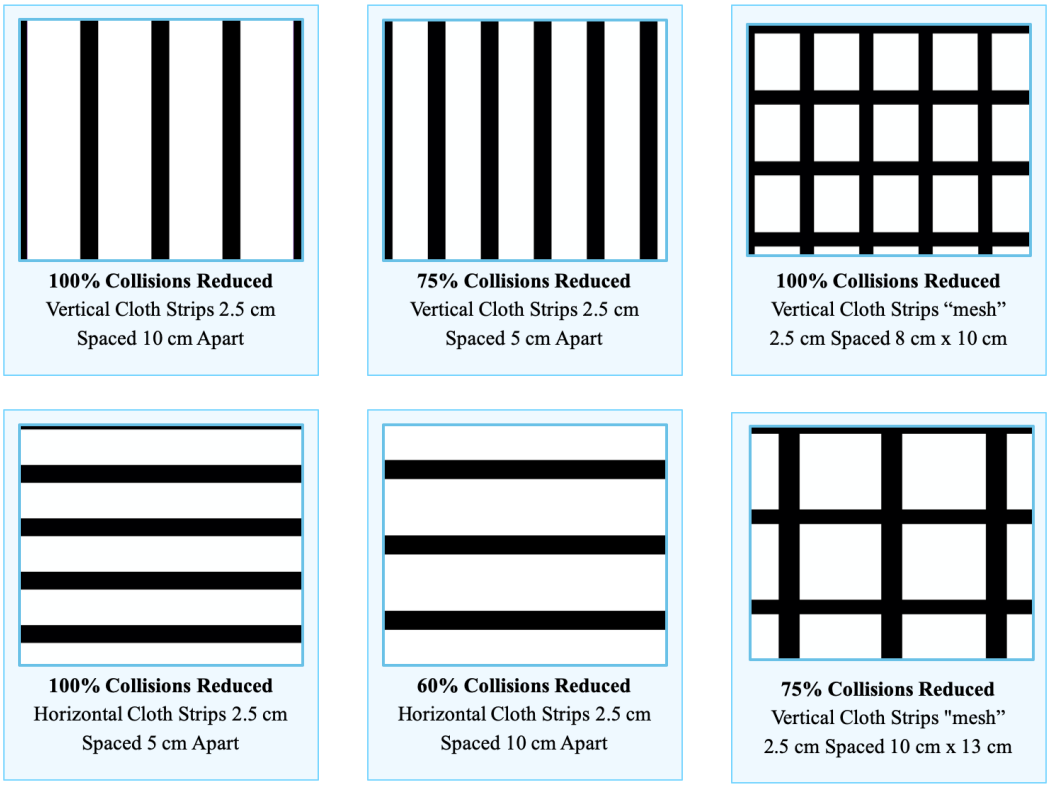

Figure 21. Klem's 1990 Experiments.

Klem himself attributes the success of the 5 cm by 10 cm patterns to birds maneuvering through trees arguing that horizontal branches are close together and vertical tree trunks are spaced further apart. Therefore, Klem claims that the spacing mimics the natural environment.[250] This hypothesis may partially explain the results of the mesh pattern, but horizontal and vertical lines alone do not accurately mimic tree trunks and branches, nor does it account for the successful results of narrower spacing. Additionally, not all bird species interact with forested habitats, have the same wingspan, or maneuver through obstacles in the same way. Not studied are the physiological reasons behind why the birds tested avoided colliding with vertical and horizontal lines at various spacings. Therefore, why these techniques successfully prevented collisions in the experiment remains unknown.

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[249] Martin Rössler, Erwin Nemeth, and Alexander Bruckner, "Glass Pane Markings to Prevent Bird-Window Collisions: Less Can Be More," *Biologia* 70, no. 4 (2015): 537-540.

[250] Daniel Klem, "The Effects of Glass in Buildings on Bird Mortality," *Audubon Chapter of Minneapolis' Session on the U.S. Bank Stadium* (March 23, 2018), https://www.youtube.com/watch?v=z2HssOtP1JQ&feature=youtu.be).

In 2009, Klem tested equally sized and spaced frit dots on the surface of the glass in Experiment 3. These frit dots were sized at 0.32 cm and spaced equally apart at 0.32 cm. Frit dots are etched into the glass; they can be seen by humans standing in close proximity but appear transparent when viewed from a distance. The frit dots were tested in flight tunnel experiments using the dark-eyed junco and the house sparrow (*Passer domesticus)* using a forced-choice test in which the birds had to choose between a transparent glass control or the frit dotted glass to escape. The frit dots prevented 100% of the collisions when compared to the control.[251] Christine Sheppard tested white dots, not ceramic frit dots, that were equally sized and spaced at 0.32 cm resulting in collisions reduced by 59%.[252] Rossler et al. tested white dots sized 1.8 cm spaced at 3.2 cm with a 100% reduction in collisions.[253] These two results indicate that ceramic frit dots are more visible to birds and could be communicating the glass surface is solid, whereas the 0.32 cm white surface dots were not detectable. If white surface dots are used instead of frit dots, they should be larger in size in order to be detectable but less than 5.64 cm in diameter. Rossler et al.'s test of 5.64 cm wide white dots only reduced collisions by 96%.[254] Additionally, Christine Sheppard tested 0.32 cm dots in two experiments placing them in a line rather than covering the glass uniformly. The vertical lines of dots spaced 1.28 cm apart reduced collisions by 90% and horizontal lines by 94%, indicating that 0.32 cm white dots could be more effective as lines than covering the surface of the glass.[255] The frit dots used in Klem's experiment were not opaque, like the cloth strips in the 1990 experiments or those used by Rossler et al. or Sheppard. They are not as transparent as the ultraviolet patterns tested in Klem's study but offer an effective solution to mitigating bird building collisions while maintaining the desired

[251] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009): 314-321.
[252] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 7-8.
[253] Martin Rössler, Erwin Nemeth, and Alexander Bruckner, "Glass Pane Markings to Prevent Bird-Window Collisions: Less Can Be More," *Biologia* 70, no. 4 (2015): 537-540.
[254] Ibid.
[255] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 7-8.

aesthetics and performance. As seen at the Jacob Javits Convention Center in Figure 22, light can still enter the space and the transparency of the glass is retained.

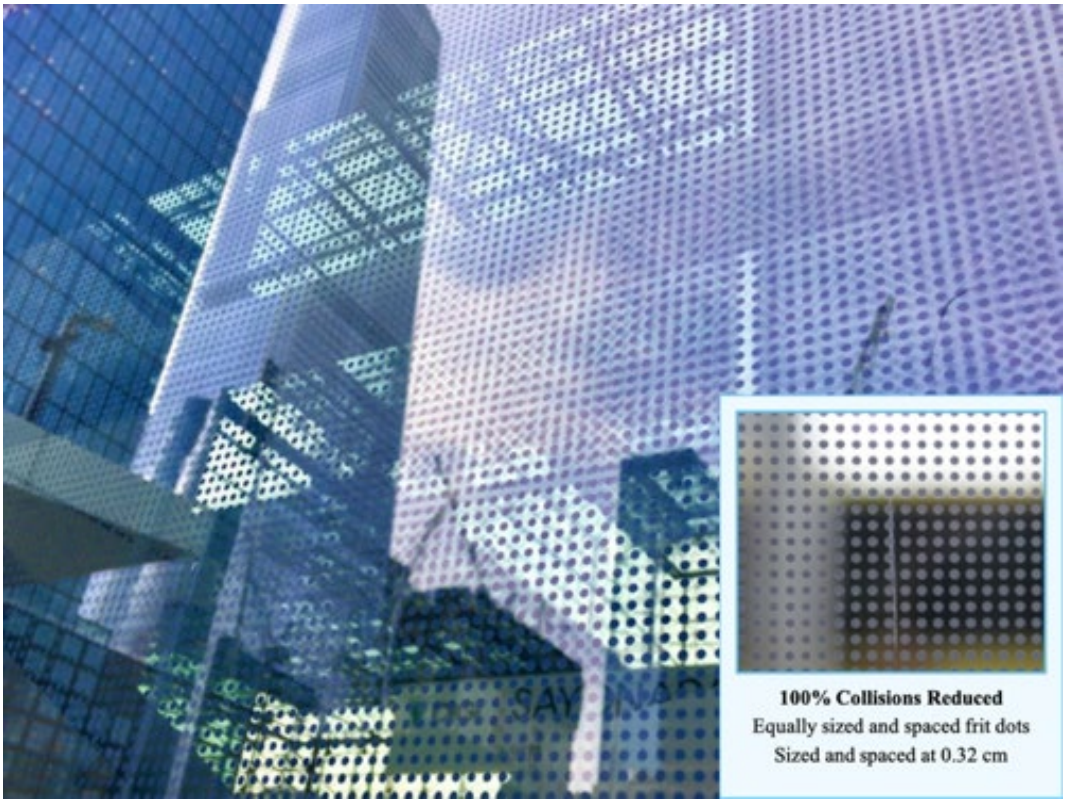

Figure 22. Frit Dots on the Jacob Javits Convention Center and Detail

Ultraviolet or UV solutions are promoted by the Audubon Society and the American Bird Conservancy as the best compromise between designers wanting unobtrusive collision prevention solutions and those advocating the maximum reduction of bird building collisions. The product advertisers claim the human eye cannot detect the pattern, but that some birds can see the UV material. Klem's 2009 experiment with UV window treatments used the flight tunnel and field testing methods. The results are shown in Figure 23. The experiments indicate that UV decals in the shape of maple leaves only reduce collisions by half. UV lines yielded surprising results. UV lines spaced at 10 cm vertically—the same spacing as the opaque black cloth strips that prevented 100% of collisions— only reduced collisions by 20%. By contrast, UV lines spaced at 5 cm horizontally reduced collisions by 100%, just as similarly spaced cloth strips did. Further, covering 50% of the surface of the glass with vertical UV strips equally spaced only

reduced collisions by 60%.[256] Christine Sheppard tested the same UV product (CPFilms) in 5 cm vertical strips spaced 5 cm apart. The flight tunnel test showed the film reduced collisions by 83%. Sheppard conducted three additional UV tests using a product reflecting UV wavelengths thought to be visible to birds (UV Blast) at the same 5 cm width and spacing. The results indicated the UV patterns reduced collisions by 64%, 71% and 86%.[257] These mixed results raise some uncertainty about the testing method, the role of pattern, and the effectiveness of both cloth strips and UV treatments in preventing collisions.

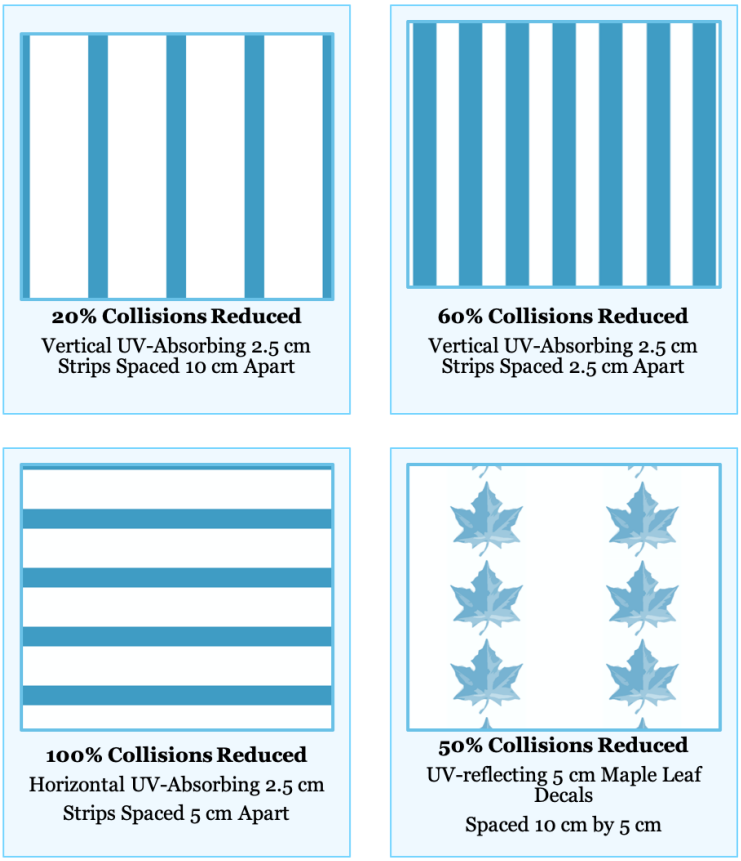

Figure 23. Daniel Klem's 2009 Flight Tunnel Experiments

Data from Klem's 2009 field experiments testing UV line patterns shown in Appendix 2 (Chart 1), indicate that only half of the 18 tests reduced collisions by 85% or more. These outcomes further suggest that UV solutions do not consistently reduce collisions. Six total experiments were conducted using UV film or strips, each with a transparent glass control. The

[256] Klem, "Preventing Bird–Window Collisions,": 314-321
[257] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 7-8.

field experiments were manually monitored for the number of collisions. One experiment describes results from both the field and four flight tunnel tests. Again, 2.5 cm wide UV strips were spaced 5 cm apart in two field experiments but had different results. Experiment 1 showed that glass with 2.5 cm UV strips spaced 5 cm apart had reduced collisions by 100%. Experiment 4 of the same spacing had only reduced collisions by 55%. However, Klem indicated the thick plastic edges of the UV strips were visible in Experiment 1 and could have been visible to the birds.[258] Experiment 2 testing the 5 cm spacing again resulted in reduced collisions by 66%. The flight tunnel test in experiment 5 (shown in Figure 24) testing UV patterns had the highest average of collisions reduced, at 95%. It is not clear why these outcomes are much higher than the field experiments. This wind tunnel experiment also tested the perforated vinyl film CollidEscape which is not a UV product. It reduced collisions by 98%. This film makes the surface of the glass appear white to the birds, similarly to[259] frit dots, which also makes the glass surface appear solid.

[258] Klem, "Preventing Bird–Window Collisions,": 314-321
[259] Ibid.

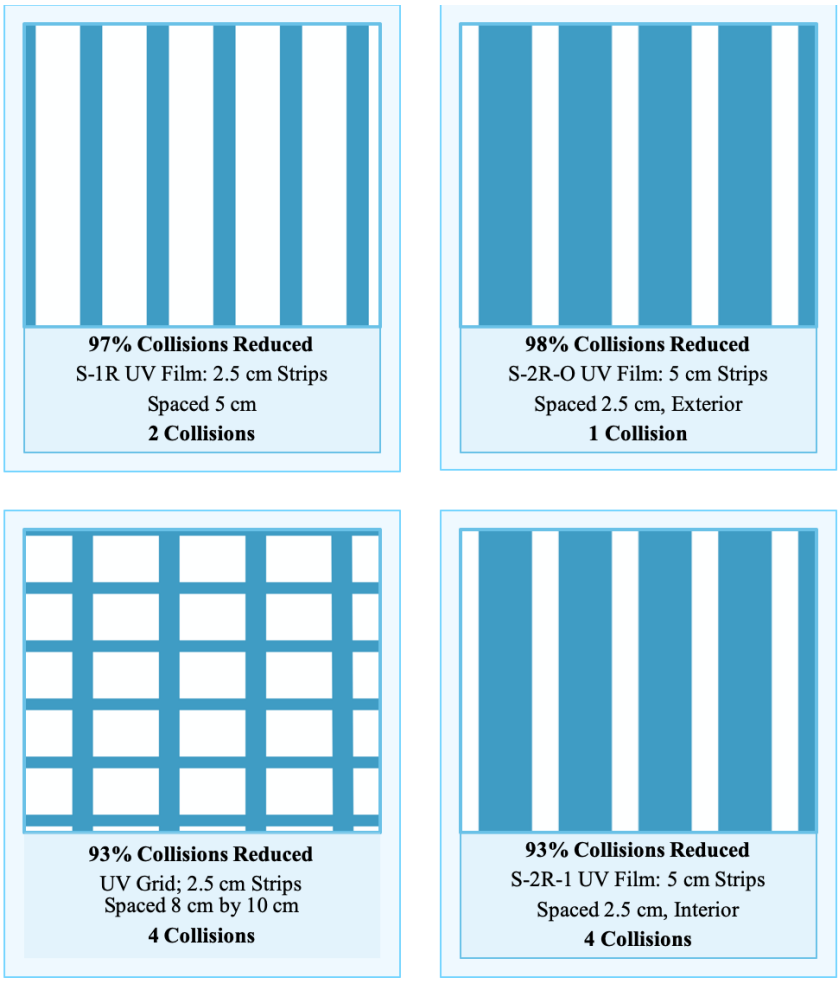

Figure 24. Klem's 2009 UV Flight Tunnel Experiments.

ORNILUX is a commercial UV coating that covers the glass in a random complex transparent pattern that mimics a spiderweb, according to the company's marketing literature. The company claims that ORNILUX mitigates collisions while being nearly undetectable by the human eye.[260] See Figure 25. Klem and Saenger's 2013 study published two experiments testing ORNILUX UV coating and UV strips in the same open field setup used in 1990 and 2009.[261] They tested the film on both clear glass and a black matte panel with clear glass and reflective glass controls. The tests were monitored for wild bird collisions and fatalities for less than four hours a day over about 16 days. Experiment 1 showed the UV coated glass using ORNILUX had 28% more collisions than the transparent glass control and 19% more fatal collisions. (See

[260] "The Clear Solution," Welcome | ORNILUX Bird Protection Glass, accessed April 6, 2020, http://Ornilux.com/).

[261] Daniel Klem and Peter G. Saenger, "Evaluating the Effectiveness of Select Visual Signals to Prevent Bird-Window Collisions," *The Wilson Journal of Ornithology* 125, no. 2 (2013): 406-411.

Chart 2 in Appendix 2.) This test indicates that ORNILUX may act more strongly than mirrored glass in attracting birds to its surface through reflection or attraction to the UV film. Experiment 2 reinforces this result as ORNILUX tested on a black opaque panel reduced the number of collisions by over half compared to a clear glass control.[262] The use of the black panel in this experiment indicates that even on a solid opaque surface or on unlighted windows at night, both typically not a threat to most birds becomes deadly when birds are attracted to the UV pattern used by ORNILUX.

Figure 25. Denning House, Stanford University and ORNILUX Detail

Klem's 2013 experiment testing ORNILUX recorded an increase of collisions when compared to clear or mirrored glass controls. Given that UV light is detectable by some birds, and is sometimes used for prey detection, it may result in unintended attraction. For example, in a 2015 study by Habberfield and St. Clair, cameras located at feeders recorded the birds' response to different UV sources: a pulsating UV light, a light-reflecting compact disk, an unlit

[262] Klem and Saenger, “Evaluating the Effectiveness of Select Visual Signals to Prevent Bird-Window Collisions,”: 406-411.

UV light acting as a novel object, and a control feeder with no UV object. They found that none of these methods using UV light deterred birds, and that there was a slight elevation in attraction to the three feeders with UV objects than the control.[263] Until it is fully understood how birds see and use UV light, UV treatments should not be recommended as an effective collision reduction solutions.

Decals and angled glass are two proposed solutions that are not effective in reducing collisions or safeguarding birds. Spaced decals are recommended by the American Brid Conservancy to reduce collisions if they are separated by no more than 5 cm. However, these floating decals have not been proven to be effective in experiments or case studies. Again, the presumption has been that birds will not fly between the decals spaced closer than their wingspan, though this has not been thoroughly tested. Decals can be successful when used to communicate that glass is solid to birds by using a pattern that replicates an intricate interconnecting design, as seen with a design used by the University of British Columbia in Figure 26. However, using a single decal to simulate the appearance of a predator is ineffective, as birds do not perceive these decals as a threat.[264] Additionally, in 1990 Klem tested a falcon silhouette and a barred owl (*Strix varia*) silhouette, both of which only reduced collisions by 20%.[265] In 2009, Klem tested a single maple leaf UV decal which reduced collisions by only 25%.[266] In some cases, ineffective techniques such as floating and predator decals may briefly appear to work due to the *novel effect*, where new additions to the habitat preclude birds from approaching. Unfortunately, once birds become habituated to the decals, collisions resume.[267] Future study could examine how long these novel window additions influence bird behavior.

In 2004, Klem tested angled glass panes in an open field test and found that angling glass from a bird's flight path can be partially effective. Tilting the glass by 20 degrees reduced collisions by half and by 40 degrees reduced collisions by over 70%.[268] However, researchers

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[263] Michael W. Habberfield and Colleen Cassady St. Clair, “Ultraviolet Lights Do Not Deter Songbirds at Feeders,” *Journal of Ornithology* 157, no. 1 (April 2015): 239-248.
[264] Thaís Brisque et al., "Relationship between Bird-of-Prey Decals and Bird-Window Collisions on a Brazilian University Campus," *Zoologia* (Curitiba) 34 (2017).
[265] Daniel Klem, “Collisions Between Birds and Windows: Mortality and Prevention.” 1990. *Journal of Field Ornithology* 61 (1). Association of Field Ornithologists, Inc.: 120–28.
[266] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009)
[267] Habberfield and St. Clair, “Ultraviolet Lights Do Not Deter Songbirds at Feeders,”: 239-248.
[268] Daniel Klem, "Preventing Bird–Window Collisions,": 314-321.

with the Fatal Light Awareness Program have disputed these findings. Their research suggests that when viewed by birds from below, the reflection of the ground or vegetation in the angled glass can be dangerous and conducive to collisions.[269] Given these conflicting findings, angled glass should not be recommended for bird-safe design. This also reinforces the need for monitoring designs on buildings recommending them as successful bird-safe designs.

Figure 26. UBC's Bird-Friendly Line Pattern

Based on the available research regarding bird building collisions, the American Bird Conservancy (ABC), in a study led by Christine Sheppard, has compiled guidelines for mitigating bird building collisions. These guidelines have provided the groundwork for many city bird-safe policies and the creation of ABC's Bird-Smart resources. Since 2008, ABC has tested over 150 materials and over 20 commercially available options using a flight tunnel located at Powdermill Avian Research Center in Pennsylvania. The following paragraphs explain how their tests are performed, the threat rating system based on the test outcomes, limitations of the tests and rating system, and novel collision deterrence options.

The flight tunnel used by ABC is made of wood, is 30 feet long, and can test transparent and reflective glass. Wild migratory songbirds captured for other scientific studies are flown in the flight tunnel one time and released immediately after the test. Birds are protected from flying into the glass by a "nearly invisible" netting. Birds flown in the flight tunnel have a choice

[269] Fatal Light Awareness Program (FLAP) Canada, "FLAP - Fatal Light Awareness Program," https://flap.org (Accessed November 1, 2019).

between the control, a transparent pane of glass, and the collision mitigation design material. The tunnel can simulate reflections by using mirrors to simulate a sky pattern or landscape onto the glass surface.[270] The results of the flight tunnel tests are used to determine how dangerous a material is to birds. This is called the threat factor. The threat factor ratings for façade materials are referenced by policies and guidelines developed for cities by the American Bird Conservancy and the US Green Building Council. The threat factor scale is 0-100, with 100 being the most dangerous materials, glass, and reflective surfaces, and 0 being the least dangerous materials, stone, brick, and wood. A material with a threat score of 30 indicates it was avoided 70% of the time in the flight tunnel tests. ABC determines that a material is Bird-Smart if has a threat factor of 30 or less (birds avoid it in at last 70 percent of the test flights). For a material to be approved by the US Green Building Council, it must have a threat factor of 15 or less (see Figure 27).

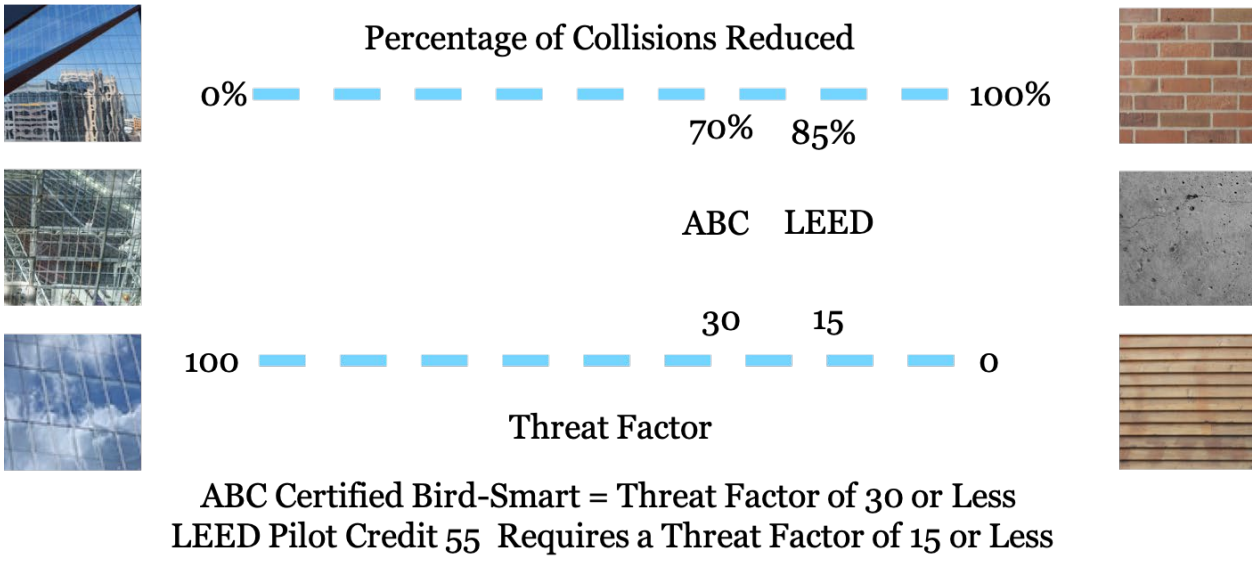

Figure 27. ABC's Threat Factor Rating Scale

While not all 150 tests can be detailed in this chapter, it summarizes the glass treatments that reduce collisions by at least 90%, as well as UV and colored film. Materials with a threat factor of 10 or less primarily include coatings with patterns that make the surface of the glass appear solid or closely spaced obstacles. These materials include continuously etched glass, 50% perforated vinyl film, insect screens or netting, and frit dots. Continuously etched panes of glass,

[270] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 1-10.

perforated vinyl film, and insect screens were given a threat level of 2. Frit dots equally sized and spaced at 0.75 cm and frit dots creating vertical lines spaced 9 cm or 10 cm received threat factor scores less than 5. Somewhat less successful were horizontal and vertical lines 0.32 cm thick and spaced 4 cm vertically and 2 cm horizontally received threat factors between 5 and 8. These measurements are half the 5 cm by 10 cm spacing recommended by Klem, indicating lines spaced closer can reduce a large number of collisions. However, horizontal, and vertical external slats that were at least 0.32 cm thick and spaced 4 cm horizontally and 10 cm vertically were given a threat factor of 5.[271]

Commercial glass and vinyl manufacturers use ABC's threat factors to promote their products as Bird-Smart.[272] The manufactures recommended by ABC, their threat factors, and product images can be found in Appendix 3. The following selected results are for UV film and colored film.

ABC tested Ultraviolet materials, but as in Klem's experiments, they did not consistently reduce collisions. Square UV-reflecting decals spaced 4 cm horizontally and 10 cm vertically received a threat factor of 10. However, the four other UV patterns tested scored between 21 and 27 on the threat factor scale. These consisted of three webbed patterns provided by ORNILUX with no more than a 4 cm opening in the pattern and a clear film by GlasPro of vertical strips spaced 5.7 cm alternating with non-UV strips.[273] One of the four ORNILUX tests fell outside of the 30 or less threat factor required for designation as Bird-Smart by ABC. None of the four meets the standard for LEED 55 (threat factor ≤ 15). The maker of ORNILUX, Arnold Glass, lists additional threat factors for their 13 products, which range from 20-33 with an average of 28.[274] The ABC threat factor ratings offer 32 UV materials with collision deterrence patterns that score better than ORNILUX.

Decorative Films produces two films that can be applied to exterior glass, each with identical image patterns; these produced interesting flight tunnel results. One film is colored with bright images of plants and birds; the other uses the same image that is frosted, appearing transparent where the image is white (see Appendix 3). They have a 15 point difference of 5 for

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[271] American Bird Conservancy. "Stop Birds Hitting Windows," American Bird Conservancy, May 21, 2020, https://abcbirds.org/get-involved/bird-smart-glass/)
[272] Ibid.
[273] "Bird Safe," GlasPro, accessed April 7, 2020, http://www.glas-pro.com/products/glas-pro-bird-glass/).
[274] Ibid.

the frosted vinyl and 20 for the colored vinyl. This point difference is significant enough for the frosted film to be approved by LEED and the colored film not.[275]

The experiments conducted by the American Bird Conservancy have limitations, and ABC acknowledges that none of the listed window products or listed guidelines guarantee the elimination of bird building collisions. A note at the bottom of each Bird-Smart webpage provides this caveat and indicates that results vary based on landscape, design features, local bird populations, and product limitations.[276] One limitation is the use of the "nearly invisible" netting to prevent harm to the birds used in the flight tunnel.[277] It is not known whether the netting interferes with the results of the tests. In addition, ABC indicates an effort to compensate for real-world limitations such as sky and landscape reflections, but their experiments do not account for artificial light. The use of artificial light can transform the least threatening materials such as brick into a beacon attracting birds to its surface at night, leading to collisions. Klem's flight tunnel experiments do not use this mesh nor are they are not able to reproduce reflections on to the glass surface.[278] Considering birds only have two options in a flight tunnel, a clear passageway (control glass) or an obstacle (patterned glass). The flight tunnel tests essentially test if an obstacle can be seen by birds rather than if it effectively communicates the glass is not maneuverable. Klem's 2009 UV flight tunnel experiments produced highly effective results reducing collisions over 90%.[279] But it is unknown if this is due to the effectiveness of UV, which preformed more poorly in open field tests, or the testing method.

The American Bird Conservancy often promotes UV collision deterrence methods. However, the limitations of UV field experiments and limited research about how different bird species see and use UV light, indicate that more studies are needed to support this solution. Klem indicated in his 2009 study that the wood-framed picture windows in the field experiments "accurately simulate those in houses."[280] In a 2019 presentation, Klem also indicated that these field tests are the only experiments that simulate real-world buildings.[281] However, Figure 20, a

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[275] American Bird Conservancy. "Stop Birds Hitting Windows," American Bird Conservancy, May 21, 2020, https://abcbirds.org/get-involved/bird-smart-glass/)
[276] Ibid.
[277] Ibid.
[278] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009)
[279] Ibid.
[280] Daniel Klem, "Audubon Chapter of Minneapolis' Session on the U.S. Bank Stadium," (March 23, 2018), https://www.youtube.com/watch?v=z2HssOtP1JQ&feature=youtu.be)
[281] Ibid.

photo taken by Klem of the field experiments referenced in his 2009 study, show that the wood-framed picture windows do not account for windows being surrounded by additional solid materials of the building. Birds in the field experiments could divert around the wood-framed windows, which would be less likely if the windows were part of a building. The field experiments also do not account for windows illuminated from within a structure at night; nor do they reflect vegetation typically surrounding urban or suburban structures. Additionally, Schmid and Sierro found in a 2000 experiment that any pattern on transparent free-standing glass surfaces can reduce collisions.[282] They placed various patters of black and white stripes and squares are varying distances on a transparent traffic road noise barrier resulting in an 80% reduction in collisions.[283] This further supports that freestanding glass does not always represent the effectiveness of patterns on glass in a built structure. Considering the limitations of the field experiments, their results should not be used to replace real-world data from case studies when determining the effectiveness of collision deterrence methods. While helpful in providing some baseline information, Klem's 2009 and 2013 UV tests do not offer conclusive evidence that UV mitigation techniques successfully protect birds.

Limitations of UV patters lie not only with the testing methods but bird behavior and physiology. An avian sensory expert, Bob Beason, is skeptical of the ORNILUX spiderweb pattern as some birds "burst through" spiderwebs, not seeing them as an obstacle.[284] Klem found in his 2009 study that reflective UV patterns that are 13% reflective reduce collisions far less than UV that is 80% reflective. Additionally, how birds see color signals across wavelength need to be considered. UV wavelengths of blue or purple are associated with attraction, sexual behavior, and food to some avian species. Wavelengths of yellow, orange, and red communicate danger to some species as well.[285]

The results of the flight tunnel and open field experiments, and the ABC threat factors that result, help to determine which materials could be an appropriate fit for a project but they should not be the only resource used to determine the potential threat of a building to birds. Artificial lighting, landscape within 100 m, the reflection of structures and clear flyways,

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[282] H. Schmid and A. Sierro. "Test of measures to prevent bird-strikes on transparent noise- protection walls." *Natur und Landschaft* 75 (2000).
[283] Ibid.
[284] Lesley Evans Ogden, "Does Green Building Come up Short in Considering Biodiversity?: Focus on a Growing Concern.," *BioScience* 64, no. 2 (2014): 86.
[285] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009)

location of the site relative to migration flyways, species variation, and overall project design determine also contribute to building collisions. The limitations of the flight tests are not communicated in guidelines such as LEED's Pilot Credit 55, which merely indicates which materials are approved for use based on the data gathered from these tests alone. Additionally, no collision deterrence methods have been tested for their impact on glass performance, an important feature of façade and lighting design that cannot be overlooked.

LIGHTING AND LANDSCAPE SOLUTIONS

Lighting influences the risk of birds colliding with glass windows, and the easiest way to mitigate this added threat is to turn out building lights at night. However, light solutions go further than turning out the lights to prevent window collisions. As human populations increase so does the use of artificial lights to a point where it is hard to find space that is not illuminated or influenced by artificial lighting. Illuminating chimneys, buildings, bridges, and monuments with floodlighting contributes significantly to migrating bird fatalities.[286] Communication towers and ceilometers have also been factors in large numbers of fatalities for migrating birds. Gautreaux Jr. and Belser have recorded two changes reducing bird deaths relating to ceilometers: filtering the wavelengths so only UV light remains and rotating the beam of light, so it is not a constant strobe. This strategy is more closely related to the intensity and color of light as well as constant or strobing patterns[287] than to the buildings' materials or landscaping. However, from the study of ceilometers, researchers discovered that a bird's ability to see wavelengths in the light spectrum differs from humans. Two findings suggest this: the increased nonlinear flight behavior near a tower with white strobing light and a significantly greater increase of nonlinear flight behavior near the towers with a red light compared to a control with no light.[288] These findings indicated that birds become disoriented by red lights or solid light sources, and are less strongly affected by strobing or white lights. Also, certain wavelengths can disrupt a bird's magnetoreception compass used for migration navigation. This is one reason the red light

[286] Catherine Rich and Travis Longcore, *Ecological Consequences of Artificial Night Lighting* (Washington, DC: Island Press, 2006), 74.
[287] Ibid., 76-84.
[288] Ibid, 85.

disorients birds.[289] A 2002 study by Wiltschko and Wiltschko found that dim blue-green light did not create the same disorientation or attraction.[290]

While light pollution in urban areas causes stress and internal clock disruption in birds, lights also attract migratory birds to lit buildings. Evans Ogden's 1996 and 2002 reports offer the best solutions to prevent building collisions due to artificial light.[291] The recommendations are to reduce light emissions by enforcing tenant awareness about reducing light use at night through signage and educational materials. His study also used computer-controlled lighting systems to turn off lights at night and found automatically turning off the lights was the best available solution to reduce fatalities. Other proposed solutions by Ogden are to direct light downward to prevent capturing birds above the buildings or light sources, to use vegetation as light buffers for lower-level lighting, and to replace beacon lights with UV lights or strobe blue-white or blue-green lights that will not capture birds.[292] While these recommendations have been referenced in several bird-safe building guides and on the FLAP (Fatal Light Awareness Program) website, how varying wavelengths of artificial light disorient specific species must be further researched to create a specific set of guidelines to reduce light emissions negatively affecting birds. Current data suggest that illumination of buildings at night should be restricted, especially during periods of bird migration. Being lit from the outside or inside causes collisions. In addition to limiting illumination on building surfaces, using other proven techniques, such as making the reflective and transparent glass appear opaque at night through turning off the lights or using blinds can help reduce bird building collisions during migration.[293]

Light pollution has been well studied and offers many solutions to safeguard birds; however, landscape solutions have not been as well studied. A building's surrounding green landscape connects humans with nature, but it often causes disorientation for birds. Native or naturalized plants attract local and migrating birds that flock to urban areas to feed or rest in maintained green spaces. The areas are especially important refuges for birds during times of

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[289] Rich and Longcore, *Ecological Consequences of Artificial Night Lighting*, 74.
[290] Ibid., 85-6.
[291] *Collision Course: The Hazards of Lighted Structures and Windows to Migrating Birds* (1996); *Summary Report on the Bird-Friendly Building Program: Effect of Light Reduction on Collision of Migratory Birds* (2002)
[292] Lesley J. Evans Ogden. "Collision Course: The Hazards Of Lighted Structures and Windows to Migrating Birds." Special report prepared for World Wildlife Fund and the Fatal Light Awareness Program. WWF, Toronto, Ontario, Canada (1996): 9-28.
[293] Blinds are not effective in preventing daytime bird building collisions. (Schneider et al., 2018)

drought and fire, but green spaces near buildings can also contribute to the loss of birds through building collisions. Implementing careful landscape design solutions can reduce these losses.[294] The U.S. Green Building Council offers credit for these types of bird-friendly landscape designs in their LEED 55 Polit Credit. The credit requires that any disturbances to the natural landscapes must be limited—including at the building perimeter, parking garages, surface walkways and patios, and constructed areas. Designers must also allow at least 12 m between the building and the vegetation or natural habitats. This buffer eliminates some of the danger birds face when they mistake reflections for habitable vegetation or food sources.[295] If the vegetation cannot be placed 40 m from the building, keeping it closer—no more than one meter away from where the building is reflective—can minimize fatal collisions. Daniel Klem found in his 2004 study that feeders placed within one meter of glass windows were not deadly but feeders placed between 5 and 10 m were deadly.[296] In this case, the short flight from the vegetation to the window does not provide enough space for most birds to build enough momentum for impact leading to injuries or deaths.[297]

While the LEED recommendation for keeping vegetation closer to buildings at one meter is still the recommended distance from glass, recent data suggests the vegetation-building buffer should be extended from 12 m to 50 m. Loss et al. 's recent November 2019 study indicates that the surrounding vegetation of a building at a 50 m and 100 m buffer influence fatalities by attracting birds to vegetation near dangerous reflective or transparent glass windows. Of the top five species recorded to collide with windows in the downtown area of Minneapolis, Minnesota in Loss et al.'s 2019 study found that four out of the five avian species were attracted to the buildings by vegetation within 50 m of the building and one species within 100 m of the building resulting in fatal collisions. [298] Reducing vegetation near reflective materials, at least within the 50 m buffer, is recommended to reduce collisions. If this is not possible, effective bird-safe treatments should be applied to reflective surfaces that reflect vegetation near the building.

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[294] C. J. Eakin et al., "Avian Response to Green Roofs in Urban Landscapes in the Midwestern USA," *Wildlife Society Bulletin* 39, no. 3 (2015): 574-582.
[295] The U.S. Green Building Council, "USGBC Site Development - Protect and Restore Habitat," www.usgbc.org/credits/ss51 (Accessed 10/01/, 2019).
[296] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009): 69.
[297] Klem, "Collisions between Birds and Windows: Mortality and Prevention,": 120-8.
[298] Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City. *PLoS ONE* 14, no. 11 (2019): 1.

CASE STUDIES

Two university campuses in the United States, Duke University and the University of Utah, reported using the commercial collision solution, Feather Friendly. Three monitoring studies were produced providing valuable data of collisions before and after mitigation strategies were applied. With little data available presenting the effectiveness of mitigation strategies on real-world buildings, these studies are incredibly valuable to the study of bird building collisions.

The buildings on the west campus of Duke University in Durham, Carolina are mostly Collegiate Gothic in style. This style generally uses relatively little transparent and reflective glass; however, recent building additions to the campus incorporate contemporary design features such as the use of large windows, increased height up to four stories, glass passageways, glass corners, and multiple wings.[299] The Fitzpatrick building is Certified LEED Silver.[300] The building has the largest percentage of overall glass surface area (57%) and surrounding forest cover (33%) than other buildings on campus and included glass walkways.[301] Over 21 days in the fall of 2014 and spring 2015, 86 bird collisions were reported and the Fitzpatrick Building had the highest number of reported bird collisions on campus at 61 collisions. Most of the species that collided with the building were migratory species the top being the cedar waxwing (*Bombycilla cedrorum*) and the ovenbird (*Seirurus aurocapilla*). Ocampo-Penuela et al. suggests that the fermented berries consumed by the cedar waxwing disturb the birds' sense of orientation. They further suggest the ovenbird is highly vulnerable to collisions due to being an understory specialist.[302] Two resident birds were frequent collision victims: the northern cardinal (*Cardinalis cardinalis*) and the tufted titmouse (*Baeolophus bicolor*).[303] This further proves that while migratory birds are most vulnerable to collisions, collisions happen year-round and impact resident species as well. In 2015, the Fitzpatrick Building was retrofitted with vinyl dots of equal size and spaced equally at 2.5 cm apart on the glass exterior provided by the company Feather

[299] Natalia Ocampo-Penuela et al., "Patterns of Bird-Window Collisions Inform Mitigation on a University Campus," *PeerJ* 4, no. 2 (2016): 3.
[300] LEED certification is based on a credit system of points given passed the potential environmental impacts and human benefits. There are four levels of certification: Certified, Silver, Gold, and the highest, Platinum.
[301] Natalia Ocampo-Penuela et al., "Patterns of Bird-Window Collisions Inform Mitigation on a University Campus," *PeerJ* 4, no. 2 (2016): 5.
[302] Ibid., 12.
[303] Ibid.

Friendly.[304] This method was tested by the American Bird Conservancy and found to be 83-97% effective in reducing collisions.[305]

A follow-up study from 2018 researching the flight path of birds on the Duke campus, reported that the alteration of the glass on the Fitzpatrick building had reduced collisions but only by about half, resulting in a yearly average of 47 collisions between 2016 and 2017.[306] The follow-up report also indicated the vinyl dots were spaced at 5 cm, not 2.5 cm apart as indicated in the first study. After the retrofit, the Fitzpatrick building still caused 47-67% of the campus' collisions. It was also observed that collisions at the transparent glass passageway were drastically reduced.[307] The mere 50% reduction in window collisions was due to inconsistencies in the application or the mitigation method chosen. The follow-up report indicated that only one-fourth of the glass surface had been covered by Feather Friendly (white vinyl dots spaced 5 cm

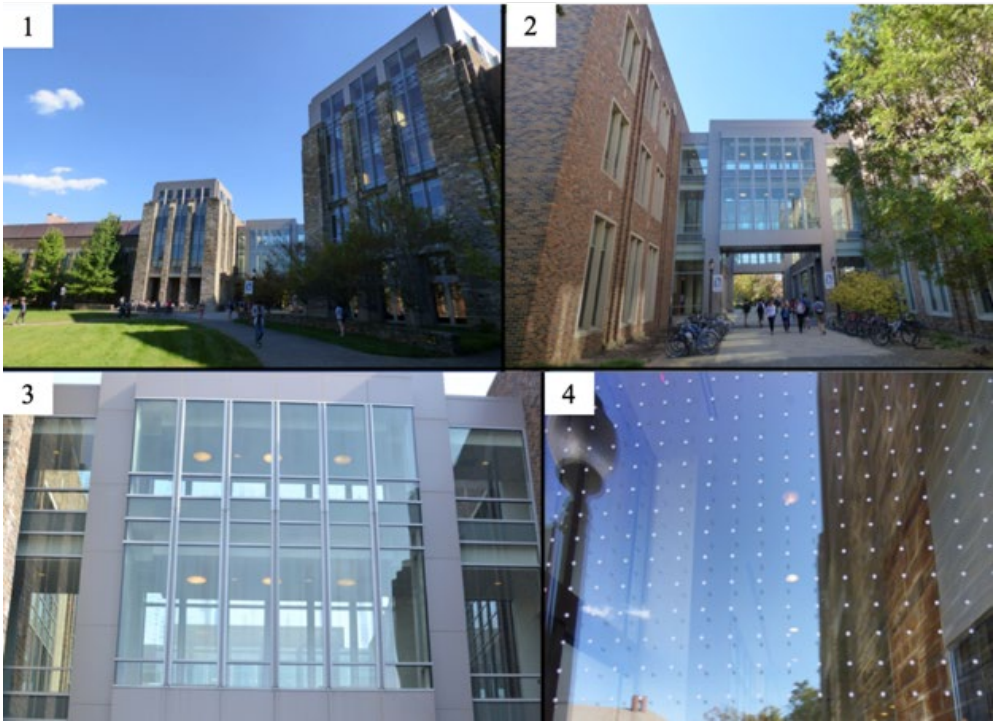

Figure 28. Fitzpatrick Building, Duke Campus
Building (1); Transparent Glass Corridor (2); Detail of Transparent Glass Corridor (3); Detail of Dots (4).

[304] Natalia Ocampo-Penuela et al., "Patterns of Bird-Window Collisions Inform Mitigation on a University Campus," *PeerJ* 4, no. 2 (2016).
[305] Feather Friendly, “Feather Friendly,” https://www.featherfriendly.com, accessed April 7, 2020, https://www.featherfriendly.com/)
[306] R. S. Winton, Natal Ocampo-Penuela and Nicolette Cagle, "Geo-Referencing Bird-Window Collisions for Targeted Mitigation.(Report)," *PeerJ* 6, no. 1 (2018), 8-10.
[307] Ibid.

apart) in areas with clear passageways or transparent corners. The vinyl dots were not applied to windows where reflections of vegetation were visible.[308]

Three buildings at the University of Utah campus use collision mitigation techniques and their effectiveness was evaluated in Brown et al.'s 2019 study. During their first winter (November 2017 – January 2018) monitoring of what the study called the "mitigation building," 7 collision fatalities were reported under the mirrored façade and 15 fatalities total for the building. In November 2018, Feather Friendly was applied to the mirrored exterior on the north side and left the western side untreated as a control. The study monitored eight total buildings in the second winter (November 2018 – January 2019) and found 22 total collisions. Mirrored windows that faced pear trees (Prunus calleryana) were found to increase collisions specifically for cedar waxwings. In winter one, 13 out of the 15 fatalities were cedar waxwings and in winter two, all ten fatalities were cedar waxwings.[309]

The results of monitoring Feather Friendly as a collision mitigation solution showed a 71% reduction in collisions. The collisions had declined from seven to two after application. The control area had eight collisions. Two of the eight monitored buildings had ceramic frit dots and ORNILUX UV film on their windows at the time of the study. During winter two monitoring, these windows only had one fatality, but the study noted with low collision fatality numbers, this data does not indicate they significantly reduced collision risks.[310]

These three studies indicate the importance of testing and monitoring mitigation techniques on real-world buildings before recommending their use and making informed decisions when choosing mitigation techniques. Also, in the case of the Duke campus, thorough research understanding why birds collide with buildings could have indicated the need for Feather Friendly to be applied to more areas of the building other than clear passageways and transparent corners. These studies show that the effectiveness of Feather Friendly to reduce collisions is lower than indicated by the wind tunnel testing conducted by the American Bird Conservancy. On the Duke University campus, collisions were reduced by only half and on the University of Utah's campus collisions were reduced by 71%, slightly lower than the 77%

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[308] R. S. Winton, Natal Ocampo-Penuela and Nicolette Cagle, "Geo-Referencing Bird-Window Collisions for Targeted Mitigation.(Report)," *PeerJ* 6, no. 1 (2018), 8-10.
[309] Barbara B. Brown et al., "Winter Bird-Window Collisions: Mitigation Success, Risk Factors, and Implementation Challenges," *PeerJ* 7 (2019).
[310] Ibid.

predicted by the American Bird Conservancy. While each site's understanding and budget limited the application of the product to all glass surfaces of the building, considering real-world results when choosing mitigation strategies is necessary when choosing the most effective product.

Few case studies document the use of techniques to prevent building collisions and provide data from both before and after retrofitting. A successful retrofitting of glass using equally sized and spaced frit dotting at the Jacob K. Javits Convention Center in New York City is a vital aspect of its success story. This self-proclaimed model of sustainability promises to have minimal impact on the environment. It not only uses the most effective bird-safe glass solution but offers habitat space on its green rooftop for 29 species of birds, five species of bats, and beehives that produce rooftop honey. As reported in 2009 by the New York Audubon Society, the Javits Convention Center had one the highest rates of building collisions in New York City killing on average 100 birds a year. The building's façade made primarily of transparent glass, was retrofitted in 2014 with opaque panels at street level on the north and south sides of the building and with equally sized and spaced frit dots covering the glass entrances on the east and west sides of the building. (See Figure 29.) The frit dots resulted in a 90% decrease in bird building collisions as recorded in 2015 (See Figure 22 for frit dots). The 7-acre green roof of the Jacob K. Javits Convention Center shown in Figure 30 is enticing to birds and would have been extremely conducive to window collisions, as it is located on top of a building constructed of transparent glass with visible support beams. It is also situated near the Hudson River and in a migration flyway. However, the fritted glass mitigates most of this danger. The rooftop is home to 29 nesting species and includes 100 gull nests. The Javits Center is an example of effective glass technology to reduce collisions. The dangers posed by artificial lighting are reduced as the illuminated glass includes frit dots or opaque panels reducing reflections by communicating to the migrating and resident birds that the glass of this building is solid. Klem's 2009 experiments showed that frit dots reduced collisions by 100%; however, in this real-world case study, the ceramic frit dots were 90% effective in reducing collisions. This 10% difference is a signal that experiments are a starting point to determine which methods have the potential of reducing collisions, but many of the results may vary due to factors on real-world buildings the tests cannot replicate. Frit dots were used successfully at two colleges in Pennsylvania: Swarthmore College in Swarthmore and Muhlenberg College in Allentown.

Swarthmore had two known collisions a year and Muhlenberg had none.[311] While the Javits Center is a success story due to the addition of frit dots, it is also a reminder that materials tested in experiments may not perform equally on real-world structures emphasizing the need for monitoring mitigation strategies after they are implemented.

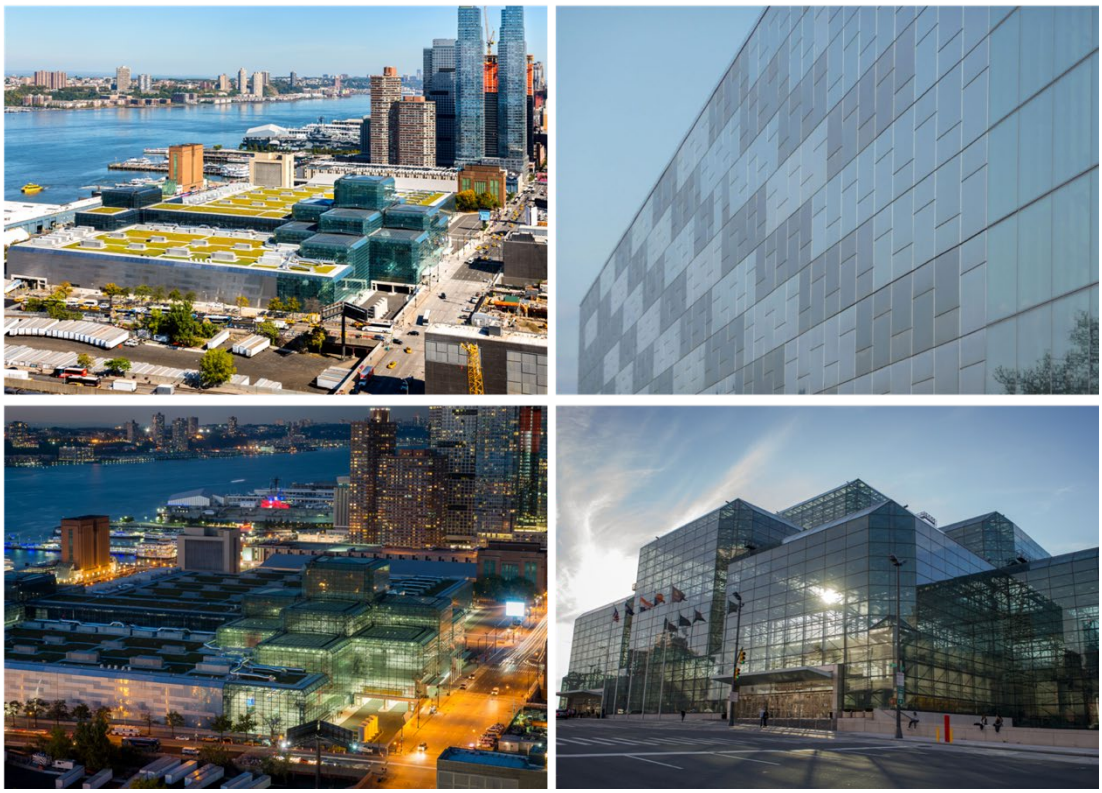

Figure 29. Jacob Javits Convention Center
Left Top and Bottom: Javits Convention Center Day and Night. Right Top: Detail of Opaque Glass. Right Bottom: Glass Façade Entrance.

The Allianz Field stadium located in Saint Paul, Minnesota and completed in 2019 is revered by bird conservation organizations like the Audubon Society for the designers' commitment to preventing bird collisions.[312] Structural engineer Walter Moore designed the Allianz Field to minimize environmental impact. With this, the designers were dedicated to making the building bird-safe as they recognized that Saint Paul, Minnesota sees over 300

[311] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009).
[312] Alisa Opar, "Minnesota's Newest Sports Stadiums Take Very Different Approaches to Bird Safety," Audubon, October 24, 2018, https://www.audubon.org/news/minnesotas-newest-sports-stadiums-take-very-different-approaches-bird-safety.

Figure 30. Jacob Javits Convention Center Green Roof
Left Top and Bottom: Javits Convention Center Green Roof. Right Top: Herring gull (Larus argentatus) Family. Right Bottom: Glass Façade and Beehives.

species of birds during the migration season. As their website states, they wanted to make "this large building is as safe as possible for our feathered friends."[313] They decided to cover 70% of their building with PTFE fabric that wraps around the structure to limit the use of reflective or transparent glass. The stadium designers report that PTFE prevents the reflections from appearing on the glass. Avoiding the use of reflective glass means the landscape can be designed with native trees without the risk of their reflections confusing birds that would lead to collisions. The glass doors by the entrance gate recede behind the edge of the PTFE fabric above but also use a bird-safe frit pattern. The PTFE fabric also reduces light pollution, and the LED lights used at the stadium face inward rather than beaming up and out into the night sky.[314] The building and the PTFE fabric are depicted in Figure 31. This case study approached bird-safe design by using new bird-safe materials to enclose the stadium as well as bird-safe lighting and landscape.

[313] Minnesota United FC, "Allianz Field is for the Birds," https://www.mnufc.com/post/2019/02/11/allianz-field-birds.
[314] Ibid.

However, there is one vital component of bird-safe design that is missing: monitoring for collisions. Collecting data proving the stadium effectively prevents collisions would strengthen the case for bird-safe designs. Located in the neighboring city from the deadly U.S. Bank Stadium in Minneapolis, this stadium is a reminder that designers and architects who value birds will incorporate bird-safe designs into their sustainability efforts. The Allianz Stadium in St. Paul, Minnesota is an example of what can be achieved when innovative bird-safe designs are

Figure 31. Allianz Field Stadium Saint Paul, MN and PTFE Detail

part of the building plan early in the concept.

Finding innovative ways to communicate that glass is solid or that the entire structure is made of solid, impassible material is essential to the future of bird-safe designs. Based on the evaluation of designs in experiments and case studies, equally sized and spaced frit dots, perforated films like CollidEscape, or breathable but solid appearing materials like PTFE achieve

this goal. As opposed to UV patterns and films, new materials such as electrochromic glass can offer a more customizable balance between human desired aesthetics or the benefits of glass and designs that reduce collisions. Electrochromic glass reduces glare by implementing a tinting technique based on the needs of humans inside the building and the weather. They also offer customizable controls.[315] With more research, this glass could incorporate tinting techniques that resemble frit dots or perforated vinyl to deter collisions. With the customizable controls, these mitigation techniques could be automatically adjusted or set on a timer to turn on during the migration season.

Daniel Klem has built a foundation for reducing window collisions by providing controlled experiments with glass solutions. Further, the American Bird Conservancy and Christine Sheppard offer more test results and valuable information about the effectiveness of commercially manufactured solutions. However, it is important to remember that these experiments, including Rossler et al.'s, offer a basic understanding of collision deterrence methods. Evaluating each suggested solution for effectiveness in the field, on and around buildings, as well as in closed experiments, will offer a complete understanding of which collision mitigation techniques are the most reliable. This also applies to the Bird-Smart glass resources provided by the American Bird Conservancy, which does not guarantee effectiveness in the field.[316]

Landscape and lighting design offer straightforward solutions that can reduce collisions through thoughtful landscaping or the more comprehensively researched lighting solutions. Reducing light use at night is the most effective and most accessible solution to reduce collisions. When this is not an option, treating glass with solutions such as frit dots or perforated vinyl and reducing the use of floodlighting can help to reduce collisions and behavior disruptors. For landscape design, understanding the impacts of vegetation, surface area, and surrounding native landscapes on native and migrating species allows mitigation techniques to be customized to specific locations. Moving places of respite, nesting, and food sources away from reflective glass and eliminating their use behind glass is the most effective prevention method.

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[315] View, "Electrochromic (Smart Glass)" https://view.com/product/how-it-works.

[316] American Bird Conservancy, "Bird Smart Glass ," https://abcbirds.org/get-involved/bird-smart-glass/ (Accessed November 1st, 2019).

While many solutions to problematic glass, lighting, and landscape designs have been evaluated and proposed in this chapter, there is a vital need for collision reduction methods that effectively reduce collisions and provide building occupants with natural light and a view of nature. This is a critical area of study that needs to be tackled from an interdisciplinary approach, involving experts in building design, landscaping, lighting, ornithology, and any researchers or innovators passionate about finding proven effective solutions to mitigating bird building collisions. For solutions to be widely effective in reducing collisions in the United States, they must be implemented in policies devoted to sustainable practices and sustainability education.

CHAPTER 4 AVIAN PROTECTION POLICIES AND DESIGN GUIDELINES

The modern era of environmental research and policy in the United States brought awareness of the impact of human actions and development on nature and birds. From the 1920s to the 1960s, America needed to rethink its relationship with nature as urban and rural growth increased and the population expanded into urban areas.[317] In 1948 the first effects of DDT on bird populations were detected by conservationist Fairfield Osborn. Osborn's early opposition to pesticide use and his book *Our Plundered Planet* were the beginning stages of a movement towards protecting the environment from anthropogenic threats. [318] The Environmental Movement in America of the 60s and 70s was ushered in by Rachel Carson and her book *Silent Spring*. It warned of an endless stillness and the end of all bird songs if humans did not change their indiscriminate use of insecticides and abandon their conquest of nature. Largely in response to the literary work of Carson, this era also brought the foundation of the Environmental Defense Fund and the Endangered Species Act much.[319] The Endangered Species Act, passed in 1973, allows state and federal governments to protect species threatened with extinction in the United States and its territories. This act shaped the legislation used to protect the peregrine falcon (*Falco peregrinus*) and led to the species' successful recovery.[320] The 80s and 90s brought more complex and controversial conservation policies as movements felt pushback from lawmakers. The Coastal Barrier Resources Act of 1981 included a federal bill that protected habitats for migratory birds and other wildlife along the Atlantic and Gulf coasts of the United States, highlighting the fundamental conflict between land development and conservationists.[321] The 20th Century introduced the green building revolution through the U.S. Green Building Council and LEED certifications, which aimed to reduce the vast amount of energy buildings consume in their construction and operation. The voluntary policies also brought awareness of protecting undeveloped land, reducing light pollution, a site's impact on the local ecosystem, and

[317] Peninah Neimark and Peter Rhoades Mott, *The Environmental Debate: a Documentary History with Timeline, Glossary, and Appendices* (Amenia, NY: Grey House Publishing, 2017), 170.
[318] Ibid.
[319] Ibid., 227-9.
[320] U.S. Fish and Wildlife Service/Endangered Species Program, "Endangered Species Act: Overview," Official Web page of the U S Fish and Wildlife Service, Accessed June 7, 2020, https://www.fws.gov/endangered/laws-policies/).
[321] Neimark and Mott, *The Environmental Debate*, 264-5.

avoiding CO2 emissions[322]; all areas of concern for bird conservation efforts. Currently, we face new conservation and policy issues as increased use of glass, light pollution, and loss of habitat from urbanization threaten bird populations across North America. Conservation policies and sustainability guidelines need to clearly outline how they are protecting avian species in addition to preventing habitat loss, reversing climate change, and providing a visual connection to nature. Visually opening buildings, allowing a connection between humans and nature to increase overall human well-being should not kill large numbers of birds.

This chapter begins by briefly summarizing selected acts and programs aimed to protect avian populations in the United States. The chapter then outlines and evaluates three sets of sustainable design guidelines, as developed by the Living Building Challenge, the U.S. Green Building Council's LEED Pilot Credit 55, and the American Institute of Architects, for their ability to safeguard bird populations in the built environment. Proposed revisions and additional guidelines are provided based on an analysis of available collision solutions. Finally, city and state policies from across the United States, primarily San Francisco, New York City, and the state of Minnesota, are outlined, compared to each other, and to a proposed federal policy, the Bird Safe Building Act of 2019. This chapter proposes a state and federal policy guidelines to create a more united front and consistent format at the end of the chapter. The scope of this chapter is to outline policies and guidelines focusing primarily on mitigation of the dangers birds face in the built environment.

ACTS AND PROGRAMS

The U.S. Department of the Interior administers the Migratory Bird Treaty Act under the Fish and Wildlife Service agency. This federal act of 1918 "makes it illegal to take (kill), possess, import, export, sell, purchase, barter, or offer for sale, purchase, or barter any migratory bird, or the parts, nests, or eggs of such bird except under the terms of a valid permit."[323] The act also implements conventions between the United States and Canada, Mexico, Japan, and Russia to protect migratory birds.[324]

[322] Neimark and Mott, *The Environmental Debate*, 631-3.
[323] "Migratory Bird Treaty Act," U.S. Fish & Wildlife Service - Department of the Interior, Accessed April 7, 2020, https://www.fws.gov/birds/policies-and-regulations/laws-legislations/migratory-bird-treaty-act.php).
[324] Ibid.

Although the Migratory Bird Treaty Act has been modified a few times over its history, it is the interpretation of "take" that has undergone the most changes and challenges in the past two decades. The dispute rests on whether the interpretation of "take" includes incidental bird deaths, such as collisions with structures or mortality that results from industrial accidents, or exclusively towards activities whose intent is to kill birds. Throughout most of the Act's history, the Fish and Wildlife Service interpreted take to include incidental killing, however there was enough legal ambiguity that the courts did not uniformly enforce this interpretation. In addition, it was the unofficial practice of the Fish and Wildlife Service to limit the prosecution of incidental takes, as there was no regulated mechanism to exempt incidental take outside of military activates.[325] Still, under the Obama administration there were at least two high profile examples of the federal government holding non-federal actors responsible for incidental bird deaths, including one that involved collisions with built structures.

In 2013, based on the Migratory Bird Treaty Act, a court ruled that two wind farms in Wyoming would be penalized 1 million dollars and 2.5 million dollars in one year for killing protected birds including the golden eagle (*Aquila chrysaetos*). Two years later, in 2015, the U.S. Fish and Wildlife Service announced it would consider holding industries more accountable for bird deaths caused by wind turbines, infrastructure such as power lines and cell phone towers, and byproducts of energy production such as oil pits and gas flares.[326] A statement made by Robert G. Dreher, acting assistant attorney general for the Justice Department's Environment and Natural Resources Division, declared that the wind farm owners, Duke Energy Renewables, "constructed these wind projects in a manner it knew beforehand would likely result in avian deaths."[327] While Duke Energy Renewables claimed that their goal is to provide clean and safe wind energy, the president of the American Bird Conservancy, George Fenwick, pointed out that clean energy that kills "hundreds of thousands of birds" is not green.[328] In an effort to make such accountability more commonplace, in January 2017 the acting Interior-Solicitor, Hilary

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[325] Andrews G. Ogden "Dying for a Solution: Incidental Taking under the Migratory Bird Treaty Act." *William and Mary Environmental Law and Policy Review* 38, no. 1 (2013): 80.
[326] Ibid.
[327] Cappiello, D. 2013, November 23. Eagle deaths at wind turbine farm: Duke Energy agrees to pay $1 million. Retrieved from https://www.nbcnews.com/news/us-news/eagle-deaths-wind-turbine-farm-duke-energy-agrees-pay-1-flna2D11644504. Accessed 18 Nov. 2019.
[328] Ibid.

Tompkins issued a legal opinion, Opinion M-37041, affirming the longstanding interpretation of the Act to include incidental take. [329]

In less than a year, however, the new Interior-Solicitor, Daniel Jorjani, permanently withdrew the actions of his predecessor and issued a new interpretation under Opinion M-37050 which states that "the take [killing] of birds resulting from an activity is not prohibited by the Migratory Bird Treaty Act when the underlying purpose of that activity is not to take birds."[330] This new interpretation could be understood as pardoning the elimination of a building known to have an active nest of vulnerable birds. If the owner of the building is not killing the birds directly, but demolishing the building, they cannot be penalized.[331] It also would not hold building owners responsible for killing hundreds of birds a year through known bird building collisions if the building was not built to kill birds. The vice-president of conservation for the Audubon Society, Sarah Greenberger, adds that the Migratory Bird Treaty Act "has been the tool the Fish and Wildlife Service has used to work with industry to implement basic management practices." Without having guidelines to hold businesses accountable, they will have no compelling reasons to implement measures like covering tar pits that kill up to a million birds a year.[332]

Under the current migratory Bird Treaty Act ruling, the 2013 penalties imposed on the two Wyoming wind farms would not occur. As reported in Cappiello's 2013 article, the wind turbines are being monitored after the golden eagle deaths and turned off if eagles were detected in the area. Also at least half of the penalty fee was used to create protected habitats for golden eagles in Wyoming. These regulations and penalties ensured there were consequences for taking birds and places value on their lives, even if monetarily. Another option to place value on the lives of birds would be implementing an education program about mitigating wind farm casualties or bird building collisions. This has been a successful strategy of FLAP and Lights Out! to persuade building owners to protect birds.

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[329] Ogden, "Dying for a Solution": 80.
[330] Ibid.
[331] Darryl Fears, D. G. 2019, April 29. The Trump Administration has Officially Clipped the Wings of the Migratory Bird Treaty Act. Retrieved from https://www.washingtonpost.com/news/energy-environment/wp/2018/04/13/the-trump-administration-officially-clipped-the-wings-of-the-migratory-bird-treaty-act/. Accessed 18 Nov. 2019.
[332] Ibid.

FLAP or the Fatal Light Awareness Program is a Canadian based program founded by Michael Mesure in 1993 after he witnessed the delayed death of a bird building collision victim, a common yellowthroat (*Geothlypis trichas*). FLAP is a Canadian non-profit that leads the country on bird building collision mitigation by working to safeguard migratory birds in the built environment. This is done through education, policy, and research.[333] As the name indicates, the program's initial focus was on reducing light pollution and lit structures that contribute to bird building collisions. The program quickly started to incorporate design strategies to mitigate deaths caused by transparent and reflective glass. FLAP's work with researchers like L. J. Evans Ogden[334] and cities across Canada to reduce the threats of light pollution on avian populations influenced the Lights Out! Program in the United States.

The successful Lights Out! collision mitigation program[335] was formed in 1999 by the Audubon Society. The first city to adopt the program was Chicago, Illinois. The Audubon Society has now established Lights Out! Programs across 40 cities in the United States. This national effort aims to reduce the bright artificial lights and skyglow of cities that lead to collisions with buildings or windows and cause confusion or exhaustion, making birds vulnerable to other threats. The program's strategy is to convince building owners and managers to turn off excess lighting particularly during migration periods. These strategies include turning off decorative lighting and lighting of higher stories, avoiding floodlights and strobe lighting, reducing atrium lighting, down-shielding exterior lighting, and using motion sensors and controls.[336] Most of the city and state bird-safe policies in this chapter reference The Lights Out! Program as well as the guidelines for the Urban Bird Treaty.

The Urban Bird Treaty is a collaborative effort between the U.S. Fish and Wildlife Service and cities in the United States to support city partners in conserving birds and their habitats. Thirty cities have joined the program since 1999. This program supports its partners to conserve urban habitats for birds, reduce urban hazards, and educate and engage urban communities. The ultimate goal of this program is for cities to become sanctuaries for birds

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[333] Fatal Light Awareness Program Canada, "About FLAP," FLAP Canada, Accessed April 7, 2020, https://flap.org/about/)
[334] "Ibid.
[335] National Audubon Society. "Existing Lights Out Programs," Audubon, January 15, 2020, https://www.audubon.org/conservation/existing-lights-out-programs).
[336] Ibid.

while increasing the health and well-being of people living in and visiting cities across the United States. The Urban Bird Treaty also focusses on community-based solutions to bird conservation intending to connect humans through healthy, beautiful, bird-friendly cities.[337] However, to make urban areas truly safe for birds, sustainable guidelines must add standards to safeguard birds.

SUSTAINABLE DESIGN GUIDELINES

There is a link between all aspects of green or sustainable building design and biodiversity. Energy, water, livability, and human health are all connected to the biodiversity of the site.[338] However, according to Mark Hostler, a system ecologist from the University of Florida, sustainable building guidelines are "failing on biodiversity." Hostler claims this is due to biodiversity not being particularly well understood and therefore is considered last when building sustainably.[339] In 2008, Marzluff and Rodewald suggested that "all urban areas have the potential to contribute to the conservation of biodiversity."[340] Their recommendations outline six principles to preserve and restore wildlife habitats in urban areas in order to conserve avian diversity.[341] (See Appendix 4). Yet, over a decade later, sustainable guidelines offer little protection of biological diversity but there are ways designers can actively protect local biodiversity through design strategies. In this section, sustainable design guidelines are outlined based on their ability to protect biodiversity, specifically bird populations.

The Living Building Challenge asks designers to imagine buildings that are not dependent on fossil fuels, are self-sustaining, function as efficiently as nature while in line with nature, and truly build sustainably. The goal of the Living Building Challenge is to "make the world work for 100% of humanity in the shortest possible time through spontaneous cooperation without ecological offense or the disadvantage of anyone". [342] The ethos of this challenge is to build in a

[337] "Urban Bird Treaty," U.S. Fish & Wildlife Service - Department of the Interior, Accessed April 7, 2020, https://www.fws.gov/birds/grants/urban-bird-treaty.php).
[338] Lesley Evans Ogden, "Does Green Building Come up Short in Considering Biodiversity?: Focus on a Growing Concern.," *BioScience* 64, no. 2 (2014): 84-5.
[339] Ibid.
[340] John M. Marzluff and Amanda D. Rodewald, "Conserving Biodiversity in Urbanizing Areas: Nontraditional Views from a Bird's Perspective," *Cities and the Environment* 1, no. 2 (2008): 1.
[341] Ibid., 12-3.
[342] International Living Future Institute, *Living Building Challenge 4.0* (2019): 1-13.

way that is socially just, culturally rich, and ecologically restorative by providing a framework for design, construction, and reshaping humanity's relationship with nature. It proposes reshaping the connection between humans and nature as a symbiotic relationship primarily through designing regenerative projects that do not simply avoid negative environmental impacts but that help to realign our ecological footprint. The Living Building Challenge aims to achieve these high building and community standards over the next ten years through seven "petals" that incorporate 20 imperatives.[343] (See Figure 32.). The Living Building Challenge 4.0, released in June 2019, details each of these imperatives and includes five levels of certification based on the adherence to imperatives in each petal. The seven petals include Place, Water, Energy, Health and Happiness, Materials, Equity, and Beauty. This thesis focuses on three petals: Place, Health and Happiness, and Beauty. These and the three additional petals, Water, Energy, and Materials,

Figure 32. Living Building Challenge Petals and Imperatives

[343] International Living Future Institute, *Living Building Challenge 4.0* (2019): 1-13.

address design standards that may positively impact bird populations indirectly; however, they do not provide specific safeguards for bird populations. By reviewing the eight imperatives, this document will outline why direct bird-safe guidelines are needed and how they can be implemented in the Living Building Challenge. Finally, the proposal of an eighth petal, Wildlife Protection, intends to balance the human-centric Challenge and to foster a cooperative relationship between humans and nature, echoing the ethos this challenge strives to achieve.

The Living Building Challenge is committed to preventing habitat loss, reducing factors that lead to climate change, providing a connection to nature, and preserving the ecology of place. These factors all of which positively impact bird populations. However, the challenge lacks specific provisions to reduce harm to birds, such as reducing building collisions in projects that use a large amount of glass. The ethos of the Living Building Challenge could be revised to incorporate specific bird protecting standards; it can also include provisions to support wildlife as a contributor to human well-being by connecting to nature through birds and other animals. Three out of the seven petals could include provisions for bird protecting designs. Connection to nature through birds could be added to four of the 20 imperatives, three of which are Core Imperatives required to be labeled a Living Building. The Ecology of Place, a core imperative, should emphasize the importance of including consideration of birds in every project. Access to Nature should emphasize bird protecting standards if a project uses transparent or reflective glass. Finally, Beauty and Biophilia and Education and Inspiration, both can incorporate birds by connecting humans to birds through designs promoting biodiversity. Additionally, providing educational examples of why bird safe designs are integral to sustainability standards will support these efforts.

Ecology of Place is located in the first petal, Place. This imperative intends to "protect wild and ecologically significant places."[344] This imperative requires all projects to demonstrate that they "contribute positively to the ecology of their place and restore or enhance the ecological performance of the site towards a healthy ecological baseline."[345] This includes cultural and social equity factors, zero use of petrochemical fertilizers or pesticides, and landscape guidelines to emulate the functionality of the local habitat. Additionally, it requires that projects "avoid

[344] International Living Future Institute, *Living Building Challenge 4.0* (2019): 1-13.
[345] Ibid.

building on pristine greenfield, wilderness, prime farmland or in a floodplain unless they meet an exception."[346] Preventing petrochemical pollution and ensuring a native landscape while protecting wild and ecologically significant places will contribute positively to the local ecology and indirectly has a positive influence on local species of birds. However, this imperative ignores the fact that the local ecology can be disrupted by a structure occupying a three-dimensional space that can place birds in danger.

The second and third imperatives for the Place petal are Urban Agriculture and Habitat Exchange. These are not core requirements but are required to achieve the Living Certification. Urban Agriculture intends to connect the community to locally grown food. While this imperative is rightfully human-centric, agriculture and green spaces will attract bird species as well as additional wildlife. The Habitat Exchange imperative requires the project to set aside a quantity of land approved by Land Trust or the Institute's Living Future Habitat Exchange Program that is equal to the project area and away from the site, to reduce habitat loss caused by urbanization.[347] While the Place petal indirectly benefits birds, the Health and Happiness petal put birds in direct danger.

The intent of the Health and Happiness petal is to foster optimal physical and physiological health as well as the overall well-being of humans interacting with the project. This petal's three imperatives were created to promote "healthy spaces that allow all species to thrive by connecting people to nature." This is primarily done through the use of large glass windows. This petal ensures that interior spaces have "healthy air and natural light," as this connection to nature, through daylight, directly affects productivity, creativity, and countering stress.[348] The core imperative, Healthy Interior Environment, requires outdoor views and daylight for 75% of regularly occupied spaces. The Healthy Interior Performance imperative, which is not a core imperative, requires a higher percentage of access to outside views and daylight in 95% of the regularly occupied spaces. These two imperatives mean that more glass will be used on projects to meet these standards. The third imperative, Access to Nature, requires all projects to connect people and nature through interactions and connectivity, primarily through the benefits of daylight, fresh air, and landscape, as well as completing a post-occupancy

[346] International Living Future Institute, *Living Building Challenge 4.0* (2019): 30.
[347] Ibid.: 28-33.
[348] Ibid., 45-49.

evaluation of health benefits.[349] While the benefits to people of this connection to nature are well documented, costs to wildlife are not. For example, bird collisions increase, sometimes significantly, with increased transparent glass used in a building. The Living Building Challenge fails to mention that bird protecting design solutions should be applied to all glass to achieve a balance between nature and the ecology surrounding the project.

The Beauty petal has two core imperatives, Beauty and Biophilia, and Education and Inspiration. Both of these imperatives intend to connect people to nature in order to inspire its preservation and conservation. This petal ideally strives to "inspire us to be better than we currently are."[350] The core imperative of Beauty and Biophilia intends to connect humans to nature through the beauty of nature, through natural materials, and biophilic design. Project designers are required to spend at least one full day of exploration of biophilic designs for the potential project. The second core imperative of the Beauty Petal is Education and Inspiration. This imperative intends to provide educational materials and information on performance related to the project to the public and the project's occupants.[351]

The four imperatives from the three petals, Place, Health and Happiness, and Beauty can all be achieved simultaneously with the Living Certification. Three of the four imperatives, Ecology of Place, Beauty and Biophilia, and Education and Inspiration can be achieved with the Petal Certification and the Core Green Building Certification. However, requiring Ecology of Place and Access to Nature in all three certifications will help to protect bird populations and make the two main aspects of the Living Building Challenge comprehensive. However, in the three petals and seven imperatives, there is no mention of bird protecting designs or other protection of wildlife. As is, the Living Building Challenge is producing buildings that reduce their impact on the earth for the sake of humans, but it lacks action to safeguard surrounding ecology that may be disrupted by structures. This set of guidelines fails to protect the creatures that occupy the habitat space the program strives to protect. It also overlooks the vital role of species, such as birds. The Living Building Challenge must not endanger birds in order to provide a connection to nature by using large amounts of glass. To design in balance with nature, designing for human benefits should not harm other living beings. To achieve this balance, this thesis proposes an eighth petal,

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[349] International Living Future Institute, *Living Building Challenge 4.0* (2019):
[350] Ibid., 64-68.
[351] Ibid.

Wildlife Protection. (See Figure 33.) Experts in various fields of biology and environmental science, as well as design and architecture, are needed to draft a comprehensive plan in order to protect the wildlife living at the site year-round or migrating to the area. While an interdisciplinary approach is vital, the petal can be generally outlined here.

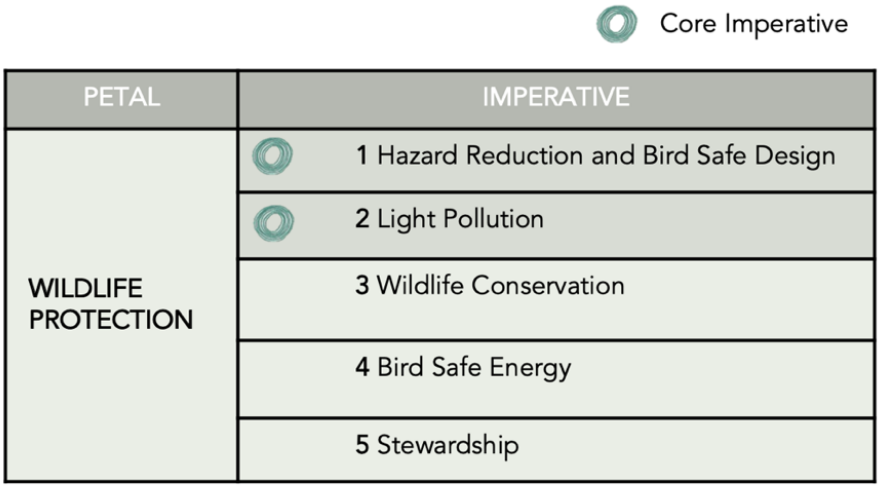

Figure 33. Proposed Wildlife Protection Petal and Imperatives
(Figure by author.)

The proposed petal, Wildlife Protection has two core imperatives and five total imperatives. The first core imperative of the eighth petal, Hazard Reduction and Bird Safe Design, should outline mitigation techniques to structural hazards for birds such as transparent and reflective glass, landscaping near reflective glass, and any transparent structures. This imperative should also address hazards the built structure, and its design, could impose on additional wildlife species. The second core imperative, Light Pollution, should address light pollution and propose/introduce mitigation techniques to ensure the project limits attraction or disorientation for migrating birds, or harms wildlife sensitive to artificial light. A third imperative, Wildlife Conservation, would allow the project to incorporate nesting boxes, green spaces, and preserve habitat aiding in conservation efforts. The land set aside in the Habitat Exchange imperative could be listed under this imperative if steps were taken to support declining species, such as the American Kestrel, by providing nesting space. Under the Urban Agriculture imperative, Wildlife Conservation can be expanded to support local wildlife such as bees and birds by placing emphasis on native plants that can produce food for humans as well as wildlife. The fourth imperative, Safe Energy, would address energy and infrastructure. Renewable energy sources such as solar or wind power and infrastructure, such as powerlines, can kill up to half a billion

birds each year in the United States. The source of renewable energy, whether on the building or not, should be evaluated for being a high risk to birds and other wildlife. Finally, the fifth imperative, Stewardship, would require the project to provide educational resources about the wildlife the project is striving to protect and how to do so. The focus of the eighth petal goes beyond the protection of birds. It is a place to provide guidelines to protect the ecology of place and the surrounding environment as a system to be preserved as a whole rather than a system to be preserved for humans alone. This can be seen with the U.S. Green Building Council and the American Institute of Architects' bird protecting guidelines.

The U.S. Green Building Council has one LEED Pilot Credit to help protect birds from bird building collisions.[352] The intent of Pilot Credit 55: Bird Collision Deterrence is to "reduce bird injury and mortality from in-flight collision with buildings."[353] This credit has been designed in collaboration with the American Bird Conservancy. The credit requires that a façade appears as a physical barrier to birds; it also necessitates the elimination of conditions that create reflections. The façade requirements are based on the threat factors applied to façade materials by the American Bird Conservancy.[354] LEED provides 18 example patterns the American Bird Conservancy has indicated as having a threat factor of 15 or less. Also included in the options are plexiglass, translucent plastics, screens, and external shutters. Only screens and external shutters have been tested. Their threat factors are under the recommended 15 or less.

To achieve the LEED credit, the fulfillment of the façade requirements must accompany the fulfillment of three other requirements: interior lighting, exterior lighting, and monitoring. To achieve the interior lighting requirements requires either that nighttime personnel turn off the lights from at least midnight to 6 am, or that an automatic system turns off the lights after 30 minutes of inactivity in the space. An exception is the lighting needed for health and safety. The exterior lighting requirements include reducing or eliminating light trespass from exterior fixtures with fixture shielding and automatic shutoff (or following the LEED SS Credit, Light Pollution Reduction). Finally, the credit requires a three-year monitoring plan to assess the effectiveness of the design in mitigating bird building collisions. This information must include

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[352] A pilot credit allows projects to test innovative credits that have not completed the drafting and balloting process.
[353] U.S. Green Building Council. "Bird Collision Deterrence," U.S. Green Building Council, Accessed April 7, 2020, https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthc-212?view=language).
[354] Ibid.

identification of species, location, quantity, date, time, and features contributing to the collision.[355] Although the LEED 55 credit requires tested materials that reduce collisions by 85% or more in flight tunnel testing, there is room for improvement. This should include implementing a rating system for materials and collision mitigation designs based on their three-year monitoring plan, including lighting, landscape, and location details. Designers and building owners then could compare which collisions solutions would be appropriate to use for their specific project or building.

Additionally, the points awarded for this credit are not enough to offset the points awarded for using large amounts of glass near green spaces. One point is awarded for this credit when requirements are met. However, four total points can be awarded for daylighting 75% of the floor area (3 points) and ensuring an unobstructed view of the landscape (1 point) that often falls within the 50 m vegetation buffer that attracts birds to dangerous transparent glass.[356] While this credit may bring awareness to the issue of bird building collisions in sustainability guidelines, it does not offer enough incentive to safeguard birds when human benefits are prioritized in the point system. This credit has room to improve by providing comprehensive nature-focused solutions similar to the Design for Ecology guidelines by the American Institute of Architects.

The American Institute of Architects (AIA) guidelines for bird-safe design constitute the most comprehensive, nature-focused, set of recommendations available today. The AIA is dedicated to sustainable design projects that aim to benefit natural ecosystems and habitats in the built environment by responding to the ecology of place, connecting with place and regional ecosystems, minimizing negative impacts on birds and other animals, and contributing to biodiversity and the preservation or restoration of habitats and ecosystem services.[357] One specific measure outlined in the AIA Committee on the Environment Top Ten sustainable design measurements, Measure 3: Design for Ecology, directs designers to focus "solely on nature."[358]

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[355] U.S. Green Building Council. "Bird Collision Deterrence," U.S. Green Building Council, Accessed April 7, 2020, https://www.usgbc.org/credits/new-construction-core-and-shell-schools-new-construction-retail-new-construction-healthc-212?view=language).

[356] Barbara B. Brown et al., "Winter Bird-Window Collisions: Mitigation Success, Risk Factors, and Implementation Challenges," *PeerJ* 7 (2019): 14.

[357] The American Institute of Architects. "History." The American Institute of Architects. Accessed April 7, 2020. https://www.aia.org/history.

[358] The American Institute of Architects. "Designing for Ecology," The American Institute of Architects, Accessed April 8, 2020, https://www.aia.org/showcases/6082454-designing-for-ecology)

This measure aims to direct design teams to "think beyond the anthropocentric world of traditional architecture and to design specifically for the rest of biodiversity."[359] This measure's top strategy is to use landscape with native plants, a high-impact strategy for saving water, decrease maintenance costs, and provide a habitat for local animals and insects. Additional strategies include lighting, bird collision deterrence, and site acoustics. [360]

The AIA's Design for Ecology's three measures—landscaping, lighting, and bird collision deterrence—are currently the most comprehensive nation-wide guidelines regarding bird safe designs. Landscaping and green spaces are crucial to support biodiversity and avian habitats in the built environment. The points discussed in this measure include covering as much non-building area with a broad diversity of native plants that thrive in the local environment and encouraging designers to have/develop an understanding of the local ecology and ecological services of the site before design to protect or restore the ecological services of the land. These guidelines also encourage design that will preserve mature trees and preserve or create habitat for local flora and fauna. The guidelines encourage the use of birdhouses and bat boxes. Finally, the landscape guidelines value ecosystem services like natural pest control and the importance of even the smaller green spaces to support biodiversity.[361]

AIA also follows the guidelines produced by Dark Skies, a program by the Dark Sky Society, an organization that supports eliminating light pollution. The Dark Skies program aims to support education and legislative efforts to eliminate light pollution. The program consists of five points addressing interior and exterior lighting design and use.[362] The first point suggests maintaining a dark natural environment by carefully designing exterior lighting according to the guidelines from the Dark Sky Society.[363] In Appendix 5, a diagram of fixtures from their Guidelines for Good Exterior Lighting Plans outlines acceptable and unacceptable lighting fixtures. [364] Point two indicates that exterior light should fully cut off at the top of the fixture and illuminate the specific surface desired. Point three suggest the timing of indoor lights should be

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[359] The American Institute of Architects. "Designing for Ecology," The American Institute of Architects, Accessed April 8, 2020, https://www.aia.org/showcases/6082454-designing-for-ecology)
[360] Ibid.
[361] Ibid.
[362] Dark Sky Society. "Dark Sky Society - Home," Dark Sky Society - Home, accessed April 7, 2020, http://www.darkskysociety.org/).
[363] Ibid.
[364] Dark Sky Society, *Guidelines for Good Exterior Lighting Plans* (2009).

limited to when the building is in use after sunset, and interior lights should not be on all night. Point five advises nighttime security should use night-vision cameras and motion active lights. Finally, point five suggests using a computer simulation to verify external lighting will not fall in line with windows attracting birds to its surface.[365]

AIA's Bird Collision Deterrence guidelines outline the causes of bird building collisions. AIA guidelines cite areas of refuge and reflections of these areas in design as deadly to birds. Additionally, the guidelines state that human well-being is also negatively impacted as it is stressful for those who witness bird building strikes. The first mitigation technique listed is to keep the window to wall ratio below 40 percent to improve energy performance, daylighting, thermal comfort, and prevent bird deaths. Design teams should also limit glazing and use shading and glare control. Buildings with areas of high risk such as facades in the "tree zone," near green spaces like green roofs, free-standing glass structures like bus stops or bridges, or clear glass corners or atriums should use design strategies to make these areas visible to birds. The guidelines suggest using the American Bird Conservancy's Bird Friendly Design Guide and UV glazing techniques or evaluate a whole-building approach to reducing strikes. Finally, all graphics and bird-friendly design solutions need to be documented and communicated to stakeholders to ensure the bird-safe plan is not overlooked.

The AIA has a strong foundation to provide guidance across the United States and to help revise state and federal policies addressing bird-safe design. If it/they can reinforce their bird-safe designs in solutions that include data indicating they reduce the majority of collisions, bird-safe designs can become a part of sustainable building standards across the country. For this to become a reality, a few changes must be made to their guidelines.

The guidelines for Dark Skies offer five useful points to help eliminate light pollution, which would help to curb behavior disruptors in birds and prevent bird building collisions. One aspect that is missing from the guidelines is the consideration of the wavelength of light, as discussed in Chapter 3. Lighting design could implement the use of blue lights, rather than red lights, for security or marking of structures. Additionally, with sustainability standards indicating the importance of daylight when trying to increase the overall well-being of the occupants, AIA could add more information about how to balance the need for people to form a connection to the natural rhythms of nature and bird-safe designs.

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[365] Dark Sky Society, *Guidelines for Good Exterior Lighting Plans* (2009).

The bird collision deterrence suggestions outlined by the AIA are comprehensive and deliver an understanding of the causes of bird building collisions. However, relying on the American Bird Conservancy's flight tunnel experiments to determine the best bird collision deterrence methods for glass should be revised to include data from any available case studies. Currently, there is little research in the area of solutions, so until more comprehensive data than the American Bird Conservancy's solutions are available, projects should have mandatory three-year monitoring for bird strikes like that required for LEED's Pilot Credit 55. Finally, there needs to be an education program at AIA to spread awareness of bird building collisions among architects and designers.

The AIA understands that sustainability is not a movement to save the planet solely for humankind. Sustainability is a movement to protect the ecology of the earth and preserve the symbiotic relationship between nature and humankind. The AIA's sustainability guidelines strive to place nature first in their Design for Ecology Measure. This is missing from the most celebrated sustainable guidelines provided by LEED and the Living Building Challenge. The design suggestions outlined for AIA improvements are crucial to mitigating bird deaths. The AIA understands that as designers and architects, the responsibility lies with humans to protect nature for all living creatures.

LEGISLATION

City, state and federal policies can ensure that architects, designers, and building administrators are aware of the importance of implementing bird safe designs. Unlike the voluntary guidelines discussed above, these can also assure enforcement of bird-safe design policies. Currently, there are seventeen city bird-safe policies and one state bird-safe policy in the United States. While each location poses its unique challenges based on local bird populations, ecology, landscape, and structures, many have similar guidelines. This section reviews the policies of three cities and one state: San Francisco, California; Minneapolis, Minnesota; New York City, New York; and the state of Minnesota. These areas were chosen to compare policies for three locations in the United States that represent varying climates, landscapes, natural resources, levels of urbanization, and are located in migration passageways. These locations were also chosen based on their guidelines. Cities in California and Minnesota

have paved the way for other cities to adopt bird protecting guidelines. However, this also means many of the guidelines outline similar recommendations and are not included this document. Additionally, this section reviews a Federal bill, the Bird-Safe Building Act of 2019, that has currently been proposed to the House of Representatives. Finally, this section suggests guidelines for city policies and a federal act based on the evaluation of currently available collision solutions.

San Francisco, California and West Coast Cities

San Francisco introduced the first city policy or ordinance to establish bird-safe design standards for buildings in October 2009 and adopted the policy in July 2011. The purpose of this bill[366] is to establish "Bird-Safe Standards" for new building construction and retrofit facades to reduce bird mortality due to bird building collisions. The first standard listed in the policy indicates using a bird-safe glazing on transparent or reflective windows. This treatment can include fritting, netting, stencils, frosted glass, screens, physical grids, or UV patterns. Any patterns should be 1/4 inches wide and spaced 4 inches apart vertically, or 1/8 of an inch in width spaced 2 inches apart horizontally. [367]

The second standard suggests where these treatments should be applied by indicating hazard areas. These hazard areas are based on the location of the building or the building features. All standards should be applied to new construction, additions that create a hazard, and any replacement of 50% or more of the glazing of an existing bird hazard. Hazards defined by location are indicated as those having open-spaced dominated by vegetation or open water or being within 300 feet of an Urban Bird Refuge[368]. Facades indicated as hazards should consist of no more than 10% untreated glazing when facing an Urban Bird Refuge. Treatment guidelines also include using treatments on the ground floor, and lobby entrances and treatment added to glass in the "Bird Collision Zone" defined by the first 60 feet of the façade and glass facades adjacent to green roofs two acres or larger. In addition, lighting should be minimal, no up-lighting is permitted, and searchlights are prohibited. Wind generators must be monitored for

[366] San Francisco Planning Department, *Standards for Bird-Safe Buildings* (2019).
[367] Ibid.
[368] The city of San Francisco defines Urban Bird Refuges as open spaces 2 acres and larger dominated by vegetation, vegetated landscaping, forest, meadows, grassland, wetlands, or open water.

their impact on wildlife. Feature-related hazards including glass walls, wind barriers, skywalks, balconies, greenhouses on rooftops, and any glazed segments of the structure that are 24 square feet or larger must use bird-safe treatments. [369]

There are several exceptions to the policy. These include residential buildings less than 45 feet high with façades of less than 50% glass. If the building has more than 50% glass, it must use bird-safe treatments. Historical buildings are exempt unless the glass is replaced, then it must be treated. Reversible treatment methods such as netting, films, grates, and screens are suggested. [370]

The San Francisco Policy includes an easy to follow design guide, though not all of its elements are based on currently available studies. This includes glazing options such as the UV film ORNILUX, glass with photovoltaic cells or solar panels, colored glass, silk-screens that create an opaque image on the glass, etched glass, and films. [371] This guide also includes solutions not proven to reduce collisions such as louvers and angled glass. Louvers have not been tested and FLAP has suggested avoiding angled glass as it endangers ground-feeding birds. Additional solutions like screening or netting have been deemed Bird-Smart by ABC.[372] However, the suggestion to add options that are not proven to be effective is concerning and the policy should be updated to reflect currently available data.

Improvements to the San Francisco city policy would conform with newer research indicating which treatments are the most effective in reducing collisions, the elimination of UV films and angled glass completely until more research is conducted, and mandatory three-year monitoring after bird-safe treatments are used on buildings to provide evidence the solutions work to reduce collisions.

While the City of Oakland has outlined similar façade treatments in their Bird Safety Measures[373], their light pollution plan and descriptions of potentially dangerous structures are more complete. The city of Oakland requires the installation of minimum intensity white strobe lights to replace solid red lights on large buildings, to reduce behavior disruptions for birds. Their measures suggest that rooftop structures or antennas should be minimized, and that

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[369] San Francisco Planning Department, *Standards for Bird-Safe Buildings* (2019).
[370] Ibid.
[371] Ibid.
[372] American Bird Conservancy. "Glass Collisions," American Bird Conservancy, April 29, 2020, https://abcbirds.org/program/glass-collisions/)
[373] City of Oakland, *Bird safety Measures* (2013).

monopole structures or antennas cannot use guy wires. Nighttime lights are to be shut off during migration seasons, and lights should be on a sensor year-round from at least 11 pm to sunrise. Buildings must reduce perimeter lighting and cut off, shielded, or directional light should be used to minimize light pollution. No beams of light pointing into the sky are allowed in the spring or fall migration. Additionally, Oakland requires solution monitoring and distributing educational materials. [374] While Oakland focuses primarily on light solutions, Portland outlines numerous glass solutions.

In 2013, Portland, Oregon, prepared a resolution[375] to direct city bureaus to incorporate bird-friendly design into city plans and projects. Projects using transparent or reflective glass must use UV glass, acid etching, frit patterns, or films on the first floor. The upper floors up to 60 feet and the first floor adjacent to green roofs must use "more robust" bird-safe materials. Ground floor line, dot, or UV patterns must follow the 2 inches by 4 inches rule. Lines must be at least 1/8 inch wide, dots ¼ inch in diameter, and UV markers 1/16 inch thick. UV markers can be placed randomly. Floors from the second floor up to 60 feet require one of six materials: fritted glass, etched glass, UV coated glass, window films that cover the entire glazed surface, permanent stencils or frosting, or exterior materials such as screens, grills, netting, louvers, fins, or mullions. The second floor through 60 feet follows the same guidelines as the first floor for lines, dots, and UV treatments. Exterior materials such as screens, grills, or netting must be at least 1/8 inch thick and spaced no more than two inches apart. Louvers, fins, or mullions must be at least 1/8 inch thick with a maximum spacing of one to one with a nine-inch limit. [376] The Portland resolution relied heavily on references from the American Bird Conservancy, San Francisco's Bird-Safe policy, and the Fatal Light Awareness Program. However, these guidelines do not specifically mention lighting regulations. Additionally, UV is still an option provided by Portland, as it is for SF, even though research does not show that it consistently prevents collisions. Also, the 2 inches by 4 inches rule is replied upon even though this has been updated by ABC to 2 inches by 2 inches, indicating that these policies need to be updated. Finally, monitoring is not required but is a vital aspect of gathering data about the effectiveness of collisions solutions.

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[374] City of Oakland, *Bird safety Measures* (2013).
[375] City of Portland Bureau of Planning and Sustainability, *Bird-Safe Window List* (2018).
[376] Ibid.

Minnesota

Minnesota has two building guidelines that impact bird populations in the state, and one specifically for Minneapolis. The first guideline, published by the University of Minnesota's College of Design, [377] intends to protect and support animal habitat resilience at the site by reducing the negative impact of the built environment on species. Additionally, the guidelines state the project should provide supporting environment for "at-risk native species" deemed "essential to ecosystem health." These guidelines apply to all projects with new or renovated glazing. The first of two points addressed in the guidelines is the need to indicate which areas of the project have a high "Threat Factor" including the "Whole Building Threat Factor." These threat factors are based on the American Bird Conservancy's threat rating system. Once the threat is determined, any "High-Risk Surface" cannot use a material with a high threat factor, 75 or greater. High-Risk Surfaces are defined as large atriums or glazed corners larger than 20 feet across, and any surface within 50 feet of the building that include landscape elements such as vegetation including green roofs or open water. Bird safety "traps" include surfaces with a threat factor greater than 25, including glass walkways and small atriums and glass corners 20 feet or less across. [378] The Minnesota guidelines work closely with ABC while implementing strict skyway regulations. What is potentially confusing about these outlines is that mitigation techniques are not directly discussed in the guidelines. A helpful addition would be information about available solutions and their ability to reduce collisions from the American Bird Conservancy or as outlined in LEED's Pilot Credit 55. The guidelines also require one-year monitoring of the building with at least two observations each week to indicate if there are any bird strikes.

The Minnesota state guidelines outline a Lights Out! management program to address when lights should be turned out to be most effective in reducing collisions. These procedures are required by law for state-owned and managed buildings. The Light Out! program advises turning off building lights during migration dates between March 15th and May 31st and between August 15th and October 31st each year. Lights should be out between midnight and dawn each day

[377] University of Minnesota's College of Design, *Code of Ordinances Article XIII – Skyways* (2016).
[378] Ibid.

except for lights that are necessary for normal use. [379] Additionally, the Minnesota guidelines require the protection of rare, threatened, or endangered species. If the project site is within two miles of the listed species, the project must plan to include a perimeter exclusion fence of at least 42 inches, an interpretive sign about the species, and provide a supported habitat for the listed species. Beyond the initial design, the project must also be managed in a way to protect and enhance the viability of the rare, threatened, or endangered species until that species is no longer listed as such. [380]

The city of Minneapolis has specific guidelines for skyways that are more concise than those for the state and offers mitigation techniques in their guidelines. A skyway is defined as an enclosed and elevated pedestrian bridge that extends from a building face to another façade, and that spans a street or alley, or is located within private property. The zoning administrator must approve all skyways. Additionally, at least 85% of the glazing area of the exterior sidewall of a skyway must meet bird-safe guidelines. Bird-safe glazing is defined by LEED Threat Factors outlined in the state guidelines.[381] Additionally, the policies protect vulnerable species. However, none of the regulations have been applied to the U.S. Bank Stadium. This shows that not all policies can be enforced in every instance but should include limits to how many birds can be killed by one building even if it was constructed before regulations went into effect.

New York City, New York

The New York City Council passed bird friendly design legislation, 1482-B, in January 2020; it will be enforced January 2021.[382] This legislation defines bird friendly material according to the American Bird Conservancy's threat factors following LEED's Pilot Credit 55, requiring the material to have a threat factor of 25 or less. Bird hazards are indicated as clear glazing and transparent glass, including awnings, handrails, guards, windbreak panels, or acoustic barriers. Fly-through conditions that may be hazards are indicated in the legislation as glass that creates the illusion of a void on the other side, including parallel glass elements such as corners. The legislation requires the exterior wall envelope to use bird friendly materials for the

[379] "Guideline S.9," B3, May 7, 2020, https://www.b3mn.org/guidelines/3-0/s_9/).
[380] Ibid.
[381] Ibid.
[382] The New York City Council, *Bird Friendly Materials* (2019).

first 75 feet of the building. Identified bird hazards should use bird friendly materials at any height above grade. Fly-through conditions at 75 feet or less must use bird friendly materials. Finally, bird friendly materials should be used on the first 12 feet adjacent to green roofs. [383] While this is a great start, there is no information about lighting or landscape design solutions outside of green roofs. This bill is similar to a pending federal bill, discussed below, as it has a basic structure of bird protecting guidelines but does not go far enough to make it clear which options are the most effective to reduce or prevent collisions. This bill could use the success of the Jacob Javits Convention Center's use of ceramic frit glass and opaque wall panels of examples of effective, appropriate, collision deterrence methods.

Bird-Safe Building Act of 2019

The Bird-Safe Building Act of 2019 is a federal bill titled is backed by the Audubon Society and sponsored by Representative Mike Quigley from Illinois that aims to make public buildings bird safe across the United States.[384] The bill was introduced in the House of Representatives on January 30th, 2019, with 46 additional supporters. The bill requires that more than 50% of the façade of public buildings be required to meet five standards. The first standard requires at least 90% of the façade in the first 40 feet cannot be composed of glass or must use modified glass. Modified glass, in this instance, refers to using elements that do not entirely obscure vision of the occupants, such as a second facade, netting, screens, shutters, and shades. Modifications also should include UV patterns or "contrasting" patterns visible to birds, though no further explanation of contrasting is provided. Modifications can follow the 2 inches by 4 inches rule and the use of opaque, etched, stained, frosted, or translucent glass. Any combination of the modification can also be used. The second standard states at least 60 percent of the façade above 40 feet should be modified according to the first standard. Standard three prohibits all transparent passageways and corners. Standard four requires all glass to be modified as listed in standard one if it is adjacent to green spaces or water. Finally, the fifth standard addresses electric light and requires lights to be shielded unless used for security.[385]

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[383] The New York City Council, *Bird Friendly Materials* (2019).
[384] U.S. Congress. 2019. 116th Congress H.R. 919 (Introduced in the House), Bird-Safe Buildings Act of 2019, Bill Text. https://search.proquest.com/congressional/view/app-gis/billtext/116_hr_919_ih.
[385] Ibid.

Existing buildings are allowed exemptions or modified requirements under the bill. The latter include using automatic controls for existing lighting rather than installing shields or limiting light to security use only. Administrators of existing buildings may also "employ any available methods and strategies that are in accordance with best practices to reduce bird mortality." Financially, existing buildings can be excused from bird-safe designs if the "required building materials and design features result in a significant additional cost for the project." Finally, buildings listed on the National Register of Historic Places and federal buildings, including The White House, Supreme Court, and United States Capitol Building and their grounds are entirely exempt. [386]

The federal policy includes one very important but often overlooked requirement of bird-safe policy, monitoring to determine if the mitigation situations work. This act requires monitoring for bird mortality; however, it does not indicate the length of time or frequency at which the buildings should be monitored. [387] This bill has additional limitations such as not offering explicit guidelines to use the most effective methods to reduce collisions. It recommends UV and contrasting patterns with no further direction for designers. Additionally, prohibiting design features without additional options limits designers' ability to find creative solutions. Finally, the lighting and landscape solutions are not comprehensive and do not offer explicit guidelines to safeguard birds based on available studies.

Suggested State and Federal Policy Guidelines

As made evident throughout this document, solving the problems birds face in the built environment do not depend solely on one discipline, a single organization, or a single, leading expert. This is an interdisciplinary task. However, general guidelines should be followed to ensure that the methods used to mitigate bird building collisions do effectively reduce collisions. They should also allow for innovative designs to be tested. The federal policy should be used to ensure that the states and cities are working towards a common goal and communicating with the same terms and language. The state and city policies address the main areas of bird-safe design that are required to mitigate bird deaths due to bird building collisions while allowing room for

[386] U.S. Congress. 2019. 116th Congress H.R. 919 (Introduced in the House), Bird-Safe Buildings Act of 2019, Bill Text. https://search.proquest.com/congressional/view/app-gis/billtext/116_hr_919_ih.
[387] Ibid.

customization. This document has outlined the recommended federal and state or city policy guidelines based on the evolution of current available acts, programs, and policies. The guidelines outlined below are provided as a starting point to update current policies and as a foundation for future policies.

Suggested Federal Bird Protecting Guidelines:

1. Cities and municipalities in the United States must have a bird-safe design plan or policy for public buildings and structures.
2. The organization of at least one avian protection task force for each participating state should include each of the following: an ornithologist, biologist, or environmental scientist; an architect, ideally with experience in bird-safe design or lighting and materials; a landscape designer or ecologist; and a researcher in any of the fields mentioned. A monitoring group must also be established to monitor buildings to ensure they reduce or prevent collisions. This group can be comprised of citizen scientists.
3. A mandatory minimum of three-year monitoring for collisions at the building or structure after its completion.[388]
4. State and city policies must use a uniform definition of terms.
5. States and cities can customize their policy to match the demands of their bird populations, built environment, landscape, and conservation issues.
6. Each state or city must have a Lights Out! plan at least during migration seasons; ideally, lighting would be reduced year-round.

City or State Bird-Safe Guidelines:

1. Glass: All glass from grade to 75 feet should be treated with bird-safe designs that have been documented to reduce collisions by at least 85%, in accordance with the LEED Pilot Credit 55 requirement. This includes designs that communicate that glass is solid, like frit dots, perforated films, and screens, rather than obstacles such as lines that follow the 2 inches by 4 inches rule. No ultraviolet glass or films, single

[388] This is based on LEED's Pilot Cred 55 three year monitoring rule and Loss et al.'s 2019 two year study of the US Bank Stadium.

decals, or angled windows currently qualify as bird-safe designs. If the bird-safe design is not proven to reduce bird building collisions by at least 85% in a case study, then the project must be monitored for collisions over three years, and the data shared publicly. If it is not successful, the project should retrofit the building or structure.

2. Lighting: All floors above 75 feet must turn out lights at night during migration season. If lights are needed for security or use of the building, internal shades must be drawn during migration season. Timers and sensors may be used for external security. If this is not possible, no external lights should point upwards or illuminate large areas of the building or structure. Lighting guidelines from the Lights Out! Program are recommended.
3. Landscape: Green spaces within 100 m of the building or structure will require any glass used in the design to use collision deterrence patterns. Green walls, green roofs, and green retaining walls adjacent to glass on the building or structure will require the glass to use bird-safe designs.
4. Exceptions: Historical Buildings can be exempt from bird-safe glass solutions if the glass is vital to the historic nature of the building. However, suitable bird-safe options, like removable vinyl, should be considered.
5. Conservation and Education: Project designers must be aware of sensitive habitats, threatened or endangered species, and migratory birds that may come in contact with their site. Conservation efforts must be made to preserve and protect these species. Educational documents should be made available to the public including monitoring data and local species impacted negatively or positively by the building or structure.
6. Updates: Policies must be updated every five years after reviewing any new data regarding bird-safe designs.

The current policies and guidelines to protect birds through bird safe design in the United States show that cities, designers, architects, and policymakers are receptive to bird safe design strategies. A review of these policies reveals, however, that there is little cohesion among them, aside from their adherence to guidelines from two organizations: the Lights Out! Program supported by the Audubon Society and the Bird Collision Deterrence guidelines provided by the

American Bird Conservancy. Both organizations are crucial in the education and support of avian conservation efforts. The Lights Out! Program has based its tactics on the work of Evans Ogdon and other researchers who examine the harmful effects of artificial light on various species. The American Bird Conservancy's Bird Collision Deterrence can be complicated to follow and is based on flight tunnel tests that do not account for external factors such as lighting or green spaces when determining the threat factor of façade materials. While these guidelines are helpful, since the research in this area is limited, monitoring of the suggested mitigation strategies should be more thoroughly investigated and supported by case studies of buildings and structures.

One aspect that is missing from all of the federal, state and city policies is the connection to nature. The sustainable guidelines, especially from AIA, offer mitigation strategies but also an understanding that birds are vital to the ecology of the built environment and even the well-being of the occupants. If birds in the built environment can improve overall well-being by increasing biodiversity and providing a connection to nature, watching a bird strike a window and finding dead birds would have a profoundly negative effect on occupant well-being. The AIA has the only set of guidelines to point out this honest consequence of dangerous design strategies. All guidelines for sustainable design and bird-safe solutions should strive to find a balance between conserving nature, protecting bird species, and fostering human well-being.

CHAPTER 5 EDUCATION AND ADVOCACY

Conservationists alone cannot mitigate the dangers birds face in the built environment. As Mark Crocker states in his book *Birds & People*, "It is only when whole societies collectively believe in the goal that it is attainable." Because wild birds are the main form of wildlife interaction for people living in urban areas, protecting birds in the built environment is crucial for maintaining public advocacy for birds more generally.[389] This chapter focuses on three areas of education and outreach that engage citizens, including architects and designers, to build a connection to nature through birds and take actions leading to their protection. These areas begin with using examples of bird-safe design to educate professionals in the field of the built environments. Second, advocating for birds and bird conservation through conservation organizations, citizen science, and avian ambassadors demonstrates the importance of educating the public about bird conservation issues. Finally, this chapter will discuss how aviaries and rehabilitation centers are focused on fostering a connection between humans and birds.

The designers of projects in this chapter have committed to using "bird-safe" or "bird-friendly" designs on one or more buildings, or for their campuses. For this chapter, the term "bird-safe" or "bird-friendly" refers to the action taken to reduce bird building collisions with the use of materials marketed as such. The owners of the buildings described here have reported that collisions have reduced dramatically, but, in all cases, data outlining the numbers of birds lost before and after a building has become "bird-safe" or "bird-friendly" are not available. Therefore, quantifying the terms "bird-safe" and "bird-friendly" based on how many birds were saved or how many collisions were prevented is not possible. The purpose of evaluating these projects is not to demonstrate their quantifiable effectiveness in reducing bird building collisions, but to promote them as educational tools to bring awareness to threats birds face in the built environment.

Today, many gaps remain in knowledge about the relationship between birds and the built environment. These gaps exist in academia and extend to public avian programs. They can profoundly influence the design and management of the urban landscape and the roles the built

[389] Daniel T. C. Cox and Kevin J. Gaston, "Urban Bird Feeding: Connecting People with Nature," *Plos One* 11, no. 7 (2016): 2.

environment can play in promoting conservation, ecosystem services, and environmental justice.[390] Education and understanding the benefits of birds in the built environment can create a movement towards incorporating bird-safe designs in architecture as enthusiastically as toward biophilic design and sustainable elements of the built environment

Educators in the built environment fields have access to examples of projects that encourage innovative solutions and incorporate examples of "bird-safe" designs as part of sustainable design projects. This can be seen, for example, in Studio Gang's "bird-safe" projects. Studio Gang is an architecture and urban design practice located in Chicago, with additional offices in New York, San Francisco, and Paris. Their website lists eight "bird-safe" projects that are designed with bird-safe glass and innovative project designs. The following are two projects that represent each approach.

The North Residential Commons was built on the campus of the University of Chicago in 2016 and achieved LEED Gold certification. Studio Gang designed the building to optimize north-south light. Where windows do not require panels or metal grills for solar shading, argon-filled low E insulated glass features a ceramic frit pattern that allows for excellent views and daylight to enter the space while protecting birds from collisions.[391] (See Figure 34.)

[390] Christopher A. Lepczyk and Paige S. Warren, *Urban Bird Ecology and Conservation* (Berkeley; Los Angeles; London: Cooper Ornithological Society, 2012), 492.

[391] Studio Gang. "University of Chicago Campus North Residential Commons," Studio Gang, accessed April 7, 2020, https://studiogang.com/project/university-of-chicago-campus-north-residential-commons)

Figure 34. University Of Chicago Campus North Residential Commons

Studio Gang designed the Ford Calumet Environmental Center in 2008. The unbuilt design won the Holcim Award from the Holcim Foundation for Sustainable Construction in 2011 and the "Proggy" Award from the People for Ethical Treatment of Animals in 2009. (See Figure 35.) Studio Gang designed the building to demonstrate the importance of coexistence between industry and ecology. They based the design on a bird's nest-making process by using discarded and local items such as salvaged steel and recyclable materials to display re-use. Because the project is located on a resting stop for migratory birds, it was formulated not only for re-use and a visual connection to nature but as a completely bird-safe building. The building description on the firm's website explains the threat transparent glass poses to birds and the strategies they used to mitigate this threat. These strategies include reclaimed barrel wood slats placed in front of north-facing windows, and a south porch that uses a mesh enclosure to protect birds from collisions.[392]

[392] Studio Gang. "Ford Calumet Environmental Center," Studio Gang, accessed April 7, 2020, https://studiogang.com/project/ford-calumet-environmental-center.

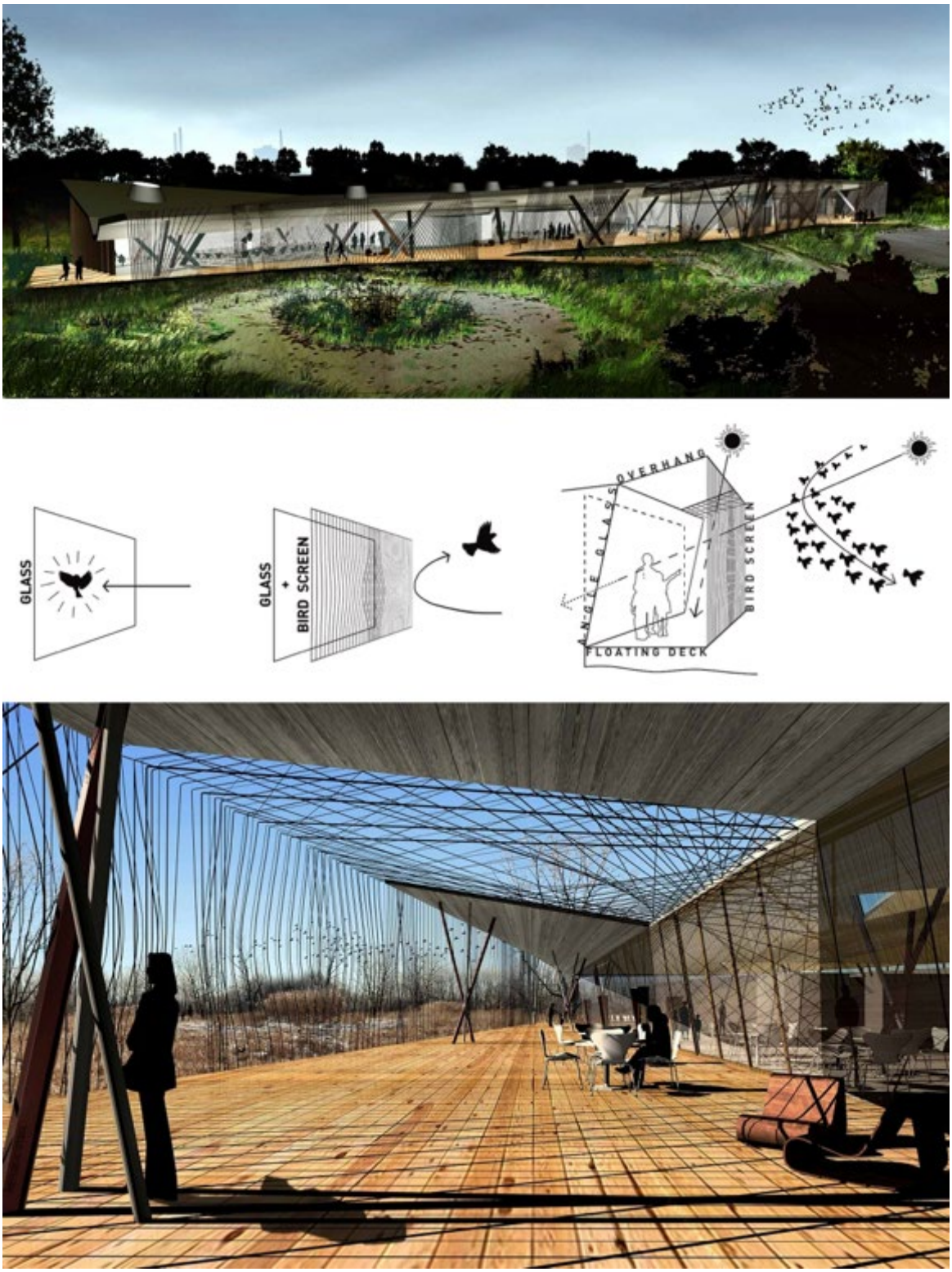

Figure 35. Ford Calumet Environmental Center Design

Both of these projects show well-known collision deterrence methods using materials paired with the innovative design inspired by birds and bird conservation. Educating architects and designers about deterrence strategies using materials and innovative design can lead to awareness of the issue of bird building collisions as well as future innovative mitigation techniques that bring us closer to a wholly bird-safe built environment.

Design educators can also promote holistic sustainability while protecting birds from building collisions. It might be challenging to offer full university-level courses on bird-safe design, given the limited research on the topic. However, another approach to bird-safe building design might refer to the Living Building Challenge's strategy to incorporate biophilic design into buildings. The Living Building Challenge suggests a full day or eight hours of exploration of biophilic design before the project design begins. Sustainability classes can devote a full lesson to learn about bird building collisions and the solutions, coming together for a charette to understand the goals or intent of bird-safe building, as well as design opportunities. The goal would be to suggest to students that bird-safe design is ideally addressed at the beginning of the design and to show students how to apply these skills in future projects. The skills learned in this experience would allow future architects and designers to be aware of how using large amounts of glass can impact the local ecology. This experience could also encourage creative ways to find a balance between human well-being and protecting birds.

Bird safe designs and habitats should also be incorporated into biophilic and restorative design courses. While the benefits of biodiversity in the built environment have not been studied thoroughly, there are benefits of feeding and observing birds. A 2016 study by Cox and Gaston found that people feed birds for psychological benefits, including pleasure, attention restoration,[393] and stress reduction[394]. The study also indicated that feeding birds fostered a connection with nature through their concern for bird welfare and a personal orientation towards nature through a sense of belonging. How a person relates to nature is shown to be a strong indicator of their environmental attitudes.[395] Additionally, Belaire et al.'s 2015 study found that residents of a Chicago-area suburb valued many aspects of birds, specifically those relating to

[393] Attention restoration theory proposed that the natural work promotes recovery from mental fatigue and offers reflection.
[394] Stress reduction theory indicates that natural environments reduces phycological arousal following stress including promoting relaxation and improving mental health.
[395] Cox and Gaston, "Urban Bird Feeding: Connecting People with Nature,": 1-2.

the bird's aesthetics and a bird's place in the ecosystem. These studies indicate that urban and suburban residents value birds for cultural and ecosystem services, which leads them to form stronger connections to the natural world. This connection then can foster participation in conservation efforts while increasing the overall well-being of humans. Further, places of education can foster stewardship by using bird-safe designs on campus buildings.

The University of British Columbia (UBC) in Vancouver, Canada, located on the Pacific Flyway, has incorporated bird-safe building designs into its campus sustainability initiatives. Protecting birds from building collisions is an important aspect of campus-wide sustainable design initiatives described in the campus' Green Building Action Plan. The Green Building Action Plan focuses on eight holistic components: biodiversity, energy, water, materials and resources, health and wellbeing, quality, climate adaptation, and place and experience. By 2035, UBC plans to make net positive contributions to humans and natural systems through this plan. Each year, a reported 10,000 birds collided with buildings on the UBC campus with a daily average of 45 outside the of the migration season and 72 collisions during the migration season per campus building. Mitigating these collisions is a core part of the biodiversity component of the Green Buildings Action Plan. Penny Martyn, a registered architect and the UBC Campus Green Building Manager, has introduced guidelines to reduce collisions in a policy document titled UBC Bird Friendly Design Guidelines for Buildings. These guidelines were based on studies of campus collisions conducted by students, staff, and Martyn, since 2014. This plan made bird-friendly designs mandatory for all university buildings by the end of 2020 and expanded to include new residential buildings located on campus by 2025.[396]

Working with UBC, Martyn incorporated an interdisciplinary approach to bird-safe design and education by collaborating with students, faculty, Environment and Climate Change Canada, and the SEEDS Sustainability Program. In the university's Living Lab, a collaboration between the departments of Applied Science and Geography, researchers developed sensors and software to map and predict bird collisions with campus buildings. This enabled the university to enhance biodiversity in their built environment.[397] Martyn also organized a monitoring system designed by UBC engineering students who eagerly took on the task with one student stating, "Who doesn't love birds?" They worked to find the appropriate equations to measure the motion of

[396] University of British Columbia, *UBC Bird Friendly Design Guidelines* (2019): 3-4.
[397] University of British Columbia, *Annual Sustainability Report* (2018-19): 3-4.

objects so that the device could accurately detect bird strikes. The device uses an accelerometer to measure vibrations of window glass and transmits the data via Wi-Fi. The system is inexpensive to set up and maintain, but the report provided no indication of accuracy [OR: its accuracy was not reported].[398]

The guidelines outline how new and existing buildings can meet their bird-safe goals. Guidelines for buildings aim to minimize the quantity of glass in designs, increase the visibility of glass, block reflections of surrounding vegetation and sky, and incorporate design elements and landscapes that minimize bird collisions. [399] Retrofit solutions include increasing the visibility of glass and blocking reflections. The guidelines also communicate ineffective strategies, such as a single bird of prey decals, angled glass, tinted glass, and interior screens or blinds. To increase the visibility of glass, the guidelines suggest using adhesive film, acid etching, or patterns that follow a 5 cm by 5 cm spacing with markers no more than .32 cm in size. These visible markers are to be used on the first four floors of the building (or to the top of mature tree height) and at least 3.6 m above a green roof. The guidelines encourage using artistic and creative patterns that follow visual guidelines but communicate a unique building identity or connect people to the landscape. The last option provided is the use of ultraviolet glass if visual markers are not preferred. Examples of these guidelines can be found across the UBC campus in the form of artistic glass designs and façade design strategies.[400]

The UBC Bookstore, shown in Figure 36, is described as having densely spaced frit designs that create visual markers on the glass using quotes from the favorite books of faculty, students, staff, and visitors. This creative solution provides a sense of community and public engagement with the site. A retrofitting solution using an artistic design was applied to the glass of the Center for Interactive Research on Sustainability. This was the result of a contest held to mitigate the bird building collisions. The winning design, by English Ph.D. student Lora Zosia Moon, uses closely spaced lines in her artwork.[401] (See Figure 26.) This design was the first bird-safe design on the UBC campus, and the intention was to raise awareness about the issue of bird collisions.

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[398] Denise Ryan, "Bird-Friendly Windows Reduce Collision Deaths at UBC," Vancouver Sun (Vancouver Sun, April 29, 2019), https://vancouversun.com/news/local-news/bird-friendly-windows-reduce-collision-deaths-at-ubc.
[399] University of British Columbia, *UBC Bird Friendly Design Guidelines* (2019): 3-4.
[400] Ibid.
[401] Denise Ryan, "Bird-Friendly Windows Reduce Collision Deaths at UBC," Vancouver Sun (Vancouver Sun, April 29, 2019), https://vancouversun.com/news/local-news/bird-friendly-windows-reduce-collision-deaths-at-ubc.

This project incorporated a 5 cm by 10 cm spacing based on an earlier version of the campus Bird Friendly Design Guidelines for Buildings. The guidelines were later updated to limited space between designs to 5 cm to protect smaller species like hummingbirds.[402]

Figure 36. UBC Library Window Pattern

Bird-safe façade design strategies at UBC include green or living walls with mesh screens, shading devices, and external barriers. These measures also have cost-effective co-benefits while they safeguard birds.[403] While no data is available from UBC, mesh netting was applied 10 inches from the Federal Bureau of Investigation in Chicago reducing collisions by 80%.[404] The

[402] University of British Columbia, *Annual Sustainability Report* (2018-19): 12, 21-22.
[403] Ibid. 33.
[404] Lesley Evans Ogden, "Does Green Building Come up Short in Considering Biodiversity?: Focus on a Growing Concern.," *BioScience* 64, no. 2 (2014): 83-4.

Center for Interactive Research on Sustainability features a living wall built of mesh screens and vines to create a barrier in front of the windows. This technique also provides food, shelter, and nesting habitat for birds. The co-benefits of the green wall are seasonal solar shading, reducing solar heat gain, and a view of nature from the interior to increase overall human health.[405] Three additional examples shown in Figure 37, are the metal screens surrounding the upper floors of the Campus Energy Centre. The zinc panels also hide vents and louvers required for ventilation. The panels still allow daylight to enter and function as weather protection for the building.[406] The Beaty Biodiversity Research Centre uses exterior screens on all sides of the building to create a barrier, which also reduces heat gain and provides shade.[407] The Earth Sciences Building uses shading devices, including screens, mesh, and grilles, to block the reflection of vegetation while reducing solar heat gain and preventing glare for occupants.[408]

[405] Lesley Evans Ogden, "Does Green Building Come up Short in Considering Biodiversity?: Focus on a Growing Concern.," *BioScience* 64, no. 2 (2014): 8.
[406] Ibid., 15.
[407] Ibid., 16.
[408] Ibid., 13-14.

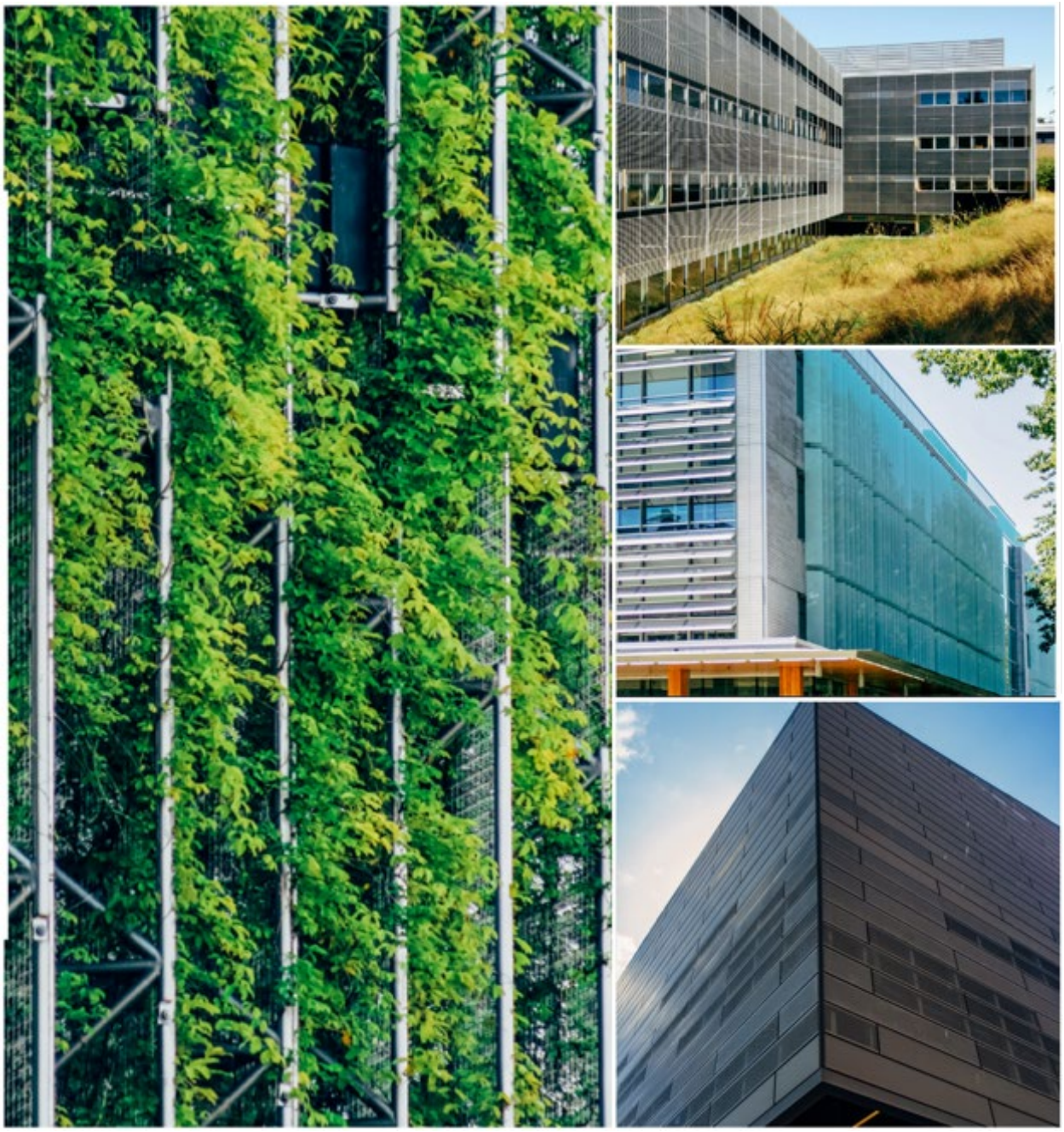

Figure 37. UBC Bird-Safe Exteriors
Left: Mesh green wall on the Centre for Interactive Research on Sustainability. Right: Screens on the Beaty Biodiversity Research Centre (top), fins and grills on the Earth Sciences Building (middle), and zinc panels on the Campus Energy Centre.

The guidelines include additional recommendations to reduce collisions. These guidelines demonstrate the university's comprehensive approach to bird-safe designs required for maintaining a bird-friendly campus. The recommendations point out that clear glass flight paths such as glass corners, parallel glass, skywalks, glass guardrails, and glass parapets can be dangerous for birds, and the guidelines suggest that collision prevention techniques in the plan be applied/employed. Thoughtful landscape design should aim to reduce vegetation located between 2 to 20 m from untreated glass surfaces.[409] The guidelines recommend reducing "bird traps" by securing enclosed spaces like mechanical ducts, pipes, and intake and exhaust vents.[410] Light pollution reduction follows the FLAP guidelines and uses green or blue light instead of white or red lights to mark tall structures.[411] Occupant strategies, such as applying exterior window screens and nets to block reflections, are offered as well.[412] Martyn's strategy of educating through example at the UBC campus shows that bird-safe design does not require designers to sacrifice aesthetics, sustainability goals, or significantly increase costs.

Two colleges in the United States have also adopted bird-safe designs on their buildings, though, not campus-wide. Like at UBC, these examples serve to reduce bird building collisions while also raising awareness about bird building collisions campus. The Atlantic Cape Community College in Cape May, New Jersey, reported several bird building collisions at their administration building due to a large amount of glass and its location in a migration flyway. Staff and students working in the building reported the upsetting experience of witnessing the collisions. They tried using silhouettes of birds of prey, but these were not successful. They contacted the American Bird Conservancy to discuss the data behind available mitigation techniques and decided to use an opaque film from CollidEscape called the Guaranteed Solution to apply on the outside of the glass. The film has small perforations that allow light to pass through the window and to maintain views the outside while appearing opaque to birds. An added benefit of the project was that it reduced direct light and heat gain in the building and

[409] University of British Columbia, *Annual Sustainability Report* (2018-19): 19.
[410] Ibid., 29.
[411] Ibid., 30
[412] Ibid., 25.

reduced cooling costs. One year after applying the film, the staff reported they had not noticed any collisions.[413]

Figure 38. Perforated Vinyl on the Stockton University K-Wing Building

At Stockton University in Galloway, New Jersey, a mural used to mitigate bird collisions was explicitly designed to educate visitors about bird building collisions. The K-Wing building of the School of Arts and Humanity's breezeway was considered a high collision risk because of its expansive double-sided windows facing the Pinelands National Reserve. John Rokita, the assistant supervisor of Academic Lab Services, recorded 851 bird collisions with these windows between 1979 and 2018.[414] The Office of the President granted funds to the campus facilities department to produce a mural to cover the windows. This was created by campus graphic designers using perforated film, much like CollidEscape. It allows light in and maintains a view of the outside; it also creates an opaque non-reflective surface on the glass exterior. This mural, seen in Figure 38, is designed to be a statement piece that brings awareness to the "waste of life" that can be prevented, and to pay homage to local bird species. One of the goals of the mural is to inspire users of buildings campus-wide to implement mitigation techniques; another is to encourage integrating bird building collision education into the ornithology course offered on

[413] *College Takes Action to Stop Bird Collisions* (American Bird Conservancy, 2017), https://www.youtube.com/watch?time_continue=6&v=dW1-mYOxMFI&feature=emb_logo.

[414] However, thousands of birds that survived impacts were rehabilitated. The campus also has a taxidermy collection of hundreds of birds that were victims of these collisions now housed in The School of Natural Sciences and Mathematics curated by John Rokita.

campus. Visitors to the building are informed about the way this mural prevents bird building collisions and includes the large visible message "Art should be striking. Not birds."[415]

These three campuses educate the students, staff, faculty, and visitors through example. Two ways these approaches could be strengthened is by providing more detailed literature and making data collected from monitoring available to researchers and the public. Applying a mitigation technique does not have to be the sole means of educating visitors to the building. Offering literature or signage that explains how many birds were killed each year before the retrofit, what prevention methods were used and why, and whether the collisions were reduced or eliminated, could further communicate the importance of bird-safe buildings beyond these campuses. This information would require systematic monitoring methods. Applying mitigation techniques can solve the immediate problem of bird building collisions. However, to solve the widespread issue of bird building collisions, more data from monitoring needs to be collected and made available.

ADVOCATING FOR BIRDS AND BIRD CONSERVATION

Conservation of bird species in the United States depends on the citizens of cities and towns, as over 80% of land in the contiguous United States is owned privately. The success of future conservation efforts depends on restoration projects on private property and on educating the owners of the private land about conservation concerns in the built environment.[416] Avian conservation organizations in the United States can help educate the public about the ecosystem services and cultural services provided by birds. They also effectively communicate the dangers birds face in the built environment. Three of the most well-known organizations that focus on the relationship between humans and birds through education are the National Audubon Society, the American Bird Conservancy, and the Peregrine Fund.

The National Audubon Society (NAS) is a nonprofit organization that aims to protect birds and their habitats in the Americas through science, advocacy, education, and conservation. The organization has over 500 state programs, local chapters, and partners that reach millions of people each year to educate them about North American birds. The National Audubon Society

[415] Daniel Gambert, "Picture Stockton Using Art to Save Birds," Stockton University (Stockton University, November 21, 2019), https://stockton.edu/news/2019/picture-stockton-using-art-to-prevent-birds-from-striking-windows.html.

[416] Desirée L. Narango, Douglas W. Tallamy, and Peter P. Marra, "Nonnative Plants Reduce Population Growth of an Insectivorous Bird," *Proceedings of the National Academy of Sciences* 115, no. 45 (2018): 11549.

informs policy, designates bird habitats from coast to coast, guides citizen science projects such as the Christmas Bird Count, and promotes education programming at Audubon centers to offer citizens the resources they need to explore conservation issues and defend the natural world. The NAS focuses on nine main areas to protect birds; bird building collisions is one of these. The Audubon Society is actively promoting the federal Bird-Safe Building Act to prevent bird building strikes across America. National and local Audubon Societies also offer information about bird building collisions deterrence techniques.[417]

The American Bird Conservancy (ABC), founded in 1994 by George Fenwick, is dedicated to the conservation of native birds and their habitats in the Americas. ABC has four conservation goals, including halting extinctions, protecting habitats, eliminating threats, and building capacity to support bird conservation. Bird building collisions is one of the eight threats that ABC addresses with their conservation goals. Their educational materials, which are available on the organization's website, are divided into residential and professional mitigation techniques.[418] Another threat ABC is researching is wind turbines. ABC has developed a Wind Risk Assessment Map that shows that vulnerable areas where placing wind energy equipment should be avoided. Because there are few proven mitigation techniques to wind turbine collisions, preventative measures like this must be taken before wind farms are built.[419]

The Peregrine Fund's primary mission is to conserve birds of prey worldwide. Their team of scientists and researchers work to publish peer-reviewed studies on the topic of raptor conservation. Their research has studied the impact of the built environment on birds, including urban noise and mitigation techniques for powerlines. The Peregrine Fund's strategy is to conserve and engage the public. Conservation is achieved by protecting raptors from extinction, in part by preserving their habitats. The Peregrine Fund is credited with the recovery of the peregrine falcon (*Falco peregrinus*) and is currently researching the decline of the American kestrel (*Falco sparverius)*. The fund works to encourage people to value raptors and to inspire

[417] National Audubon Society. "About Us," Audubon, accessed April 7, 2020, https://www.audubon.org/about).
[418] American Bird Conservancy. "Glass Collisions," American Bird Conservancy, April 29, 2020, https://abcbirds.org/program/glass-collisions/.
[419] American Bird Conservancy. "Wind Risk Assessment Map," American Bird Conservancy, May 3, 2020, https://abcbirds.org/program/wind-energy-and-birds/wind-risk-assessment-map/.

action to change increase raptor conservation. [420] The Peregrine Fund has become the leader in bird of prey conservation due to its dedication to raptor species, education, and research.

These three organizations provide the opportunity for citizens to engage with birds and conservation issues through their educational programming but also through citizen science projects. Citizen scientists are members of the public who engage in scientific work by collaborating with or working as volunteers for professional scientists or institutions to address real-world problems. Citizens participate in the scientific process by formulating research questions, conducting experiments, collecting and analyzing data, making discoveries, developing new technologies, and solving complex problems in support of project or research leaders. The federal government has listed over 400 citizen science projects on their Citizen Science website, which is designed to accelerate the use of crowdsourcing and citizen science across the United States. The site does so by providing a catalog of projects, a toolkit for maintaining projects, and a gateway to the community of hundreds of practitioners and coordinators.[421] In the context of birds and the built environment, two of the important tasks for citizen scientists to engage in are monitoring bird building collisions and surveying regional and migrating birds.

Two ways of contributing to surveys are through the identification apps iNaturalist and eBird. The app iNaturalist is a joint initiative by the California Academy of Sciences and National Geographic. The app helps users identify plants and animals, connect to a community of over a million scientists, and foster a connection to nature. The data gathered by the app is used to better understand and protect nature. Projects can be created to pool information from citizens towards a common interest. A recent project was the City Nature Challenge 2020 held from April 24th to the 27th. The goal of the project was to record observations of all wild living organisms in and around the city, including birds. This data was then verified, compiled, and made freely available to the public.[422] iNaturalist was used to collect bird building collisions data

[420] The Peregrine Fund. "Mission and Vision: The Peregrine Fund," Mission and Vision | The Peregrine Fund, accessed April 7, 2020, https://peregrinefund.org/mission-and-vision.
[421] U.S. General Services Administration. "About CitizenScience.gov," CitizenScience.gov, accessed April 7, 2020, https://www.citizenscience.gov/about/#)
[422] "City Nature Challenge 2020's Journal," iNaturalist, accessed April 7, 2020, https://www.inaturalist.org/projects/city-nature-challenge-2020/journal)

in 2016 and 2018 at Duke University's West campus in Durham, North Carolina[423] and at the University of Utah in 2019.[424] Winton et al. suggested the app could be used to collect valuable and much needed data regarding collisions including geo-referencing data.[425]

The eBird app developed by the Cornell Laboratory of Ornithology works similarly to iNaturalist but is for tracking bird sightings. The app has recorded over 100 million bird sightings each year from around the world, making this project the world's largest biodiversity-related citizen science venture. The data collected has documented bird distribution, abundance, habitat use, and trends through a checklist framework indicating the user's location and time. These data are stored and verified by regional experts before being made freely available to the public in a daily updated archive.[426] The conservation impacts of eBird include using the data gathered to inform monitoring for conservation planning, supporting habitat management and protection, providing population assessment and management, and informing law and policy.[427]

Citizen scientists are contributing to the study of bird building collisions by providing their monitoring services. Monitoring buildings for collisions before and after the use of mitigation techniques provides crucial data that researchers and designers can use to make informed decisions about which mitigation techniques are best for their project. Monitoring opportunities are available through local Audubon Societies, Lights Out Programs, and aviaries such as Tracy Aviary in Salt Lake City, Utah, which organize local collision monitoring of buildings. There is not an app similar to iNaturalist and eBird that collects data on the location, species, and date of bird building collisions. However, FLAP does have a website based Global Bird Collison Mapper, but it lacks the convenience and reach of the apps mentioned.

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[423] R. S. Winton, Natal Ocampo-Penuela and Nicolette Cagle, "Geo-Referencing Bird-Window Collisions for Targeted Mitigation.(Report)," *PeerJ* 6, no. 1 (2018).
[424] Barbara B. Brown et al., "Winter Bird-Window Collisions: Mitigation Success, Risk Factors, and Implementation Challenges," *PeerJ* 7 (2019).
[425] R. S. Winton, Natal Ocampo-Penuela and Nicolette Cagle, "Geo-Referencing Bird-Window Collisions for Targeted Mitigation.(Report)," *PeerJ* 6, no. 1 (2018), 8.
[426] eBird. "About EBird," eBird, accessed April 7, 2020, https://ebird.org/about)
[427] eBird. "Conservation Impacts," eBird, accessed April 7, 2020, https://ebird.org/science/conservationimpacts)

AVIARIES AND REHABILITATION CENTERS

Avian educators are crucial to the movement towards bird-safe building designs because they nurture personal connections between humans and birds. Avian educators are conserving the distinctive relationships between humans and birds that has been seen across all cultures throughout millennia. Reaching the public is crucial to communicating the need for a bird-safe built environment and creating this movement. Citizens are often the ones who push the hardest for change and are stewards for bird conservation. Educating the public about how commercial and public buildings are reducing bird building collisions can be applied to residential buildings as well. This section explains how two U.S. aviaries, the National Aviary and Tracy Aviary use architecture as an educational tool and a potential source of valuable data about mitigation solutions. The data gaps regarding bird building collisions can also be filled by rehabilitation centers that receive birds that have collided with buildings. Additionally, centers like the California Raptor Center, which are home to birds that have been injured by the built environment, can spread awareness of the dangers that birds face.

The National Aviary, located in Pittsburgh, Pennsylvania, is home to over 500 birds representing 150 species from around the world. This indoor non-profit zoo offers a large walk-through habitat to allow for intimate interactions between visitors and free-flying birds. Also, the zoo is an environmental organization comprised of educators, researchers, and conservationists that works to "inspire respect for nature through an appreciation of birds."[428] In 2018, the aviary sought to upgrade and remodel the greenhouse area that houses both birds and plants in their Tropical Rainforest exhibit. The Executive Director, Cheryl Tracy, indicated that the aviary intended to use bird-friendly glass in the redesign that could benefit both the birds inside of the aviary and outside while retaining the character of the original structure built in 1952.[429] The renovation included over 19,000 square feet of laminated Starphire Ultra-Clear glass by Virto Architecture Glass, which was acid-etched by Walker Glass with AviProtek Velour.[430] This

[428] The National Aviary. "The National Aviary," The National Aviary - About Us, accessed April 7, 2020, https://www.aviary.org/about-us)
[429] Ibid.
[430] Glass On Web. "National Aviary Tropical Rainforest Featuring Acid-Etched STARPHIRE Glass Wins National Award for Exhibit Design," glassonweb.com (glassonweb.com, October 2, 2019), https://www.glassonweb.com/news/national-aviary-tropical-rainforest-featuring-acid-etched-starphire-glass-wins-national-award)

finish communicates a solid surface to birds while allowing high visible light transmittance.[431] This technique also maximized the ultraviolet and natural light transmittance to sustain the plant and wildlife within the space that is home to more than 80 birds.[432] This design is a permanent educational tool that shows the public and designers that collision prevention treatments on glass can still allow natural light to enter the space while communicating that the glass is solid to birds. Also, it is an example of retrofitting a primarily glass structure while retaining its original design and intended use. This design, shown in Figure 39, won The Association of Zoos and Aquariums 2019 Exhibit Design Award.

[431] Walker Glass."Velour Acid-Etched Glass," Verrerie Walker, accessed April 7, 2020, https://www.walkerglass.com/products-options/velour/)

[432] Glass On Web. "National Aviary Tropical Rainforest Featuring Acid-Etched STARPHIRE Glass Wins National Award for Exhibit Design," glassonweb.com (glassonweb.com, October 2, 2019), https://www.glassonweb.com/news/national-aviary-tropical-rainforest-featuring-acid-etched-starphire-glass-wins-national-award)

Figure 39. National Aviary, Pittsburgh, PA

Tracy Aviary in Salt Lake City, Utah, is one of the oldest and largest free-standing aviaries in the nation. Tracy Aviary uses education and conservation to inspire curiosity and caring for birds and nature. The aviary's education programs include onsite interactive exhibits, camps, and

classes, as well as visits to local neighborhoods and schools. Their education programming reaches over 60,000 children every year. The aviary is also dedicated to the conservation of avian species and their ecosystems. This aviary depends on citizen science volunteers to provide the information that leads to decisions impacting species survival and preserving the natural beauty of the area.[433] Tracy Aviary sponsors Nature in the City Programs, focusing on building a connection to nature through urban wildlife and landscapes in Salt Lake City with educational programming open to all ages. The aviary also provides professional workshops to build skills for environmental educators and the public to appreciate nature and birds.[434]

The Visitor's Center at Tracy Aviary includes three types of collision mitigation techniques on its LEED Gold certified building. Figure 40 shows two of these techniques: a metal design outside of the glass to break up the reflection and where glass is visible, and square decals spaced two inches apart horizontally and four inches apart vertically applied to the remaining areas of visible glass to meet the LEED Pilot Credit 55's guidelines. Additionally, some glass is treated with ORNILUX. These sections of glazing face a pond and trees and were identified by the aviary as occupying a location with a high risk of collisions. The aviary has indicated that they wanted to use ORNILUX as an educational tool to show additional options available to mitigate collisions.[435] A monitoring program is in place; however, the data was not available at the time of this document. The Avian Health Center at Tracy Aviary is LEED-certified Silver and was designed to be a bird-safe building. The design features a reduced use of glass and silhouette decals on both sides of the minimal glass surface.[436] While ORNILUX and silhouette decals have been shown in prior experiments to be ineffective, monitoring data from both buildings would be useful in determining whether these strategies are effective for/in reducing bird building collisions on real-world structures. Tracy Aviary is dedicated to promoting sustainable building practices that benefit our planet and specifically protect bird species.

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[433] Johnnae Nardone, "About Us," Tracy Aviary (Tracy Aviary, November 11, 2019), https://tracyaviary.org/about)
[434] Ibid.
[435] Ibid.
[436] U.S. Green Building Council. "Tracy Aviary Avian Health Center," U.S. Green Building Council, accessed April 7, 2020, https://www.usgbc.org/projects/tracy-aviary-avian-health-center)

Tracy Aviary also participates in the Lights Out Salt Lake Program[437] and organizes bird collision monitoring in Salt Lake City. Both programs are part of the aviary's Community Science program. The program is an effort between citizen scientists and researchers at Tracy Aviary to protect birds and study the natural world. The Salt Lake Avian Collision Survey consists of citizen scientists voluntarily walking downtown Salt Lake City looking for evidence of bird building collisions at specific locations. Additionally, the public can report a bird building collision on their website. This is a survey-based collection of data that is not yet available to the public.[438]

Figure 40. Tracy Aviary's Bird-Safe Designs

[437] Tracy Aviary. "Lights Out Salt Lake," Tracy Aviary Conservation Science, accessed April 7, 2020, http://www.tracyaviaryconservation.org/lightsoutsaltlake)

[438] Tracy Aviary. "Salt Lake Avian Collision Survey," Tracy Aviary Conservation Science, accessed April 7, 2020, http://www.tracyaviaryconservation.org/slacs)

The California Raptor Center at the University of California, Davis, combines a rehabilitation center and Bird of Prey Aviary in one location. The center is housed in the School of Veterinary Medicine and treats over 300 birds each year. The goal of the center is to release recovered birds back to the wild. However, some of the birds cannot be released and live out their lives at the center. The California Raptor Center has 35 resident birds of prey that are educational ambassadors. Through educational programming, the public learns about conservation issues and can see birds up-close in an intimate venue in ways that are not possible in wilderness settings. While this experience fosters a connection to wildlife, it also gives visitors a personal account of the dangers of the built environment. Four of the resident owls were hit by cars, and two golden eagles (*Aquila chrysaetos*) were found near wind turbines. While their injuries were not life-threatening, they are not able to be released.[439]

While centers like the California Raptor Center become permeant homes for non-releasable birds, rehabilitation Centers such as the Carolina Waterfowl Rescue and Paws Seattle are small nonprofit wildlife rescue centers that have valuable bird collision data for local researchers. The Carolina Waterfowl Rescue provides care to over 1,000 birds a year across 40 different species.[440] Their work with local biologists to determine if an illness caused the collisions, as well as their injuries and outcomes, could be useful in understanding bird building collisions in addition to collision data such as species and date of the collision.[441] PAWS Seattle Wildlife Center takes on the role of educator as well as rehabilitator by offering species-specific guides to solving and preventing conflicts with birds, including bird building collisions.[442] Educating the public about threats birds face in the built environment, in addition to recording collision data, make rehabilitation centers vital sources in advocating for a bird-safe built environment.

Every resident of a city or town has had interactions with birds. These interactions can play an important role in promoting the conservation of nature and building a strong connection between humans and the natural world. Education about bird building collisions offers a unique educational avenue to teach about human-made threats that birds face. However, the study of

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[439] UC Davis Veterinary Medicine. "School of Veterinary Medicine," School of Veterinary Medicine, accessed April 7, 2020, https://crc.vetmed.ucdavis.edu/)

[440] Carolina Waterfowl Rescue. "Carolina Waterfowl Rescue," Carolina Waterfowl Rescue, accessed April 7, 2020, https://www.cwrescue.org/)

[441] This is the rescue that treated the over 100 stunned or injured Chimney Swifts that collided with the NASCAR Hall of Fame in 2019.

[442] PAWS, "Songbirds," PAWS, accessed April 7, 2020, https://www.paws.org/resources/songbirds/)

urban birds and birds in the built environment does not have enough research about how birds interact with designed structures and how they impact society. The use and evaluation of collision mitigation strategies and innovative building designs can help to fill in both of these gaps. Examples of collision deterrence methods implemented on campus buildings can help raise awareness to the public while reaching sustainability goals. These make it clear that bird preservation and sustainability are not two separate areas of study in the built environment; they can be achieved together. Bird conservation organizations and citizen science projects such a species surveys and collision monitoring engage the public in advocating for a bird-safe built environment. Furthermore, in the case of avian ambassadors at aviaries and rehabilitation centers, birds themselves can be their own advocates reminding us to act for their welfare. Finally, aviaries are the center of public education, and those like Tracy Aviary and The National Aviary highlight through example the need for sustainable buildings that do not kill birds.

CONCLUSION AND FUTURE WORK

In the 1960s, Rachel Carson played a crucial role in communicating the urgency of limiting the anthropogenic threats to other species. She was particularly concerned with the overuse and careless distribution of pesticides. Today we face additional challenges, such as climate change and habitat loss, that threaten species, including our own. The urgency of sustainable living practices is more evident with each passing year. Despite birds' adaptability, they remind us that the infrastructure needed to support our lifestyles can often be devastating to theirs. Buildings and structures in the built environment kill hundreds of millions of birds each year in the United States. Still, professionals in the built environment often overlook one crucial aspect of sustainability that is also preventable with human action: bird building collisions.

To build sustainably, designers must factor in environmental matters.[443] Some principles of sustainable design specifically impact birds positively, like reducing CO2 emissions. However, some impact them negatively, like the extensive use of windows near green spaces. While sustainability strives to connect humans with natural systems in the built environment, "sustainable" solutions must not be merely in the interests of humans. Designers intent on designing sustainably should strive to create built environments in harmony with the natural environment.[444] The American Institute of Architects offers mitigation strategies but also an understanding that birds are vital to the ecology of the built environment and the well-being of the occupants of buildings. The AIA does this in part by explaining that bird collisions will harm the well-being of occupants. All policies and guidelines for sustainable design and bird-safe solutions should strive to find a balance between conserving nature, protecting bird species, and enhancing human well-being.

Structures awarded for their commitment to meeting sustainability standards should not kill birds routinely[445]. Protecting birds through design strategies must be upheld as a vital component of comprehensive sustainable standards, policies, and education. Currently, collision

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[443] *The Brundtland Report: Seizing the Opportunity: IIED Thoughts towards the Follow-up of the WCED Report "Our Common Future."* (London: International Institute for Environment and development, 1987); Ingrid Leman Stefanovic and Stephen Bede Scharper, *The Natural City Re-Envisioning the Built Environment* (Toronto, ON: University of Toronto Press, 2014), 13.

[444] Stephen R. Kellert, *Building for Life : Designing and Understanding the Human-Nature Connection* (Washington, DC: Island Press, 2005), 92.

[445] The U.S. Bank Stadium in Minneapolis, Minnesota as certified LEED Platinum in 2019, the first professional sports stadium to do so. However, its reflective glass facade kills over 100 birds every year.

mitigation techniques focus primarily on window collisions, since transparent and reflective glass are the most dangerous elements of the built environment for birds. However, lighting design, landscape design, and avian behavior and life history are important factors that affect the likelihood of window collisions. While many solutions to problematic glass, lighting, and landscape designs have been evaluated in this thesis, this is a critical area of study that needs further interdisciplinary research. This research requires expertise from the fields of architecture, design, landscaping, lighting, and ornithology. Until there is increased awareness among designers and architects of the dangers that birds face in the built environment and the available solutions, up to one billion migrating and resident birds will continue to die each year in the United States.

It has become so commonplace to cite Carson's world-altering book *Silent Spring* when speaking about anthropogenic threats to nature that the title's stark meaning escapes us. We forget the startling prediction that there will be a "silent spring"—without the sound of birds—if we do not act quickly. We face this threat even more immanently now than in the 1960s. Birds face climate change, habitat loss, and bird building collisions that have contributed to the substantial net loss of 3 billion birds in North America since 1970.[446] We should feel the same urgency that Carson felt in the 1960s when we understand that structures kill up to one billion birds in the United States each year.

Future Work

The subject of birds and the built environment spans many topic areas and disciplines allowing for future opportunities to collaborate with researchers in various fields. Future work related to this project includes a comprehensive monitoring project of a set of buildings, like a university campus, to record collisions before and after implementing collision solutions. This would provide much needed data to the topic of bird building collisions. Aiding in the development of an app like eBird or iNaturalist for exclusively bird building collisions that allows data and photos to be collected from the location would help to increase data as well. Based on the evaluations in this thesis, a comprehensive guide comparing all available solutions from various fields in the built environments would be a useful tool for educators as well as

[446] Kenneth V. Rosenberg et al. "Decline of the North American Avifauna." *Science* (New York, N.Y.) 366, no. 6461 (2019): 120-124.

architects and designers. The degree of awareness of this issue in the built environment field is unknown. A survey evaluating the level of knowledge and concern professionals have for this issue would help direct guidelines and education goals. This interdisciplinary topic requires collaboration on much of its future work. Future research should include determining, for example, if ultraviolet and vinyl films impact glass performance. Further, studying how collision mitigation techniques impact the natural light of an interior space or visual connection with nature is needed to find a middle ground between the human experience and protecting birds. Studying birds as part of biodiversity in biophilic design to increase human well-being would support this as well. Additionally, better understanding aspects of avian physiology such as sight and maneuverability are crucial to design new collision mitigation techniques, but there are few studies available on these two topics. It is essential to remember that each bird species behaves differently. Studying how birds adapt to or benefit from design is an essential step in mitigating dangers birds face as they interact with the built environment. This work would include using data collected from monitoring to aid in the development of software that can indicate dangerous areas of a building in need of collision mitigation solutions and possibly provide species-specific solutions. Finally, the study of the history of birds in the built environment can lead to a better understanding of how birds interact with these spaces.

APPENDICES

APPENDIX 1: LOSS ET AL.'S 2019 FIGURE 3: COLLISION FATALITIES.

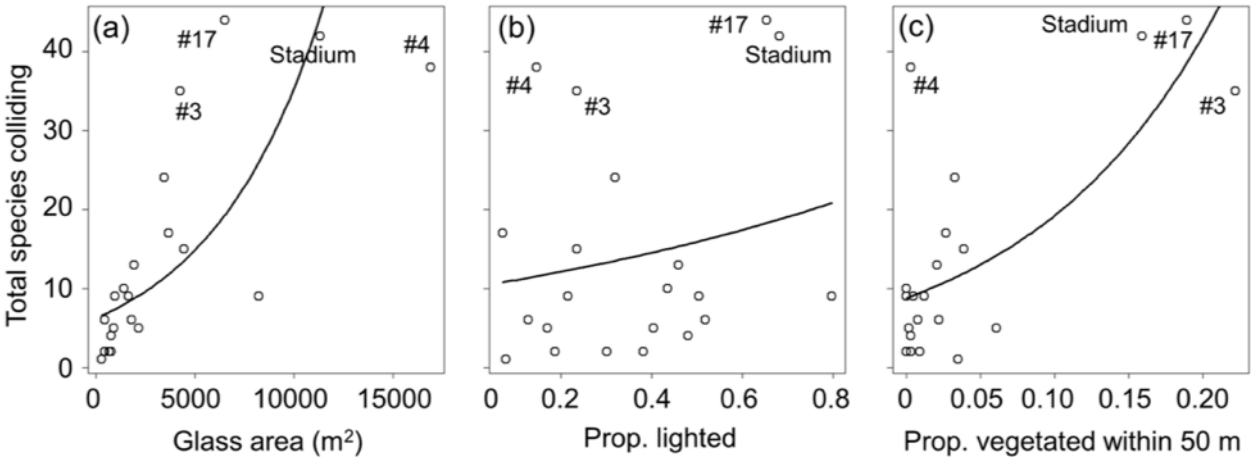


Figure 3. Correlates of numbers of collision fatalities (all buildings).
Loss et al., "Factors Influencing Bird-Building Collisions in the Downtown Area of a Major North American City.": 15.

APPENDIX 2: DATA TABLES OF KLEM'S 2009 AND 2013 OPEN FIELD EXPERIMENTS.

Table 1. Daniel Klem's 2009 UV Open Field Experiments Tested	Total Collisions	% Reduced
Experiment 1		
Clear Glass	14	-
Mirrored Glass	28	-
2.5 cm UV Strips Spaced 5 cm	0	100%
Experiment 2		
Clear Class	35	-
Vertical 2.5 cm UV Film* Strips Spaced 5 cm	12	66%
UV Film*	12	66%
Experiment 3		
Clear Glass	51	-
UV Film: Outside Glass	24	53%
UV Film: Inside Glass	20	61%
UV Film: 65% Visible	30	41%
UV Film: 55% Visible	24	47%
UV Film: High Reflection	21	41%
UV Film: Low Reflection	24	47%
Experiment 4		
Clear Glass	49	-
2.5 cm UV Strips Spaced 5 cm	27	55%
CollideEscape**	1	98%
Experiment 5		
Clear Class	60	-
CUV-O UV Film: Outside Glass	8	87%
CUV-1 UV Film: Inside Glass	7	88%
Experiment 5 - Flight Cage (See Figure 24)		
S-1R UV Film: 2.5 cm Strips Spaced 5 cm	2	97%
S-2R-O UV Film: 5 cm Strips Spaced 2.5cm, Exterior	1	98%
S-2R-1 UV Film: 5 cm Strips Spaced 2.5cm, Interior	4	93%
UV Grid: 2.5 cm Strips Spaced 8 cm by 10 cm	4	93%
Experiment 6		
Clear Glass	39	-
CUV-O UV Film	11	72%
S-1R UV Film	3	92%

*UV Film Provided by CPFilms.
**CollideEscape made the glass appear white.

Table 2. Daniel Klem's 2013 UV Open Field Experiments Tested	Total Collisions	% Reduced	Fatal Collisions	% Fatal
Experiment 1				
Clear Glass	32	-	2	6%
Mirrored Glass	40	25% Increase	6	15%
UV Coated Glass (ORNILUX)	41	28% Increase	11	27%
Experiment 2				
Clear Glass	69	-	21	30%
Vertical 3.175 mm UV Strips Spaced 8.9 cm	5	93%	Unknown	Unknown
Vertical 3.175 mm UV Strips Spaced 10.8 cm	7	90%	1	14%
UV Coated Black Panel (ORNILUX)	31	55%	Unknown	Unknown

Tables by the author.

Data in Table 1: Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009).

Data in Table 2: Daniel Klem and Peter G. Saenger, “Evaluating the Effectiveness of Select Visual Signals to Prevent Bird-Window Collisions,” *The Wilson Journal of Ornithology* 125, no. 2 (2013).

APPENDIX 3: THE AMERICAN BIRD CONSERVANCY'S (ABC) THREAT FACTOR RESULTS

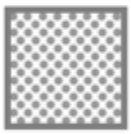
The American Bird Conservancy recommends the following manufacturers for buying commercial or residential bird collision deterrence materials.

I. Viracon uses ABC's threat factor to show the effectiveness of their products.[447] Without clear information about the threat factor scale, however, it can be confusing for consumers to understand what they mean.

Scenario 1: Threat Factor 6
Color: V901 Dark Gray Viraspan
Pattern: 1/8" horizontal lines alternating with 1/2" spaces (screen 2256); 20% coverage

Scenario 2: Threat Factor 10
Color: V948 Medium Gray Viraspan
Pattern: 1/8" horizontal lines alternating with 1/2" spaces (screen 2256); 20% coverage

Scenario 3: Threat Factor 41
Color: V175 High Opacity White
Pattern: 1/8" dots, 1/4" on center (screen 5065); 20% coverage



Scenario 4: Threat Factor 24
Color: V175 High Opacity White
Pattern: 1/8" dots (screen 5006); 40% coverage

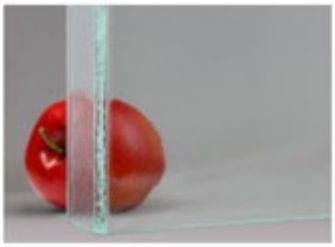
Scenario 5: Threat Factor 17
Color: Digital White and Digital Etch (every other line switches between the colors)
Pattern: 1/8" horizontal lines 2" on center; 6% coverage

Scenario 6: Threat Factor 29
Color: Digital White and Digital Etch (1/8" lines were etch and 1/16" lines were white)
Pattern: alternating 1/8" and 1/16" horizontal lines all 2" on center; 5% coverage

[447] Viracon. "Tech Talks," Viracon, accessed April 7, 2020, https://viracon.com/page/tech-talks)

II. Bendheim Glass scored a threat factor of 29 for the Clarissimo finish and 34 for the Rough finish. Their website does not list them as Bird-Smart. The frosted effect of the Rough finish deterred collisions 66%, much lower than could be expected from a non-reflective surface indicating the need to study avian sight further.[448]

504 Rough Cast™ Channel Glass (Ultra-Brilliant Low-Iron or Regular)



Clarissimo™ Channel Glass (Ultra-Brilliant Low-Iron or Regular)

[448] Bendheim. "Architectural Glass: Product Catalog," Bendheim, accessed April 7, 2020, https://bendheim.com/professional/glass/)

III. Walker Glass' AviProtek has nine bird-friendly glass options with three tested by ABC. Of the three tested, their threat factors are 23, 30, and 30. The six dot designs not tested by ABC are listed as bird-friendly options as they are spaced at least 5 cm horizontally or 10 cm vertically. [449] However, the 5 cm by 10 cm rule tested by Klem used lines, not dots.[450]

IV. CollidEscape provides vinyl window coverings and patterned tape for use on commercial or residential buildings. Their products do not have their threat factors listed; however, their products are divided into guaranteed solutions and high-performance solutions. The guaranteed solutions provide four films that cover the entire window and one repeating dot pattern. ABC tested CollidEscape's white perforated film and assigned the mitigation

[449] Walker Glass. "Transparent Bird Friendly Glass: AviProtek T," Verrerie Walker, accessed April 7, 2020, https://www.walkerglass.com/products/transparent-bird-friendly-glass/)

[450] Daniel Klem, "Preventing Bird–Window Collisions," *The Wilson Journal of Ornithology* 121, no. 2 (2009), 314-321.

technique a threat factor of 2, indicating it reduced collisions by 98%. This result is the same as Klem's 2009 experiment. The film appears opaque from the outside but allows light to enter the building and does not block the view. Colored vinyl and customizable images, text, and designs can be ordered as well. The opaque vinyl options claim to absorb or reflect up to 50% of incoming solar heat. However, no studies of their claim were cited.[451] The clear options have not been tested and do not protect against territorial aggression.[452] The dot window covering uses 0.36 cm dots spaced 5 cm apart. The high-performance patterns include clear or white dots sized 1.9 cm spaced 5 cm apart on a single line tape roll. The dots are made of the same perforated vinyl as the full window covering. The perforated vinyl is also available in strips 1.9 cm to 7.6 cm in width in clear or white in the same single line tape roll format. ABC has not tested the dot and line tape options.[453]

[451] CollidEscape. “Energy Savings,” CollidEscape 2020, accessed April 7, 2020, https://www.collidescape.org/copy-of-leed)

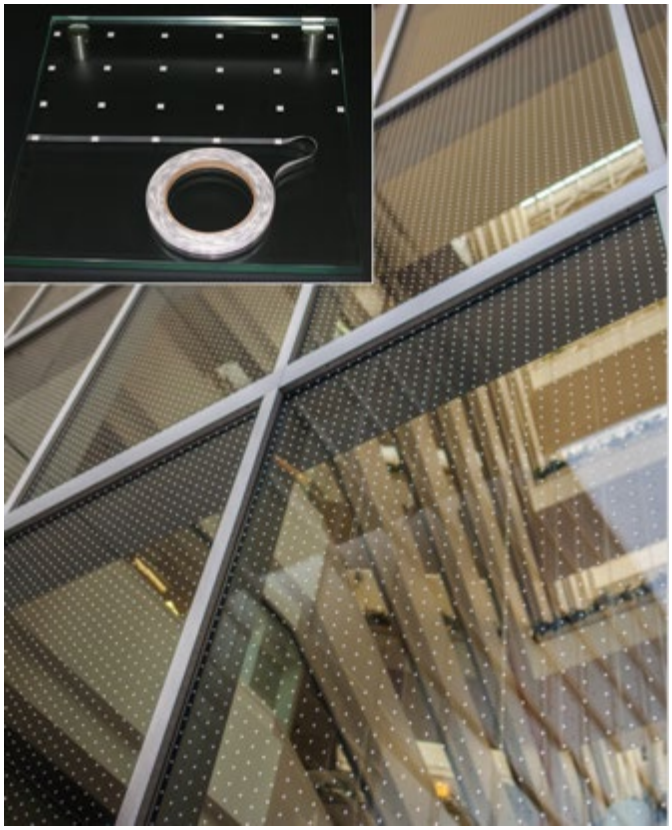
[452] Territorial aggression is when birds see their own reflection in a reflective surface such as windows or mirrors and attack the "intruder" to protect its territory.

[453] CollidEscape. “Prevent Birds Hitting Windows: CollidEscape,” CollidEscape 2020, accessed April 7, 2020, https://www.collidescape.org/)

V. Decorative Films, a window privacy film company, have six bird safety films. They include horizontal lines 0.32 cm thick spaced 2.54 cm, vertical lines 0.32 cm thick spaced 5 cm, a trellis pattern with 0.32 cm lines leaving 13 cm diamond-shaped openings, a dot pattern size 0.63 cm spaced 5 cm, a frosted bird pattern design, and a colored bird pattern design. ABC tested the frosted and colored bird pattern designs, resulting in threat factors of 5 and 20, respectively.[454] This 15 point difference of the same pattern indicates limitations of the testing method, that color is a less reliable deterrent, or an aspect of avian physiology not yet understood.

[454] Decorative Film. "Decorative Films: Window Film: Stained Glass: Privacy Film: Window Treatments," Decorative Films, LLC., accessed April 7, 2020, https://www.decorativefilm.com/specialty-bird-safety)

VI. Feather Friendly is a bird collision deterrent manufactured by 3M for residential and commercial use. Square dots sized 0.32 cm are spaced two inches apart and have a threat factor of 23.[455]



VII. Window Alert is a residential mitigation technique that sells shaped UV decals. Hawk and maple leaf decals have been tested by Klem and did not significantly reduce collisions. ABC tested the 8.9 cm square UV decals spaced 5 cm horizontally and 10 cm vertically. The threat factor was 10 and in Sheppard's 2019 study they scored a threat factor of 8 when spaced 2.4 cm apart horizontally and 5 cm apart vertically.[456] However, this product has four decals per envelope, and while the directions recommend using the

[455] Feather Friendly, "Feather Friendly," https://www.featherfriendly.com, accessed April 7, 2020, https://www.featherfriendly.com/)

[456] Christine D. Sheppard, "Evaluating the Relative Effectiveness of Patterns on Glass as Deterrents of Bird Collisions with Glass," *Global Ecology and Conservation* 20 (2019): 7.

5 cm by 10 cm spacing, multiple packs would be required to cover one window.[457] Additionally, UV decals do not consistently prevent collisions at a high percentage in tests.

VIII. GlasPro is a film made of vertical strips spaced 5.7 cm alternating UV and non-UV strips.[458] This is one of the four UV materials that fall outside of the 30 or less threat factor required to be determined Bird-Smart by ABC.

[457] Window Alert. "Classic Square Decal Envelope - 4 Decals," Window Alert, accessed April 7, 2020, https://windowalert.com/classic-square-decal-envelope-4-decals/)
[458] GlasPro. "Bird Safe," GlasPro, accessed April 7, 2020, http://www.glas-pro.com/products/glas-pro-bird-glass/).

APPENDIX 4: PROMOTING BIRD CONSERVATION IN URBANIZING LANDSCAPES

Box 1. Recommendations to planners and policy-makers interested in promoting bird conservation in urbanizing landscapes.

1. **Protect natural areas as parks or other open spaces within urbanizing landscapes in order to both (a) provide habitat to wildlife and (b) improve the quality of the landscape matrix.** While preserving the largest contiguous areas of habitat possible is always advisable, simply increasing the amount of natural habitat within the landscape improves the ability of all habitat patches to support birds.

2. **Plan explicitly for open spaces and natural habitats within new subdivisions.** By carefully planning the amount and location of habitat within subdivisions, developments are more likely to capture inherently diverse areas and provide suitable habitat to birds.

3. **Within developments, use a variety of arrangements of built and open space.** Because species differ widely in their ecological requirements, no single habitat management approach will meet the needs of the regional suite of avian communities. Application of different management and design approaches ensures that a diversity of species will be supported.

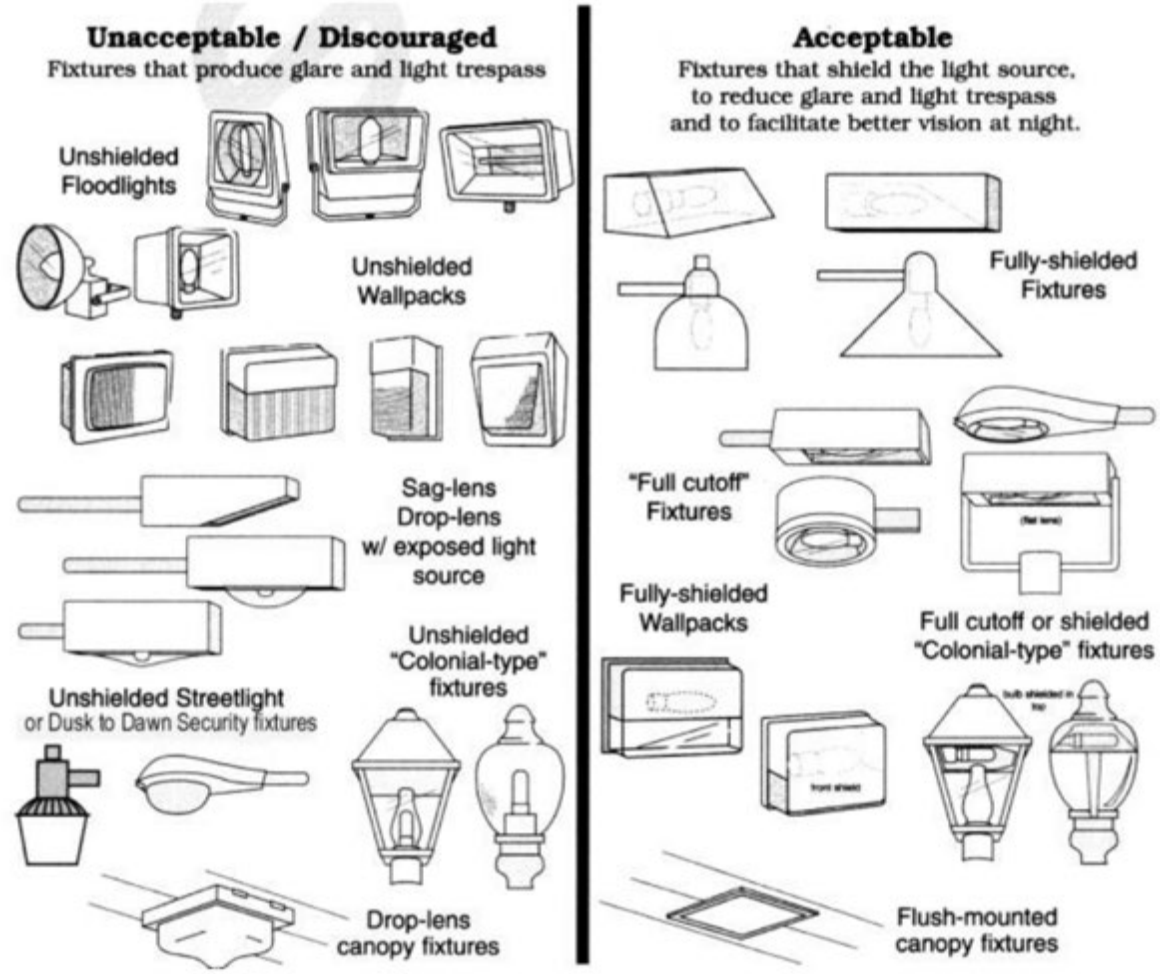
4. **Enhance and restore habitat within existing open green spaces and natural areas.** Though birds generally respond positively to greater structural and floristic diversity of habitat, some species may require more deliberate management to provide their specific requirements (e.g., nest cavities).

5. **Improve habitat quality within the matrix of urban land uses rather than focusing only on management within parks, reserves, and open spaces.** Ultimately there will not be a sufficient number of reserves and parks to conserve biodiversity. Effective conservation requires that we think outside the park and explore creative ways to improve the habitat available to birds within the urban landscape itself.

6. **Celebrate urban biological diversity to foster connections between people and the natural heritage of their local ecosystems and regional biomes.** Not only does interaction with nature enrich our lives, but such interactions foster sensitivity to environmental issues – something needed as we face tremendous global change.

(Marzluff and Rodewald, 2008)

APPENDIX 5: DARK SKY SOCIETY'S GUIDELINES FOR EXTERIOR LIGHTING



Diagrams courtesy of Bob Crelin

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