Bird-Friendly Building Design

AMERICAN BIRD CONSERVANCY

NEW YORK CITY AUDUBON

Vassar's Bridge for Laboratory Sciences, shown here under construction in October 2015. The building is scheduled to open in January 2016. Cover rendering and photos courtesy of Ennead Architects

Exterior glass detail

Glass detail, showing frit pattern

Cover rendering and photo this page: The new Bridge for Laboratory Sciences building at Vassar College, designed by Richard Olcott/Ennead Architects, redefines the identity of the sciences on the College's historic campus and provides technologically advanced facilities for students, faculty, and researchers.

Fundamental to the building's design is its seamless integration with the natural landscape, scale, and campus aesthetic of the College. In this natural wooded setting, the need for strategies to reduce bird collisions with the building was apparent. In response, the building was designed to comply with LEED Pilot Credit 55: Bird Collision Deterrence.

Ennead managing partner Guy Maxwell is a nationally recognized champion of bird-friendly design and has led Ennead's innovative approach to make the building's glazing safer for birds, employing patterned glass, screens and sunshades, and Ornilux glass, a specialty glass product that uses a UV coating visible to birds but not humans.

By framing and showcasing views of the landscape, the building celebrates and connects students with the surrounding environment, while the overall development of the precinct repurposes an underutilized sector of campus.

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The area of glass on a façade is the strongest predictor of threat to birds. There are also other reasons to limit glass. Skidmore Owings Merril's Bronx, New York, Emergency Call Center is a handsome example of creative design with restricted glass, for a building intended to be both secure and blast-resistant. Photo by Chris Sheppard, ABC

For updates and new information, see **collisions.abcbirds.org**

Executive Summary

A bird, probably a dove, hit the window of an Indiana home hard enough to leave this ghostly image on the glass. Photo by David Fancher

Collision with glass claims the lives of hundreds of millions of birds each year in the United States. It is second only to domestic cats as a source of mortality linked directly to human action. Birds that have successfully flown thousands of miles on migration can die in seconds on a pane of glass; impacts kill fledglings before they can truly fly. Because glass is dangerous for strong, healthy, breeding adults, as well as sick or young birds, it can have a particularly serious impact on populations.

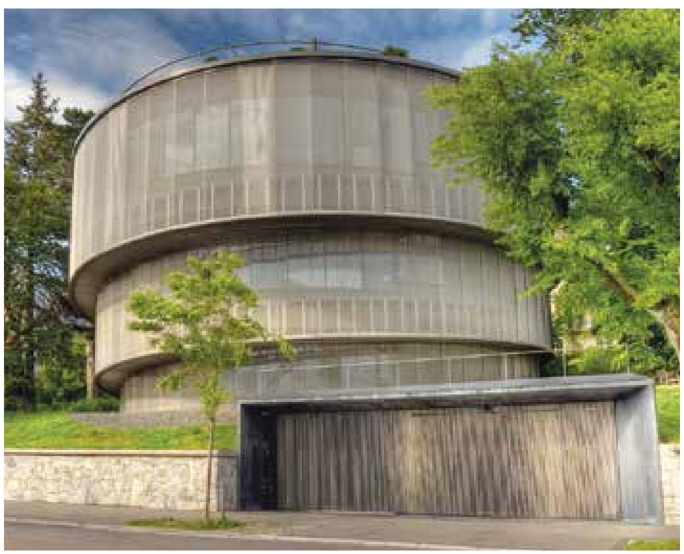
Bird kills occur at buildings across the United States and around the world. We know most about mortality patterns in cities, because that is where most monitoring takes place, but virtually any building with glass poses a threat wherever it is. The dead birds documented by monitoring programs or provided to museums constitute merely a fraction of the birds actually killed. The magnitude of this problem can be discouraging, but there are already effective solutions and an increasing commercial commitment to developing new solutions, if people can be convinced to adopt them.

That artificial lighting at night plays a significant part in mortality from glass is widely accepted, but often misunderstood. The majority of collisions with buildings take place during daylight. There are many well-documented instances of bright lights at night disorienting large numbers of birds—usually night-migrating passerines but also seabirds—some of which may circle in the light, sometimes until dawn. Nocturnal mortality associated with circulation events is caused by collision with guy wires and other structures. Such events were described starting in the late 19th century at lighthouses, and later at the Washington Monument, Statue of Liberty, and Empire State Building, which were the only brightly lit structures in their areas. Today, such events occur mostly at offshore drilling platforms and communication towers. These situations have in common bright light surrounded by darkness, and their frequency has decreased in cities as areas of darkness around bright structures have also become lit. However, there are strong indications that birds are still being disoriented by urban lights and that lights are linked to mortality, even though mortality patterns have changed.

Advances in glass technology and production since the mid-twentieth century have made it possible to construct skyscrapers with all-glass walls, homes with huge picture windows, and miles of transparent noise-barriers on highways. There has been a general increase in the amount of glass used in construction—and the amount of glass on a building is the best predictor of

Newhouse III, designed by Polshek Partnership Architects, is part of Syracuse University's S.I. Newhouse School of Public Communications. This building incorporates an undulating, fritted glass façade with the words of the first amendment etched in letters six feet high along the base. Photo by Christine Sheppard, ABC the number of birds it will kill. However, while glass is important for bringing light into buildings, a façade with over 30-40% glass dramatically increases energy use for heating and cooling. Bird-friendly design is becoming recognized as part of sustainable design, required increasingly by legislation across North America.

New construction can incorporate from the beginning bird-friendly design strategies that are cost neutral. There are many ways to reduce mortality from existing buildings, with more solutions being developed all the time. Because the science is constantly evolving, and because we will always wish for more information than we have, the temptation is to postpone action in the hope that a panacea is just around the corner. But we can't wait to act. We have the tools and the strategies to make a difference now. Architects, designers, city planners, and legislators are key to solving this problem. They not only have access to the latest building construction materials and concepts; they are also thought leaders and trend setters in the way we build our communities and prioritize building design issues.

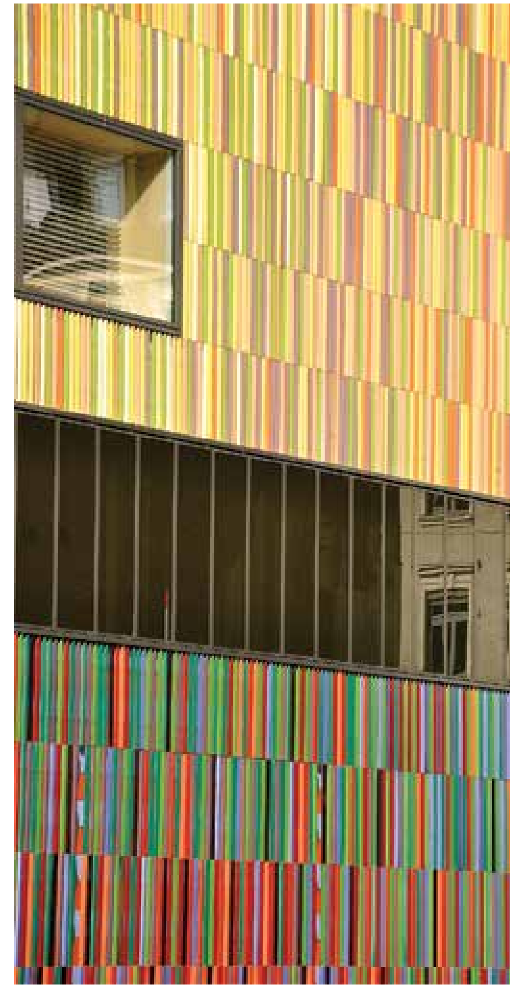


The steel mesh enveloping Zurich's Cocoon in Switzerland, designed by Camenzind Evolution, Ltd, provides privacy, reduces heating and cooling costs, and protects birds, but still permits occupants to see out. Photo by Anton Volgger

This publication aims to provide planners, architects, and designers, bird advocates, and local, municipal, and federal authorities, as well as the general public, with a clear understanding of the nature and magnitude of the threat glass poses to birds. Since the first edition, in 2011, there has been increased awareness of collisions, evidenced by new ordinances and guidelines for bird-friendly construction, new materials to retrofit existing buildings, and promotion by the glass industry of bird-friendly materials.

This edition includes an updated review of the underlying science, examples of solutions that can be applied to both new construction and existing buildings, and an explanation of what information is still needed. We hope it will spur individuals, businesses, communities, scientists, and governments to address this issue and make their buildings safer for birds. Constructing bird-friendly buildings and eliminating the worst existing threats require only imaginative design, effective retrofits, and recognition that birds have intrinsic and cultural as well as economic and ecological value to humanity.

American Bird Conservancy's Collisions Program works at the national level to reduce bird mortality by coordinating with organizations and governments, developing educational programs and tools, evaluating and developing solutions, creating centralized resources, and generating awareness.



The façade of Sauerbruch Hutton's Brandhorst Museum is a brilliant example of mixing glass and non-glass materials. Photo by Tony Brady

INTRODUCTION

Why Birds Matter

For many people, birds and nature have intrinsic worth. Birds have been important to humans throughout history, often symbolizing cultural values such as peace, freedom, and fidelity. In addition to the pleasure they can bring to people, we depend on them for critical ecological functions. Birds consume vast quantities of insects and control rodent populations, reducing damage to crops and forests and helping limit the transmission of diseases such as West Nile virus, dengue fever, and malaria. Birds play a vital role in regenerating habitats by pollinating plants and dispersing seeds. Birds are also a direct economic resource. According to the U.S. Fish and Wildlife Service, bird watching is one of the fastest growing leisure activities in North America, an over $40 billion industry accounting for many jobs.

The Legal Landscape

At the start of the 20th century, following the extinction of the Passenger Pigeon and the near extinction of other bird species due to unregulated hunting, laws were passed to protect bird populations. Among them was the Migratory Bird Treaty Act (MBTA), which made it illegal to kill a migratory bird without a permit. The scope of this law, which is still in effect today, extends beyond hunting, such that anyone causing the death of a migratory bird, even if unintentionally, can be prosecuted if that death is deemed to have been foreseeable. At present, the scope of the MBTA is under challenge in federal court and it is impossible to say whether it will ever be used to curb glass collisions. However, courts in Canada have ruled that building owners are responsible for mortality caused by glass.

Violations of the MBTA can result in fines of up to $500 per incident and up to six months in prison. The Bald and Golden Eagle Protection Act (originally the Bald Eagle Protection Act of 1940), the Endangered Species Act (1973), and the Wild Bird Conservation Act (1992) provide further protections for birds that may apply to building collisions. Recent legislation, primarily at the city and state levels, has addressed the problem of mortality from building collisions and light pollution. Starting with Toronto, Canada, in 2009 and San Francisco, California, in 2010 an increasing number of states and municipalities have passed laws mandating bird-friendly design, while other authorities have passed voluntary measures.

Glass: The Invisible Threat

Glass is invisible to both birds and humans. Humans learn to see glass through a combination of experience and visual cues like mullions and even dirt, but birds are unable to use these signals. Most birds' first encounters with glass are fatal when they collide with it at full flight speed. Aspects of bird vision contribute to the problem. Whereas humans have eyes in the front of their heads and good depth perception, most birds' eyes are placed at the sides of their heads. Birds thus have little depth perception beyond the range of their bills but extensive fields of view to the side and behind. They judge their flight speed by the passing of objects to their sides, so their focus in flight is not necessarily ahead. Besides simply using designs with less glass, we can protect birds by using screens, shutters, and details that partly obscure glass while still providing a view, or by using two-dimensional patterns that birds perceive as actual barriers. However, birds have poor contrast sensitivity compared to humans: shapes at a distance merge into a blur at closer range for birds. This means that most signals that make glass safe for birds will probably be readily visible to people.

Reflections on home windows are a significant source of bird mortality. The partially opened vertical blinds here may break up the reflection enough to reduce the hazard to birds. Photo by Christine Sheppard, ABC

Birds may try to reach vegetation seen through two or more glass walls or windows; the single decal here is not enough to solve the problem, but two or three could do the trick. Photo by Christine Sheppard, ABC

(Opposite) The White-throated Sparrow is the most frequent victim of collisions reported by urban monitoring programs. Photo by Robert Royse

Lighting: Exacerbating the Threat

Most birds, with obvious exceptions, are active by day, with eyes best adapted for daylight sight. However, many bird species migrate by night, allowing them to use daylight hours for feeding. We still don't know everything about how night-flying birds navigate. We do know that birds probably have two special senses that allow them to determine location and direction using the Earth's magnetic field. One of these, located in the eye, may allow birds to "see" magnetic lines in the presence of dim blue light. Star maps, landmarks, and other mechanisms are also involved.

Artificial night lighting seemingly disrupts orientation mechanisms evolved to work with dimmer, natural light sources and can cause birds to deviate from their flight paths. The problem is compounded for birds flying in mist or cloud, which can cause them to fly lower and closer to artificial light sources, depriving them of celestial and magnetic cues. As birds fly near light sources, they may become disoriented and eventually land in the built environment.

The majority of collisions with buildings actually take place by day. As birds seek food to fuel their next migratory flight, they face a maze of structures, and many, unable to distinguish between habitat and reflections, hit glass. The amount of light emitted by a building is a strong predictor of the number of collisions it will cause, more so than building height. Patterns of light intensity across a nocturnal landscape may influence the pattern of birds landing in that landscape at the end of migration stages. Thus, reducing light trespass from all levels of buildings and their surroundings is an important part of a strategy to reduce collisions with glass. There is some recent evidence that electromagnetic radiation outside the visible spectrum may also disorient birds.

Light at night can disorient birds, and the problem is not restricted to tall buildings. This scene of Las Vegas by night depicts a threat to any bird migrating nearby at night. Photo by BrendelSignature, Wikipedia

Birds and the Built Environment

Humans first began using glass in Egypt around 3500 BCE. Glass blowing, invented by the Romans in the early first century CE, greatly increased the ways glass could be used, including the first crude glass windows. The 17th century saw the development of the float process, enabling production of large sheets of glass. This technology became more sophisticated, eventually making glass windows available on a large scale by the 1960s. In the 1980s, development of new production and construction technologies culminated in today's glass skyscrapers and increasing use of glass in all types of construction.

Sprawling land-use patterns and intensified urbanization degrade the quality and quantity of bird habitat across the globe. Cities and towns encroach on riverbanks and shorelines. Suburbs, farms, and recreation areas increasingly infringe upon wetlands and woodlands. Some bird species simply abandon disturbed habitat. For resident species that can tolerate disturbance, glass is a constant threat, as these birds are seldom far from human structures. Migrating birds are often forced to land in trees lining our sidewalks, city parks, waterfront business districts, and other urban green patches that have replaced their traditional stopover sites.

The amount of glass in a building is the strongest predictor of how dangerous it is to birds. However, even small areas of glass can be lethal. While bird kills at homes are estimated at one to 10 birds per home per year, the large number of homes multiplies that loss to millions of birds per year in the United States, representing over 46% of the total problem. Other factors can increase or decrease a building's impact, including the density and species composition of local bird populations; local geography; the type, location, and extent of landscaping and nearby habitat; prevailing wind and weather; and patterns of migration through the area. All must be considered when planning bird-friendly buildings.

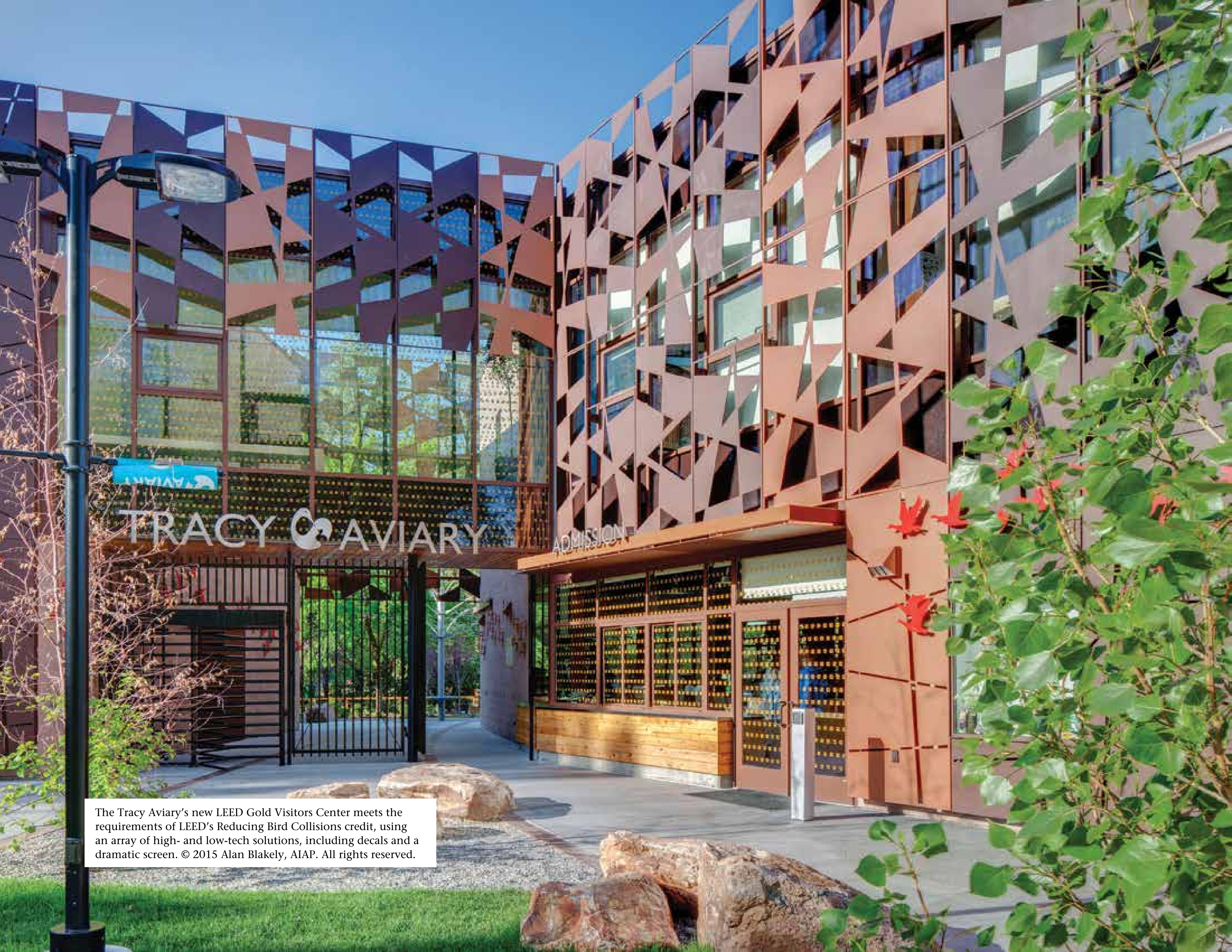
Impact of Collisions on Bird Populations

About 25% of species are now on the U.S. Watch List of birds of conservation concern (abcbirds.org/birds/watchlist), and even many common species are in decline. Habitat destruction or alteration of both breeding and wintering grounds remains the most serious man-made problem, but collisions with buildings are second only to domestic cats as direct fatality threats. Nearly one-third of the bird species found in the United States—more than 258 species, from hummingbirds to falcons—are documented as victims of collisions. Unlike natural hazards that predominantly kill weaker individuals, collisions kill all categories of birds, including some of the strongest, healthiest birds that would otherwise survive to produce offspring. Without action, the cumulative effect of these deaths will result in significant population declines. Most of the mortality is avoidable. This document is one piece of a strategy to keep building collisions from increasing and, ultimately, to reduce them.

Bird Collisions and Sustainable Architecture

In recent decades, advances in glass technology and production have made it possible to construct tall buildings with all-glass walls, and we have seen a general increase in the amount of glass used in all types of construction. This is manifest in an increase in picture windows in private homes, glass balconies and railings, bus shelters, and gazebos. New applications for glass are being developed all the time. Unfortunately, as the amount of glass increases, so does the incidence of bird collisions.

The Cape May campus of Atlantic Cape Community College inherited a building with large areas of glass that did not have coatings or film to control temperature and glare—and there were many collisions. The addition of Collidescape has eliminated the threat to birds while reducing heating and cooling costs. Photo by Lisa Apel-Gendron



The Tracy Aviary's new LEED Gold Visitors Center meets the requirements of LEED's Reducing Bird Collisions credit, using an array of high- and low-tech solutions, including decals and a dramatic screen. © 2015 Alan Blakely, AIAP. All rights reserved.

In recent decades, growing concern for the environment has stimulated the creation of "green" standards and rating systems for development. The best known is the U.S. Green Building Council (USGBC) Leadership in Energy and Environmental Design, or LEED. While the USGBC concurred that sustainable buildings should not kill birds, it was initially difficult to create recommendations within the LEED credit system. The solution was based on a technique called "tunnel testing," a non-lethal method using live birds that permits a relative threat score to be assigned to patterned glass and other materials. (The section on Research in Chapter 6 reviews the work underlying the assignment of threat scores.)

On October 14, 2011, USGBC added Pilot Credit 55: Bird Collision Deterrence to its Pilot Credit Library. The credit was drafted by American Bird Conservancy (ABC), members of the Bird-Safe Glass Foundation, and the USGBC Sustainable Sites Technical Advisory Group (TAG). Building developers that wish to earn this credit must quantify the threat level to birds posed by various materials and design details. These threat factors are used to calculate an index, or weighted average, representing the building's façade; that index must be below a standard value to earn the credit. The index is intended to provide wide latitude in creating designs that meet the criteria. The credit also requires adopting interior and exterior lighting plans and post-construction monitoring.

Pilot Credit 55 is one of the most widely used credits in the pilot library. A revised version of the credit, posted in the fall of 2015, expands its availability to all LEED rating systems except "neighborhoods."

ABC is a registered provider of the American Institute of Architects (AIA) Continuing Education System, offering classes on bird-friendly design and LEED Pilot Credit 55 in face-to-face and webinar formats. Contact Christine Sheppard, csheppard@abcbirds.org, for more information.

Defining What's Good for Birds

It is increasingly common to see the term "bird-friendly" used in a variety of situations to demonstrate that a particular product, building, legislation, etc., is not harmful to birds. All too often, however, this term is unaccompanied by a clear definition and lacks a sound scientific foundation to underpin its use. Ultimately, defining "bird-friendly" is a subjective task. Is bird-friendliness a continuum, and if so, where does friendly become unfriendly? Is "bird-friendly" the same as "bird-safe?" How does the definition change from use to use, situation to situation? It is impossible to know exactly how many birds a particular building will kill before it is built, and so, realistically, we cannot declare a building to be bird-friendly before it has been carefully monitored for several years.

There are factors that can help us predict whether a building will be particularly harmful to birds or generally benign, and we can accordingly define simple "bird-friendly building standards" that, if followed, significantly reduce potential hazard to birds. That said, a 75% reduction of mortality at a structure that kills 400 birds a year means that structure will still kill 100 birds a year. Because window kills affect reproductively active adult birds, the cumulative effect of saving some birds is amplified by their reproductive output. Because a 100% reduction in mortality may be difficult to achieve, ABC takes the position that it is better to take reasonable available actions immediately than to put off taking action until a perfect solution is possible or to take no action at all.

Hariri Pontarini Architects with Robbie/Young + Wright Architects used botanical imagery in 3M laminates to depict the plants that produce many of the compounds used by students at the University of Waterloo School of Pharmacy, Canada. Photo by Christine Sheppard, ABC

Problem: Glass

The glass in this Washington, D.C., atrium poses a double hazard, drawing birds to plants inside as well as reflecting sky above. Photo by Christine Sheppard, ABC

Properties of Glass

Glass, as a structural material, can range in appearance from transparent to mirrored to opaque. Its surface can completely reflect light or let virtually 100% of light pass through. A particular piece of glass will change appearance depending on environmental factors, including position relative to the sun, the difference between exterior and interior light levels, what may be reflected, and the angle at which it is viewed. Combinations of these factors can cause glass to look like a mirror or a dark passageway, or be completely invisible. Humans do not actually "see" clear glass, but are cued by context such as mullions, dirt, or window frames. Birds, however, do not perceive right angles and other architectural signals as indicators of obstacles or artificial environments: they take what they see literally. While local birds may become familiar with individual pieces of glass, they do not ever grasp the concept "glass."

The glass-walled towers of the Time Warner Center in New York City appear to birds as just another piece of the sky. Photo by Christine Sheppard, ABC

Reflection

Under the right conditions, even transparent glass on buildings can form a mirror, reflecting sky, clouds, or nearby habitat attractive to birds. When birds try to fly to the reflected habitat, they hit the glass. Reflected vegetation is the most dangerous, but birds also attempt to fly past reflected buildings or through reflected passageways, with fatal results.

Transparency

Birds strike transparent windows as they attempt to access potential perches, plants, food or water sources, or other lures seen through the glass, whether inside or outside. Large planted atria are frequent problems, as are glass balcony railings and "skywalks" joining buildings. The increasing trend toward glass used in landscapes, as walls around roof gardens, as handrails or walkway dividers and even gazebos is dangerous because birds perceive an unobstructed route through them to habitat beyond.

Black Hole or Passage Effect

Birds often fly through small gaps, such as spaces between leaves or branches, into nest cavities, or through other small openings that they encounter. In some light, the space behind glass can appear black, creating the appearance of just such a cavity or "passage" with unobstructed access through which birds try to fly.

Transparent handrails are a dangerous trend for birds, especially when they front vegetation. Photo by Christine Sheppard, ABC

Large facing panes of glass can appear to be a clear pathway. Photo by Christine Sheppard, ABC

The same glass can appear transparent or highly reflective, depending on weather or time of day.

Photos by Christine Sheppard, ABC

Factors Affecting Rates of Bird Collisions for a Particular Building

Every site and every building can be characterized as a unique combination of risk factors for collisions. Some of these, particularly aspects of a building's design, are very building-specific. Many problem design features can be readily improved, or, in new construction, avoided. Others of these—for example, a building's location relative to migration stopover sites, regional ecology, and geography—are difficult if not impossible to modify.

Building Design

People like glass and it has become a popular building material. All-glass buildings have become more and more common as glass has become a low-cost material for construction. Glass causes virtually all bird collisions with buildings. Studies based on monitoring data have shown a direct relationship between the amount of glass on a building and the number of collisions at that site—the more glass, the more bird deaths.

Mirrored glass is often used intentionally to make a building "blend" into a vegetated area by reflecting its surroundings, making those buildings especially deadly to birds. However, all-glass buildings are coming increasingly into question. According to groups like the American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) and the International Code Council, when there is more than 30-40% glass on a façade, heating and cooling costs begin to increase.

Building Size

Glass skyscrapers, because of their height and visibility, are often the main focus of collision documentation, and they do account for more collisions per building than smaller structures. However, because there are many more homes and low-rise buildings, the latter account for more total mortality. A study published by scientists at the Smithsonian in 2014 estimated 508,000 annual bird deaths for high-rises, 339 million for low-rises, and 253 million for homes. More collisions probably occur at glass on lower floors, where most bird activity takes place, but when monitors have had access to setbacks and roofs, they have consistently found at least some carcasses, indicating that glass at any level can be a threat.

Orientation and Siting

Because migrating birds are frequent collision victims, it is often assumed that more collisions will occur on north- and south-facing façades. However, most building collisions take place during the day, and building orientation in relation to compass direction has not been implicated as a factor. Siting of buildings with respect to surrounding habitat and landscaping has more

Birds flying from a meadow on the left are channeled toward the glass doors of this building by a rocky outcrop to the right of the path. Photo by Christine Sheppard, ABC

Mirrored glass is dangerous at all times of day, whether it reflects vegetation, sky, or simply open space through which a bird might try to fly. Photo by Christine Sheppard, ABC

Plantings on setbacks and rooftops can attract birds to glass they might otherwise avoid. Chris Sheppard, ABC

implications. Physical features like walkways that provide an open flight path through vegetated landscape, or obstacles like outcrops of rock or berms, can channel birds toward or away from glass and should be considered early in the design phase. Movement patterns of birds within surrounding habitat may cause unanticipated collisions. Birds often fly between landscape features, for example, between two stands of trees, and may be at risk from structures along their route.

Glass that reflects shrubs and trees causes more collisions than glass that reflects pavement or grass. Studies that measured vegetation within only 15 to 50 feet of a façade have led to the misconception that plantings beyond a certain distance don't influence collisions, but vegetation at much greater distances can easily be visible in reflections. Vegetation around buildings will bring more birds into the vicinity of the building; the reflection of that vegetation brings more birds into the glass. Taller trees and shrubs correlate with more collisions. It should be kept in mind that vegetation on slopes near a building will reflect in windows above ground level. Studies using bird feeders (Klem *et al.* 1991) have shown that fatal collisions result when birds fly toward glass from more than a few feet away.

Time of Day

Collisions tend to happen most when birds are most active. Many studies have documented that although collisions peak during the early morning, they can happen at almost any time of day. Most monitoring programs have focused on early morning before cleaning crews have swept sidewalks because of the increased likelihood of finding birds and because it is easier to obtain volunteer searchers in the pre-work hours.

Green Roofs and Walls

Green roofs bring elements attractive to birds to higher levels, but often they are built in close proximity to glass. However, recent work shows that well-designed green roofs can become functional ecosystems, providing food and even nest sites for birds. Siting of green roofs, as well as green walls and rooftop gardens, should therefore be carefully considered, and glass adjacent to these features should have protection for birds.

Green roofs and walls can provide food and other resources to birds, but they can also attract birds to glass that they might not otherwise encounter. Emilio Ambasz's ACROS building in Fukuoka, Japan, is an interesting example. Photo by Kenta Mobuchi

This atrium has more plants than anywhere nearby on surrounding streets, making the glass deadly for birds seeking food or shelter in this area. Photo by Christine Sheppard, ABC

Solutions: Glass

It is possible to design buildings that can reasonably be expected to kill few or no birds. Numerous examples already exist, not necessarily designed with birds in mind but simply to be functional and attractive. These buildings may have many windows, but their screens, latticework, louvers, and other devices outside, or patterns integrated into the glass, warn birds before they collide. Finding glass treatments that can eliminate or greatly reduce bird mortality, while minimally obscuring the glass itself, has been the goal of several researchers, including Martin Rössler, Daniel Klem, and Christine Sheppard. Their work, discussed in more detail in the Science chapter, has focused primarily on the spacing, length, width, opacity, color, and orientation of elements marked on glass, and has shown that patterns covering as little as 5% of the total glass surface can deter most strikes under experimental conditions. They have shown that as a general rule, most songbirds will not attempt to fly through horizontal spaces less than 2 inches high or through vertical spaces 4 inches wide or less. We refer to this as the 2 x 4 rule, and it is clearly related to the size and shape of birds in flight. (See chart on page 47).

Designing a new structure to be bird-friendly does not require restricting the imagination or adding to the cost of construction. Architects around the globe have created fascinating and important structures that incorporate little or no dangerous glass. In some cases, inspiration has been borne out of functional needs, such as shading in hot climates; in others, from aesthetics. Being bird-friendly usually has been incidental. Now, however, buildings are being designed with birds in mind, and materials designed for this purpose are multiplying. Until recently, retrofitting existing buildings has been more difficult and costly than it is today. However, new materials are appearing and costs can be controlled by targeting problem areas rather than entire buildings.

Bird-friendly materials and design features often overlap in function with materials to control heat and light, security measures, and decorative design details. Bird-friendly building-design strategies also fall into three general categories, although all three could be combined in a single structure. These are:

1. Using minimal glass (Bronx Call Center, U.S. Mission to the United Nations)
2. Placing glass behind some type of screening (de Young Museum, Cooper Union)
3. Using glass with inherent properties that reduce collisions (Brooklyn Botanic Garden Visitors Center; Student Center at Ryerson University, Toronto; and Cathedral of Christ the Light)

Netting, Screens, Grilles, Shutters, Exterior Shades

There are many ways to combine the benefits of glass with bird-friendly design by incorporating elements that preclude collisions while providing light and views. Some architects have designed decorative façades that wrap entire structures. Decorative grilles are also part of many architectural traditions. Exterior, motorized solar screens and shades are effective at controlling heat and light, increase security, and can be adjusted to maximize view or bird and sun protection at different times. Netting, grilles, and shutters are common elements that can make glass safe for birds on buildings of any scale. They can be used in retrofit or be an integral part of an original design and can significantly reduce bird mortality.

(Opposite) The external glass screen on the GSA Regional Field Office in Houston, Texas, designed by Page Southerland Page, helps control heat but also reduces the likelihood of collisions. Photo by Timothy Hursley

The Brooklyn Botanic Garden's Visitors Center, designed by Weiss/Manfredi, was intended to be bird-friendly from its inception—a challenge, as it makes extensive use of glass. Photo @ Alber Vecerka, ESTO

Glass walls and doors at the Brooklyn Botanic Garden's Visitors Center include a custom fritting pattern that meets bird-friendly criteria. Monitoring for collisions after the building opened indicates that the design was successful. Photo by Christine Sheppard, ABC

Overhangs block viewing of glass from some angles, but do not necessarily eliminate reflections. Photo by Christine Sheppard, ABC

Reflections in this angled façade can be seen clearly over a long distance, and birds can approach the glass from any angle. Photo by Christine Sheppard, ABC

Before the current age of unopenable windows, screens protected birds in addition to serving their primary purpose of keeping bugs out. Screens are still among the most cost-effective methods for protecting birds, and, if insects are not an issue, nearly invisible netting can often be installed. Screens and netting should be installed at some remove from the window so that the impact of a strike does not carry birds into the glass. Several companies sell screens that can be attached with suction cups or eye hooks for small areas of glass. Others specialize in much larger installations. (Find sources at collisions.abcbirds.org).

Awnings and Overhangs

Overhangs have been frequently recommended to reduce collisions. However, there are many situations in which overhangs do not eliminate reflections and only block glass from the view of birds flying above. They are thus of limited effectiveness as a general strategy. Overhangs work best when glass is shadowed from all sides. Functional elements such as balconies and balustrades can block the view of glass, protecting birds while providing an amenity for residents.

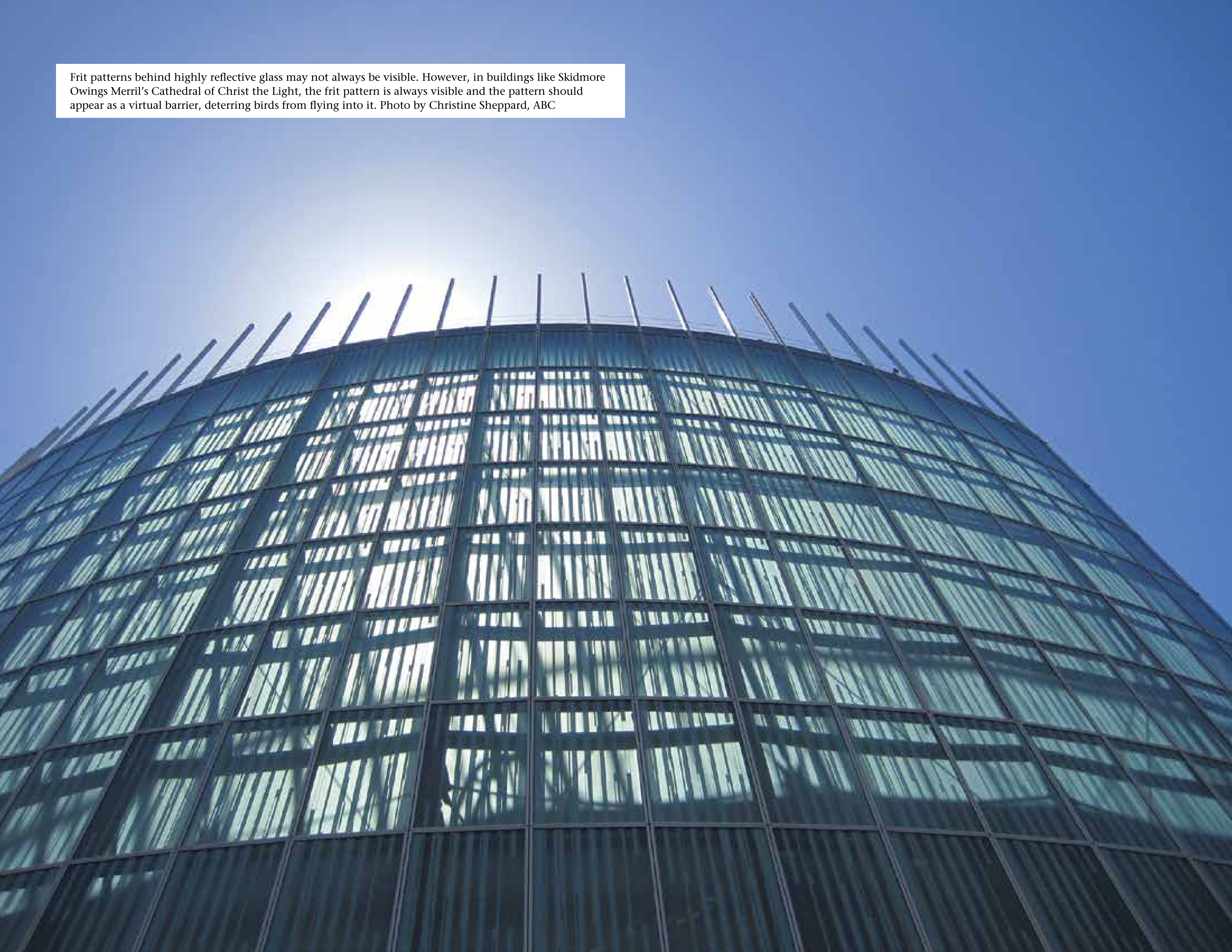
Angled Glass

In a study (Klem et al., 2004) comparing bird collisions with vertical panes of glass to those tilted 20 or 40 degrees, the angled glass resulted in less mortality. Klem speculated that this was because the glass reflected the ground, not vegetation. Using angled glass has become a common recommendation as a bird-friendly feature. However, while angled glass may be useful in special circumstances, the birds in the study were flying parallel to the ground from nearby feeders, hitting the glass at acute angles, with less force than a perpendicular strike. In most situations, however, birds may approach glass from any angle.

Patterns on Glass

Ceramic dots, other types of "frits," and other materials can be screened, printed, or otherwise applied to glass surfaces. This is often done to reduce the transmission of light and heat and can also provide design detail. In some cases, frit patterns are hardly visible, but when designed according to the 2 x 4 rule (see p. 47), patterns on glass can also prevent bird strikes. Patterns on the outside surface of glass deter collisions most effectively because they are always visible, even with strong reflections. This type of design, useful primarily for new construction, is currently more common in Europe and

A custom frit pattern was designed by Ennead Architects for Vassar College's Bridge for Laboratory Sciences building. Elements of the pattern occur on two separate surfaces, increasing visibility to birds in flight, who will see a constantly changing pattern that may appear to move. Photo by Christine Sheppard, ABC



Frit patterns behind highly reflective glass may not always be visible. However, in buildings like Skidmore Owings Merril's Cathedral of Christ the Light, the frit pattern is always visible and the pattern should appear as a virtual barrier, deterring birds from flying into it. Photo by Christine Sheppard, ABC

While some internal fritted glass patterns can be overcome by reflections, Frank Gehry's IAC headquarters in Manhattan is so dense that the glass appears opaque. Photo by Christine Sheppard, ABC

Ornilux Mikado's pattern reflects UV wavelengths. The spiderweb effect is visible only from very limited viewing angles. Photo courtesy of Arnold Glass

Asia, but is being offered by an increasing number of manufacturers in the United States. New technologies allowing printing of ceramic inks on the outside surface of glass may greatly increase options for bird-friendly design in the U.S.

More commonly, frit is applied to an internal surface of insulated glass units. This type of design may not be visible if the amount of light reflected by the frit is insufficient to overcome reflections on the outside surface of the glass or if frit is applied as dots below the visual threshold of birds. Some internal frits may only help break up reflections when viewed from some angles and in certain light conditions. However, with the right combination of surface reflectivity and frit application, a pattern on an inside surface can still be effective. The headquarters of the internet company IAC in New York City, designed by Frank Gehry, is composed entirely of fritted glass, most of high density and always visible. No collision mortalities have been reported at this building after two years of monitoring by New York City Audubon. FXFOWLE's Jacob Javits Center, also in Manhattan, reduced collisions by as much as 90% with a renovation that eliminated some dangerous glass and replaced other glass with a visible frit pattern. Another example of a visible internal frit pattern is seen in Skidmore Owings Merril's Cathedral of Christ the Light in Oakland, California.

UV Patterned Glass

Songbirds, gulls, parrots, and other birds can see into the ultraviolet (UV) spectrum of light, a range largely invisible to humans (see page 41). Other bird types, including raptors, kingfishers, hummingbirds, and pigeons, are less sensitive to UV. Ultraviolet reflective and/or absorbing patterns "invisible to humans but visible to birds" are frequently suggested as the optimal solution for many bird collision problems, but few such products are available commercially as of 2015. Progress in development of bird-friendly UV glass has been slow, but with legislation in multiple locations mandating bird-friendly design, glass manufacturers and distributors, as well as window-film manufacturers, are taking an active role in developing new solutions for this application. Research indicates that UV patterns need strong contrast to be effective, especially in the early morning and late afternoon, when UV in sunlight is at low levels. However, UV patterns may be ineffective for many species that have been reported as victims of collisions with glass, including hummingbirds, flycatchers, American Woodcock, and woodpeckers.

Opaque and Translucent Glass

Opaque, etched, stained, or frosted glass and glass block are excellent options to reduce or eliminate collisions, and many attractive architectural applications exist. They can be used in retrofits but are more commonly used in new construction. Frosted glass is created by acid etching or sandblasting transparent glass. Frosted areas are translucent, but various finishes are available with differing levels of light transmission. An entire surface can be frosted, or frosted patterns can be applied. Patterns should conform to the 2 x 4 rule described on page 47. For retrofits, glass also can be frosted by sandblasting on site. Stained glass is typically seen in relatively small areas but can be extremely attractive and is not conducive to collisions. Glass block is versatile, can be used as a design detail or primary construction material, and is also unlikely to cause collisions. Another promising material is photovoltaic glass, which has been used in stained-glass windows and highway noise barriers. This solution is especially interesting, because

The Wexford Science and Technology Building in Philadelphia, designed by Zimmer, Gunsul, Frasca, uses translucent glass to provide light without glare, making it safe for birds. Photo courtesy of Walker Glass transparent highway noise barriers can cause collisions, and such barriers are beginning to be installed in the United States.

Window Films

Most patterned window films were initially intended for use inside structures as design elements or for privacy. Now, outside surface applications intended to reduce bird collisions are coming onto the market, and some have proved highly effective and popular. The oldest such product creates an opaque white surface on the outside of glass that still permits viewing from the inside. Patterns can be printed on this material, although images of trees and other habitat are not recommended.

A film with a pattern of narrow, horizontal stripes has eliminated collisions at the Philadelphia Zoo Bear Country exhibit for over five years (see photo opposite) and has been similarly successful in other installations when applied to outside surfaces of glass. In these cases, the response has been positive. Another option is to apply vinyl patterns like window film but with the transparent backing removed.

Solutions Applied to Interior Glass

Light colored shades have been recommended as a way to deter collisions. However, when visible, they do not effectively reduce reflections, and reflections may make them completely invisible. Closed blinds have the same problems, but if visible and partly open, they can produce the appearance of a 2 x 4 pattern. If an exterior solution is not possible and tape or sticky notes are applied to the inside of windows, be sure to check the windows several times a day to ensure that these materials are visible.

Decals and Tape

Decals are probably the most familiar solution to bird collisions, but their effectiveness is widely misunderstood. Birds do not recognize decals as

A Zen Wind Curtain is an inexpensive but extremely effective way to deter collisions. Lengths of parachute cord or similar materials are strung vertically, every four inches, in front of problem glass, creating both a visual and a physical barrier. Photo by Glenn Phillips

This window at the Philadelphia Zoo Bear Country exhibit was the site of frequent bird collisions until window film was applied. Collisions have been eliminated for over five years, with no complaints from visitors about visibility of bears! Photo courtesy of the Philadelphia Zoo

ABC BirdTape

ABC, with support from the Rusinow Family Foundation, has produced ABC BirdTape to make home windows safer for birds. This easy-to-apply tape lets birds see glass while letting you see out, is easily applied, and lasts up to four years. For more information, visit abcbirdtape.org

Photos by Dariusz Zdziebkowski, ABC

silhouettes of falcons, spiderwebs, or other natural objects, but simply as obstacles that they may try to fly around. Decals can be very effective if applied following the 2 x 4 rule on the outside of glass, but in general, they must be replaced frequently, at least annually. Tape is generally more cost effective and quicker to apply, but most household tapes don't stand up well to the elements. Tape intended to last for several years on the outside of windows has become commercially available and is effective when applied following the 2 x 4 guide.

The Consilium Towers, a mirror-glass complex in Toronto, once killed thousands of birds each year. After being taken to court, its owners retrofitted the lower 60 feet of glass with a Feather Friendly dot pattern that has greatly reduced bird mortality.

Reflected in this glass is Michael Mesure, the founder of Toronto's Fatal Light Awareness Program. Photos by Christine Sheppard, ABC

Temporary Solutions

In some circumstances, especially for homes and small buildings, quick, low-cost, temporary solutions, such as making patterns on glass with paint, stickers, or even post-its, can be very effective in the short term. Even a modest effort can reduce collisions. Such measures can be applied when needed and are most effective following the 2 x 4 rule. (For more information, see ABC's flyer "You Can Save Birds from Flying into Windows" and other sources at collisions.abcbirds.org).

ABC BirdTape was effective at the Forest Beach Migratory Reserve in Wisconsin (left), and also performed well in tunnel tests conducted in Austria. Photo by Christine Sheppard, ABC

REMEDIATION CASE STUDY: Javits Center

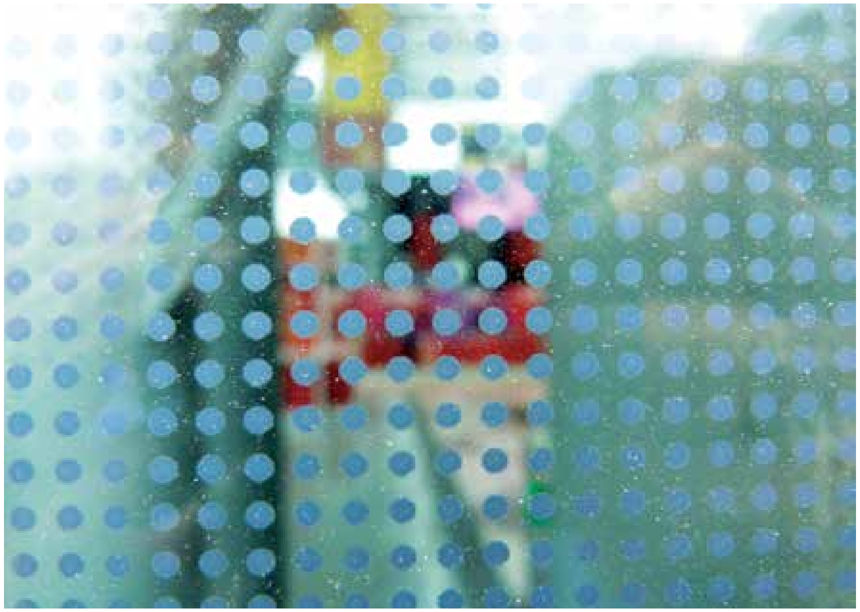
In 2009, the New York City Audubon Society identified the Jacob K. Javits Convention Center as having one of the highest bird-collision mortality rates in New York City.

A major renovation and expansion, designed by the bird-friendly architectural firm of FXFOWLE, was completed in 2014. Some especially deadly glass at street level was replaced with opaque panels. Large panes of clear fritted glass with varying surface characteristics were brought to the site and compared to find the right combination for birds and people.

A 6.75-acre green roof, with adjacent translucent glass, crowns the building and is already providing resources for birds.

Best of all, collisions at the now much larger site have been reduced by 90%.

From a distance, the Javits Center looks like a potential threat to birds.



At close range, a visible pattern of frit dots breaks up reflections, making the glass safe for birds. Photos by Glenn Phillips

Light: Problems and Solutions

Fixtures such as these reduce light pollution, saving energy and money and reducing negative impacts on birds. Photo by Dariusz Zdziebkowski, ABC

Birds evolved complex complementary systems for orientation and vision long before humans developed artificial light. We still have much more to learn, but recent science has begun to clarify how artificial light poses a threat to birds, especially nocturnal migrants. Although most glass collisions take place during daylight hours, artificial lighting at night plays a role in the number and distribution of collisions across the built environment. Unfortunately, the details of how birds respond to night lighting are less well understood than has been commonly believed.

Many collision victims, especially songbirds, are ordinarily active by day and have eyes specialized for color vision and bright light. But although they migrate at night, these birds have poor night vision. Instead, they have magnetic senses that allow them to navigate using the Earth's magnetic field. One of these is located in the retina and requires dim blue natural light to function. Red wavelengths found in most artificial light have been shown to disrupt that magnetic sense. Studies in Germany and Russia have documented birds flying through beams of light and diverting from their course anywhere from a few degrees to a full circle. Areas with significant light pollution may be completely disorienting to birds.

Birds are attracted to relative brightness, and by day often orient toward the sun. If a songbird flies into a home, darkening the room and opening a bright window is the best way to release it. Birds are thought to be attracted to artificial light at night, but we don't know what light level at what distance is sufficient to cause attraction or other behavioral impacts. Gauthreaux and Belser, discussing impacts of night lighting on birds, speculated that in fact, birds affected by night lighting may simply be on course to pass over the lights, not necessarily attracted from a distance. Marquenie and Van de Laar, studying birds and lights on a drilling rig in the North Sea, estimated that when all the lights on the platform were lit, they affected birds up to 3 to 5 kilometers away, causing many to circle the platform.

The science is inconclusive: Lights may only impact birds as they end a migratory stage and come down close to the built environment, or lights may divert birds that would ordinarily pass by. Bad weather can cause birds to fly lower and closer to lights, while also eliminating any visual cues. The interactions that produce correlations between building light emissions and collisions may take place at relatively close range. Once birds come close to a light source, the electromagnetic radiation actively interferes with their magnetic orientation mechanism.

Overly lit buildings waste electricity and increase greenhouse gas emissions and air pollution levels. They also pose a threat to birds. Photo by Matthew Haines

Houston skyline at night. Photo by Jeff Woodman

Examples of Acceptable/Unacceptable Lighting Fixtures

Reprinted courtesy of DarkSkySociety.org

Some combination of attraction and disorientation may result in larger numbers of birds in the vicinity of brighter buildings and thus, by day, in more collisions. Interestingly, there seem to be no reports of lights attracting or disorienting migrants as they take off on a new migratory stage.

There has been a tendency to associate collision events with very tall structures, though published reports clearly document impact from light at all levels. Early reports of this phenomenon came from lighthouses. Contemporary reports of light-associated circling events are common at oceanic drilling rigs, and disoriented birds have been reported at night skiing sites. A study in Toronto, using the number of lighted windows on a series of buildings as an index of emitted light, found that the amount of light emitted, not the height of the building, was the best predictor of bird mortality.

Solutions

Poorly designed or improperly installed outdoor fixtures add over $1 billion to electrical costs in the United States every year, according to the International Dark Skies Association. Recent studies estimate that over two-thirds of the world's population can no longer see the Milky Way, just one of the nighttime wonders that connect people with nature. Glare from poorly shielded outdoor light fixtures decreases visibility and can create dangerous conditions, especially for older people, and recent studies suggest that long-term exposure to night lighting can increase the risk of breast cancer, depression, diabetes, obesity, and sleep disorders. Together, the ecological, financial, and cultural impacts of excessive building lighting are compelling reasons to reduce and refine light usage.

Reducing exterior building and site lighting has proven effective at reducing mortality of night migrants at individual buildings, but achieving overall reduction in collisions will require applying those principles on a wider scale. At the same time, these measures reduce building energy costs and decrease air and light pollution. Efficient design of lighting systems plus operational strategies to reduce light trespass or "spill light" from buildings while maximizing useful light are both important strategies. In addition, an increasing body of evidence shows that red light and white light (which contains red wavelengths) particularly confuse birds, while green and blue light may have far less impact.

Light pollution is largely a result of inefficient exterior lighting, and improving lighting design usually produces savings greater than the cost of changes. For example, globe fixtures permit little control of light, which shines in all directions, resulting in a loss of as much as 50% of energy, as well as poor illumination. Cut-off shields can reduce lighting loss and permit use of lower powered bulbs. Most "vanity lighting" is unnecessary. However, when it is used, down-lighting causes less trespass than up-lighting. Where light is needed for safety and security, reducing the amount of light trespass outside of the needed areas can help by eliminating shadows. Spotlights and searchlights should not be used during bird migration. Communities that have implemented programs to reduce light pollution have not found an increase in crime.

Using automatic controls, including timers, photosensors, and infrared and motion detectors, is far more effective than relying on employees turning off lights. These devices generally pay for themselves in energy savings in less than a year. Workspace lighting should be installed where needed, rather than in large areas. In areas where indoor lights will be on at night, minimize perimeter lighting and/or draw shades after dark.

Switching to daytime cleaning of office buildings is a simple way to reduce lighting while also reducing costs.

Lights Out Programs

Despite the complexity of reducing bird collisions with glass, there is one simple way to decrease mortality: turn lights off. Across the United States and Canada, "Lights Out" programs at the municipal and state levels encourage building owners and occupants to turn out lights visible from outside during spring and fall migration. The first of these, Lights Out Chicago, was started in 1995, followed by Toronto in 1997. The programs themselves are diverse. Some are directed by environmental groups, others by government departments, and still others by partnerships of organizations. Participation in most, such as Houston's, is voluntary. Minnesota mandates turning off lights in state-owned and leased buildings.

Many jurisdictions have monitoring components. Monitoring programs can provide important information in addition to quantifying collision levels and documenting solutions. Ideally, lights-out programs would be in effect year-round and be applied widely, saving birds and energy costs and reducing emissions of greenhouse gases. ABC stands ready to help develop new programs and to support and expand existing programs.

Powerful beams of light, even in a landscape of urban light pollution, can entrap migrating birds, seen here circling in the beams of the 9/11 Memorial Tribute in Light in New York City. Because birds may circle for hours, monitors watch all night, and the light beams are temporarily turned off to release large accumulations of birds. Photo by Jason Napolitano

Solutions: Policy

Legislation

Changing human behavior is generally a slow process, even when the change is uncontroversial. Legislation can be a powerful tool for modifying behavior. Conservation legislation has created reserves, reduced pollution, and protected threatened species and ecosystems. Policies that promote bird-friendly design and reduction of light pollution have recently proliferated across the United States and Canada, following the early examples of Toronto and San Francisco. They vary considerably in scope and detail, often reflecting local politics. (A real-time database of ordinances and other instruments mandating or promoting bird-friendly action, including links to source language, can be found at collisions.abcbirds.org).

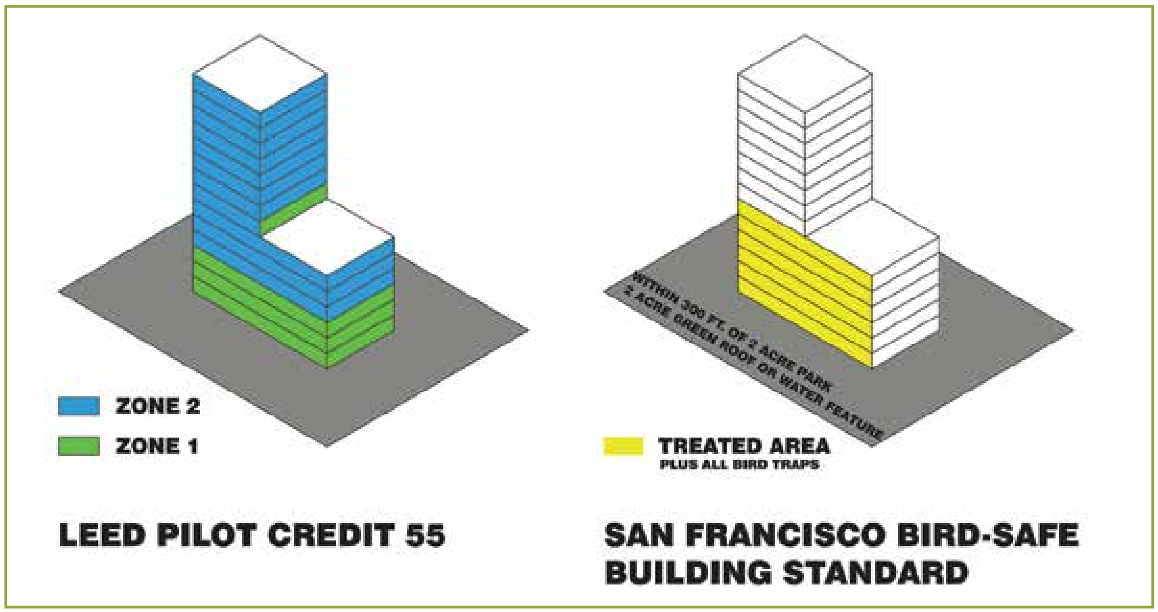
An early challenge in creating effective legislation was the lack of objective measures that architects could use to accomplish their task. For example, a common recommendation, to "increase visual noise," because it was unquantified and undefined, made it difficult for architects and planners to know whether a particular design complied with requirements. Material testing (see p. 45) has made it possible to assign relative threat factors to various building façade materials and to use those scores to create quantitative guidelines and mandates.

The illustration to the right broadly compares San Francisco's Bird-safe Building Standard with LEED Pilot Credit 55, both based on the use of materials with quantified threat levels. San Francisco's standard applies generally to new construction and is restricted to façades within 300 feet of a two-acre park or pond. The LEED credit is intentionally very flexible. It applies to all building facades and allows for restricted amounts of high-threat glass, or larger amounts of bird-friendly glass. Because birds are found throughout the built environment, ABC prefers the LEED model. (ABC's model legislation can be found on page 35.)

Bird lovers across the country are proposing bird-friendly design ordinances at both local and state levels. ABC is ready to actively support such efforts. Both mandatory and voluntary instruments can be effective. Voluntary guidelines are easier to modify if they prove to have unintended consequences and can lead to a mandate, but can also be ignored. Generally ABC recommends mandatory guidelines, beginning with a small subset of buildings and expanding as community support increases and resistance decreases.

Incorporating bird-friendly design issues into local sustainability policies is another way to drive change. An interesting example of this is the Fairfax County, Virginia, proffer system. New construction projects are required to address a series of sustainability issues, including potential bird mortality, and either to describe

The design of the Grange Insurance Audubon Center in Columbus, Ohio, includes many panels of glass, fritted with the silhouettes of species of birds in flight. Photo by Christine Sheppard, ABC



courtesy of Deborah Laurel

(Opposite) United States Capitol, Washington, D.C. Photo by stock.xchng

For its new Visitors Center in Sempach, opened in May 2015, the Swiss Ornithological Institute designed a mandala from bird silhouettes (below) that was applied on the inside of all glass using digital printing. The design provides 40-50% coverage and generates much discussion among visitors, an achievement second only to preventing bird collisions.

Photos by Hans Schmid

how these will be addressed by the project or explain why such action is not possible.

Priorities for Policy Directives

ABC generally recommends against attempting to map locations where bird-friendly design is required because birds can be found in almost every environment, even in seemingly inhospitable ones. However, there may be occasions when it is necessary to compromise on the scope of legislation. In such cases, it must be recognized that proximity to undeveloped land, agricultural areas, parks, and water often correspond to increased bird populations and therefore increased risk of collisions. In addition, areas located in between landscape features desirable to birds may also pose higher risks. For example, in New York City some evidence suggests that birds approach Central Park from due south during spring migration, creating a greater risk zone directly south of the park. Also, building features such as green roofs should be considered when determining greater risk zones for policy purposes.

Sustainability Rating Programs

Another driver of bird-friendly policies consists of sustainability rating programs like the Green Building Council's LEED program, Green Globes, Living Building Challenge, and others. There is general agreement that sustainable buildings should not kill birds. This tenet appears with differing levels of robustness in different systems, with the most specific being the LEED program, which grants Pilot Credit 55: Bird Collision Deterrence. The credit is calculated using a weighted average of the relative threat rating of each material on a building's façade. The credit has attracted a lot of attention, with many projects applying for it. The new Vassar Bridge for Laboratory Sciences on the cover of this publication was one of the first to be designed with the credit in mind and to earn the credit.

Because a number of glass-walled buildings have been awarded LEED certification at the highest level, at one point there was concern that sustainable design was not compatible with bird-friendly design. This was ironic, as in addition to providing natural light, glass on sustainable buildings is intended to link people inside with the natural world outside. However, according to both ASHRAE and ICC, costs for heating and cooling increase when total glass surface exceeds 30-40% of the total building envelope, depending on climate. This is more than sufficient for providing light and views when glass placement is considered thoughtfully. This is a great place to start the design of a bird-friendly structure.

The façade of the WÜRTH Building in Switzerland is mostly glass, laminated with a fabric that is black on the inside but aluminium-coated outside. The inner surface delivers good visibility, and the fabric provides shade and interesting visual effects outside. Preliminary studies by the Swiss Ornithological Institute suggest that the materials used in this building may also deter bird collisions. Photo by Hans Schmid

Model Ordinance for Bird-Friendly Construction

[ORDINANCE Name] Sponsored by:
[list names]

WHEREAS, birds provide valuable and important ecological services,

WHEREAS, [location] has recorded [ ] species of resident and migratory bird species,

WHEREAS, birding is a hobby enjoyed by 64 million Americans and generates more than $40 billion a year in economic activity in the United States,

WHEREAS, as many as one billion birds may be killed by collisions with windows every year in the United States,

WHEREAS, reducing light pollution has been shown to reduce bird deaths from collisions with windows,

WHEREAS, new buildings can be designed to reduce bird deaths from collisions without additional cost,

WHEREAS, there exist strategies to mitigate collisions on existing buildings,

WHEREAS, more than 30% glass on a façade usually increases costs for heating and cooling

WHEREAS, bird-friendly practices often go hand-in-hand with energy efficiency improvements,

And WHEREAS [any additions specific to the particular location]

NOW, THEREFORE, BE IT ORDAINED, by [acting agency] [title of legislation and other necessary language]

(a) In this section the term "Leadership in Energy and Environmental Design (LEED)" means a green building rating system promulgated by the United States Green Building Council (USGBC) that provides specific principles and practices, some mandatory but the majority discretionary, that may be applied during the design, construction, and operation phases, which enable the building to be awarded points from reaching present standards of environmental efficiency so that it may achieve LEED certification from the USGBC as a "green" building.

b) [acting agency] does hereby order [acting department] to take the steps necessary to assure that all newly constructed buildings and all buildings scheduled for capital improvement are designed, built, and operated in accordance with the standards and requirements of the LEED Green Building Rating System Pilot Credit 55: Bird Collision Deterrence.

(c) The USGBC releases revised versions of the LEED Green Building Rating System on a regular basis; and [acting department] shall refer to the most current version of the LEED when beginning a new building construction permit project or renovation.

(d) New construction and major renovation projects shall incorporate bird-friendly building materials and design features, including, but not limited to, those recommended by the American Bird Conservancy publication *Bird-Friendly Building Design*.

(e) [acting department] shall make existing buildings bird-friendly where practicable.

The Studio Gang's Aqua Tower in Chicago was designed with birds in mind. Strategies included fritted glass and balcony balustrades. Photo by Tim Bloomquist

The Science of Bird Collisions

Hundreds of species of birds are killed by collisions. These birds were collected by monitors with FLAP in Toronto, Canada. Photo by Kenneth Herdy

Magnitude of Collision Deaths

The number of birds killed by collisions with glass every year is astronomical. Quantifying mortality levels and impacts on populations has been difficult, however. Until recently, local mortality studies—despite producing valuable information—aimed more at documenting mortality than quantifying it, and did not follow rigorous protocols. Loss *et al*. (2012) created methodology and techniques of analysis to determine the magnitude of anthropogenic mortality, using existing data sets. The authors comprehensively acquired published and unpublished data sets on collisions with buildings (Loss *et al*., 2013). Data sets were filtered using a variety of criteria to ensure that they could be used in single analyses. Loss *et al*. (2014b) have also comprehensively described how to collect meaningful data on collisions.

The authors calculated the median annual mortality at homes at 253 million, or 2.1 birds per structure. Urban residences without feeders account for 33% of this mortality cumulatively, as there are more such residences, even though residences with feeders produce more collisions individually. Rural residences without feeders account for 31% of residential mortality, followed by urban residences with feeders (19%) and rural residences with feeders (17%). Median mortality at low-rise buildings (4 to 11 stories), calculated from two data sets, was averaged as 339 million, or 21.7 birds per building. High-rises, although collectively causing the least mortality (508,000), individually had the highest median rate of 24.3 bird collisions per building. Combining all building classes produces an estimate of 365 and 988 (median 599) million birds killed annually in the United States.

Machtans, *et al*. (2013) estimated that about 25 million (ranging from 16 to 42 million) birds are killed by colliding with windows in Canada annually, with 90% of building-related mortalities caused by houses, slightly less than 10% by low-rise buildings, and approximately 1% by tall buildings. In both cases, the total mortality caused by houses is a function of their large number compared to the two other classes of buildings.

Previously, Dunn (1993) surveyed 5,500 people who fed birds at their homes and recorded window collisions. She derived an estimate of 0.65-7.7 bird deaths per home per year for North America. Klem (1990) estimated that each building in the United States kills one to 10 birds per year. Using 1986 U.S. census data, he combined numbers of homes, schools, and commercial buildings for a maximum total of 97,563,626 buildings, producing an estimate of 100 million to one billion birds killed annually.

Klem *et al*. (2009a) used data from New York City Audubon's monitoring of 73 Manhattan building façades to estimate 0.5 collision deaths per acre per year in urban environments, for a total of about 34 million migratory birds annually colliding with city buildings in the

This Barn Swallow illustrates the type of acrobatic flying that may keep swallows from being frequent collision victims. If birds do identify glass as a barrier at close range, perhaps by sound or air movements, most species may be unable to react fast enough to avoid striking the surface. Photo by Keith Ringland

A sample of collision victims from Baltimore. Photo by Daniel J. Lebbin, ABC

Sharp-shinned Hawk. Photo by Ted Ardley

United States. However, there could be major differences in collision patterns in cities across the United States, and these numbers should be confirmed using data from additional locations.

In *The American Bird Conservancy Guide to Bird Conservation* (Lebbin *et al.*, 2010) the authors state "…we have reached a point in history when the impacts of human activities are so profound and far-reaching that from now on, it will always be impossible to untangle the completely natural declines from those that are partially or completely anthropogenic. From a conservation standpoint, it is largely irrelevant, anyway. Any human-caused stress that we can alleviate from a declining species can potentially benefit its population, and we should take action to lessen that stress if we can." This is abundantly true for bird mortality from glass because there are actions that many, if not most, individuals can take themselves, directly, to reduce the toll taken by existing glass.

Patterns of Mortality

It is difficult to get a complete and accurate picture of avian mortality from collisions with glass. Collision deaths can occur at any time of day or year. Monitoring programs focus on cities, and even intensive monitoring programs cover only a portion of a city, usually visiting the ground level of a given site at most once a day and often only during migration seasons. Many city buildings have stepped roof setbacks that are inaccessible to monitoring teams. Some studies have focused on reports from homeowners on backyard birds (Klem, 1989; Dunn, 1993) or on mortality of migrants in an urban environment (Gelb and Delacretaz, 2009; Klem *et al.*, 2009a; Newton, 1999). Others have analyzed collision victims produced by single, large-magnitude incidents (Sealy, 1985) or that have become part of museum collections (Snyder, 1946; Blem *et al.*, 1998; Codoner, 1995). There is general support for the fact that birds killed in collisions are not distinguished by age, sex, size, or health (for example: Blem and Willis, 1998; Codoner, 1995; Fink and French, 1971; Hager *et al.*, 2008; Klem, 1989), but the majority of work has focused on data taken during migratory periods, primarily east of the Mississippi River.

Species at Risk

Snyder (1946), examining window collision fatalities at the Royal Ontario Museum, noted that the majority were migrants and "tunnel flyers"—species that frequently fly through small spaces in dense, understory habitat. Conversely, resident species well adapted to and common in urban areas, such as the House Sparrow and European Starling, are not prominent on lists of fatalities, possibly because individuals surviving their first collision may teach offspring to avoid windows.

It is well known that zoo birds in exhibits with glass walls can and do learn about specific pieces of glass, but birds do not learn about glass as a general concept.

Dr. Daniel Klem maintains running totals of the number of species reported in collision events in countries around the world. (This information can be found at http://tinyurl.com/ob3nc4s). In 2015, the site identifies 868 species globally, with 274 from the United States. The intensity of monitoring and reporting programs varies widely from country to country, however.

Hager *et al.* (2008) compared the number of species and individual birds killed at buildings at Augustana College in Illinois with the density and diversity of bird species in the surrounding area. The authors concluded that the total window area, the habitat immediately adjacent to windows, and behavioral differences among species were the best predictors of mortality patterns, rather than the mere size and composition of the local bird population. Kahle *et al*. (2015) reached similar conclusions in an analysis of five years of data at the California Academy of Sciences, also finding that migrants do not make up the preponderance of birds killed and that males are overrepresented relative to their abundance in habitats adjacent to the museum. Dunn (1993), analyzing winter data from homes with bird feeders, found that the frequency distribution of birds at the feeders closely paralleled the distribution of species killed by nearby windows. Dunn found few collisions on windows of less than one square meter, and an increase in collisions with an increase in window size.

Species such as the White-throated Sparrow, Ovenbird, and Common Yellowthroat appear consistently on top 10 lists from urban areas. It is possible that these species respond more readily to light and thus are more likely to end migratory stages in the built environment, but this needs to be confirmed. Additionally, Loss *et al*. (2013) noted that Golden-winged Warbler, Painted Bunting, Canada Warbler, Wood Thrush), Kentucky Warbler, and Worm-eating Warbler—species identified as birds of conservation concern—were also disproportionately represented in building kills. Hager (2009) noted that window-strike mortality was reported for 45% of raptor species found frequently in urban areas of the United States and was the leading source of mortality for Sharp-shinned Hawks, Cooper's Hawks, Merlins, and Peregrine Falcons. Because most data on glass collisions are from the eastern half of the United States, these lists are presumably biased toward species occurring in that range.

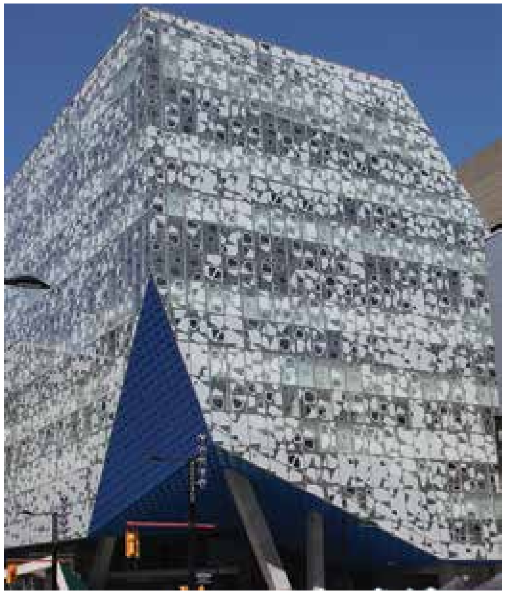
Common Yellowthroat. Photo by Owen Deutsch

Characteristics of Buildings

Amount of Glass

From a study of multiple buildings in Manhattan, Klem *et al*. (2009a) concluded that both the proportion and absolute amount of glass on a building façade best predict mortality rates, calculating that every increase of 10% in the expanse of glass correlates to a 19% increase in bird mortality in spring and 32% in fall. How well these equations predict mortality in other cities remains to be tested. Collins and Horn (2008), studying collisions at Millikin University in Illinois, concluded that total glass area and the presence/absence of large expanses of glass predicted mortality level. Hager *et al*. (2008, 2014) came to the same conclusion, as did Dunn (1993) and Kahle *et al*. (2015). However, the "patchiness" of glass across a façade—how many pieces, their size, how they are separated, etc. (another way of saying "visual noise")—has not yet been explored in detail but could be important.

The façade of the New York Times building, by FXFOWLE and Renzo Piano, is composed of ceramic rods, spaced to let occupants see out while minimizing the extent of exposed glass—good for controlling heat and light, and safe for birds. Photo by Christine Sheppard, ABC



Snohetta's Student Learning Centre at Ryerson University is one of the first constructed under Toronto's design law. Photo by Rick Ligthelm

Time of Day

Most monitoring programs focus on early morning hours to document mortality during migration, often starting monitoring routes at dawn, before sidewalks are cleared. This can, however, lead to the misperception that night-flying migrants are crashing into lighted buildings at night, or only in early morning, whereas in fact most collisions take place during the day. It should be noted that "dawn" is a time that varies among species (Thomas *et al.* (2002), with some bird species active before humans start to see light in the sky.

Hager and Craig (2014), in a study of resident population collisions in northwestern Illinois between June and early August, found that 66% of birds died between sunrise and 4:00 p.m., with no collisions between 4:00 p.m. and sunset. Delacretaz and Gelb (2006) found collisions from early morning until mid-afternoon, but with a peak during morning hours. This finding is confirmed by monitoring programs like that of Pennsylvania Audubon, where routes were followed three times in succession early each day, with birds found at each pass (Keith Russell, pers. comm.) and where people living or working in buildings report window strikes through afternoon hours (Olson, pers. comm).

Local Landscape

Gelb and Delacretaz (2006, 2009) evaluated data from collision mortality at Manhattan building façades. They found that sites where glass reflected extensive vegetation were associated with more collisions than glass reflecting little or no vegetation. Of the 10 buildings responsible for the most collisions, four were "low-rise." Klem (2009) measured variables in the space immediately associated with building façades in Manhattan as risk factors for collisions. Both increased height of trees and increased height of vegetation increased the risk of collisions in fall. Ten percent increases in tree height and the height of vegetation corresponded to 30% and 13% increases in collisions in fall. In spring, only tree height had a significant influence, with a 10% increase corresponding to a 22% increase in collisions. Confusingly, increasing "facing area," defined as the distance to the nearest structure, corresponded strongly with increased collisions in spring and with reduced collisions in fall. Presumably, vegetation increases risk both by attracting more birds to an area and by being reflected in glass.

Bayne *et al.* (2012) confirmed that the risk of bird–window collisions varies according to location (urban versus rural, home versus apartment, with or without feeders, and age of neighborhood). They used online surveys and determined that rural residences had more collisions than urban ones and residences with feeders had almost twice as many collisions as those without feeders. For urban dwellings, incidence of collisions increased with age of neighborhood, associated with presence of mature trees. Frequency of collisions varied seasonally: 24% in fall, 35% summer, 25% spring, 16% winter. Mortality patterns were similar: 26% fall, 31% summer, 26% spring, 17% winter. Forty-eight species were reported.

Hager *et al.* (2013) noted that estimates of bird-collision mortality often postulate a relatively constant range of collisions at all buildings (for example, Klem, 1990). However, they suggested that each building in a landscape has its own mortality "signature," based not only on characteristics of the structure but also on the distribution of resources throughout the local landscape, including land cover, habitat type, water, and pavement. Their protocol selected buildings at random and has recently been expanded to multiple other sites across North America.

Avian Vision and Collisions

Bird species like falcons are famous for their acute vision, but taking a "bird's-eye view" is much more complicated than it sounds. To start with, where human color vision relies on three types of sensors, birds have four, plus an array of color filters that together allow birds to discriminate between many more colors than people (Varela *et al.* 1993) (see figure this page).

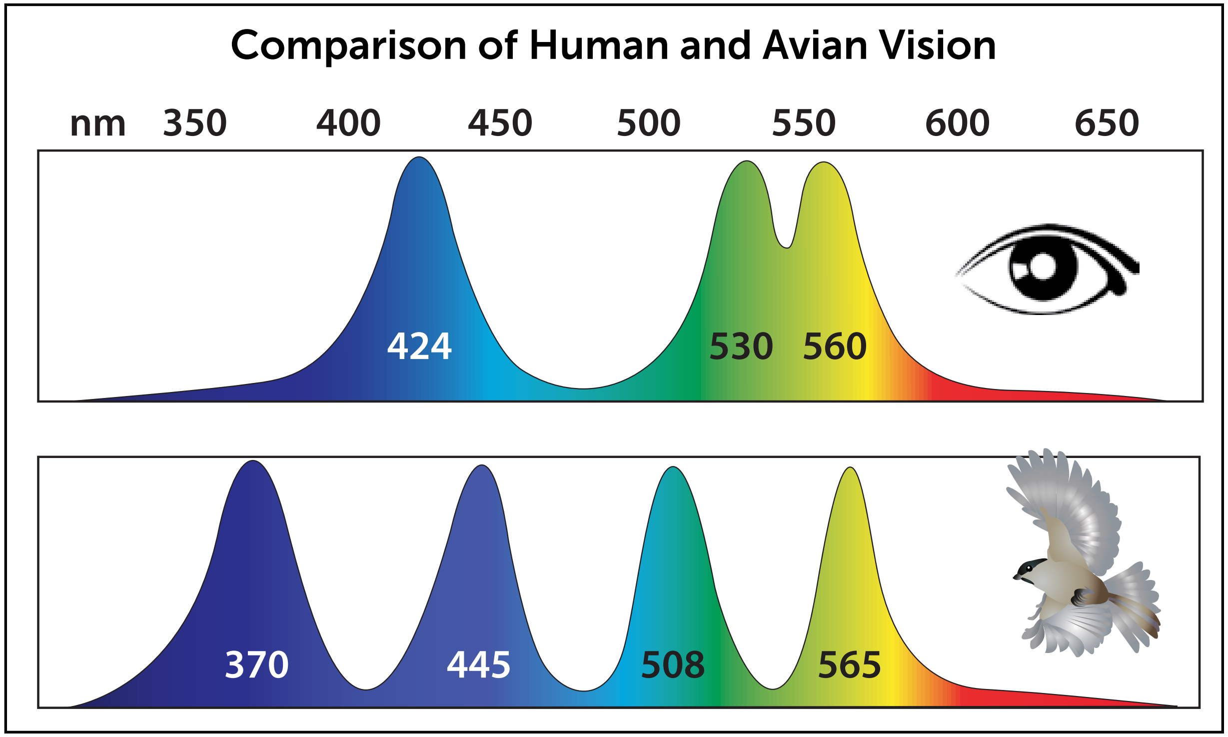
There is also variation in vision among different groups of birds. While some birds see only into the violet range of light, many birds, including most passerines (Ödeen and Håstad, 2003, 2013) see into the ultraviolet spectrum (UVS species).

Ultraviolet can be a component of any color (Cuthill *et al.* 2000). Whereas humans see red, yellow, or red + yellow, birds may see red + yellow, but also red + ultraviolet, yellow + ultraviolet, and red + yellow + ultraviolet—colors for which we have no names. Every object absorbs, reflects, and transmits ultraviolet light along with the other wavelengths in the visible spectrum. UV patterns on glass are often cited as desirable solutions to collisions—visible to birds but not to humans. However, aside from manufacturing complexities, many bird taxa that collide frequently with glass, including raptors, pigeons, woodpeckers, and hummingbirds, may not be able to perceive UV patterns (Håstad and Ödeen, 2014). Additionally, birds are often active in early morning, when UV light levels are low.

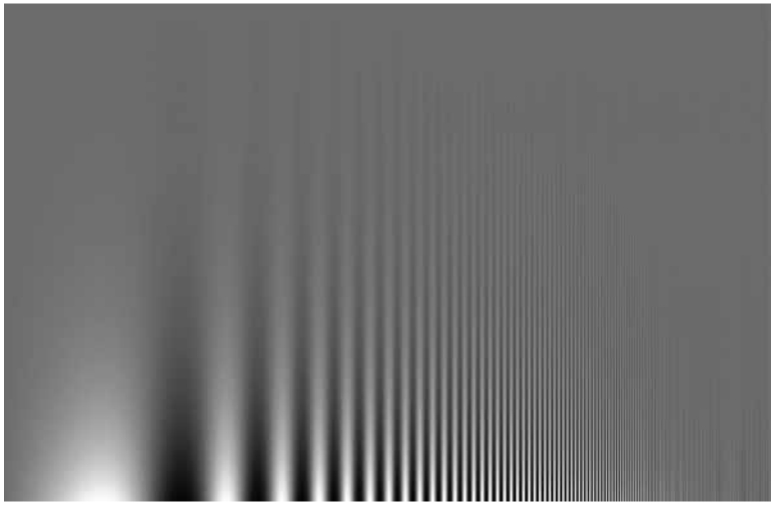
Humans and other primates have relatively flat faces, with eyes close together. The overlap of visual fields means that humans have good depth perception and a tendency to focus on what is ahead. Most birds have eyes at the sides of their heads, giving them excellent peripheral vision but poor depth perception, often limited to the length of their beaks, presumably to judge potential food items. They may be much less intent on what is in front of them (Martin 2011, 2012) but able to watch for potential predators to the side or behind them. Many species' most acute vision is to the side. Without much 3D vision, birds use a mechanism called "visual flow fields" to judge their speed and rate of progress in flight by the passage of environmental features to their sides (Bhagavatula *et al.* 2011). Collisions with glass may be partly a result of birds expecting open air ahead, combined with relatively poor forward vision.

Birds process images faster than humans; where we see continuous motion in a movie, birds would see flickering images (D'Eath, 1998; Greenwood *et al.* 2004; Evans *et al.* 2006). This speed helps many birds maneuver quickly in

Painted Bunting. Photo by Ted Ardley



Based on artwork by Sheri Williamson



Contrast sensitivity is a measure of the limit of visibility for low-contrast patterns. Each person's contrast sensitivity can be measured by the extent to which he or she can see the bars that form an arch in this photograph. The exact location of the peak of the curve varies with one's distance from the image; the area within the arch is larger when one is closer. For a given distance, the area under the arch is smaller for birds. Image courtesy of Izumi Ozawa, Berkeley Neuroscience Laboratory

response to unexpected obstacles as they fly through complex habitats. In one respect however—spatial contrast sensitivity—human vision outperforms avian (Ghim and Hodos, 2006). Contrast sensitivity is "the ability of the observer to discriminate between adjacent stimuli on the basis of their differences in relative luminosity (contrast) rather than their absolute luminances." Birds' lack of contrast sensitivity may be an impediment to creating signals to prevent collisions that are effective for birds but not visually intrusive to humans.

Avian Orientation and the Earth's Magnetic Field

In the 1960s, it was discovered that migrating birds possess the ability to orient themselves using cues from the sun, polarized light, stars, the Earth's magnetic field, visual landmarks, and possibly even odors to find their way. Exactly how this works—and it likely varies among species—is still being investigated. (For a comprehensive review of the mechanisms involved in avian orientation, see Wiltschko and Wiltschko, 2009).

The Earth's magnetic field can provide both directional and positional information. It appears that night-flying migrants, and perhaps all bird species, have magnetic field-detecting structures in the retina of the eye that depend on light for function and provide compass orientation. This magnetic sense is wavelength-dependent. Experiments have shown that the compass is disrupted by long wavelength light but requires low-intensity short wavelength light (Wiltschko *et al.* 2007). This research has taken place only in laboratories, and it is important to determine how it translates to the real world.

In addition, anthropogenic electronic noise, found throughout urban environments, has recently been shown to disrupt magnetic compass orientation in European Robins at very low intensities (Engels *et al.* 2014). This finding may have serious implications for strategies aimed at reducing collisions by reducing artificial night lighting alone and should be a priority for additional work.

A second magnetic mechanism, providing birds with positional information, has been postulated, but its details have not been determined. (For a review of magnetoreception and its use in avian migration, see Mouritsen, 2015.)

Birds and Light Pollution

The earliest reports of mass avian mortality caused by lights were from lighthouses, but this source of mortality essentially disappeared when steady-burning lights were replaced by rotating beams (Jones and Francis, 2003). Flashing or interrupted beams apparently allowed birds to continue to navigate, which has also been found more recently at cell towers with strobe lighting (Gehring *et al.* 2009). The emphasis on tall structures by Lights Out programs ignores the fact that light from many sources, from urban sprawl to parking lots, can affect bird behavior and potentially strand birds in the built environment (Gauthreaux and Belser, 2006). Evans-Ogden (2002) showed that light emission levels of 16 buildings, ranging in height from 8 to 72 floors and indexed by the number of lighted windows observed at night, correlated directly with bird mortality, and that the amount of light emitted by a structure was a better predictor of mortality level than building height, although height was a factor. Parkins *et al.* (2015) made similar findings.

Mass collision events of migrants associated with light and often with fog or storms have been frequently reported (Weir, 1976; Avery *et al.* 1977; Avery *et al.* 1978; Crawford, 1981a, 1981b; Gauthreaux and Belser, 2006; Newton, 2007). But these are no longer the predominant sources of mortality, possibly because the night landscape has changed radically since early reports of mass collision events at tall structures like the Washington Monument and Statue of Liberty. These and other structures were once beacons in areas of relative darkness, but are now surrounded by square miles of light pollution. While collisions at structures like cell towers continue to take place at night, the majority of collisions with buildings now take place during the day. (Hager, 2014; Kahle *et al.*, 2015; Olson, pers. comm.)

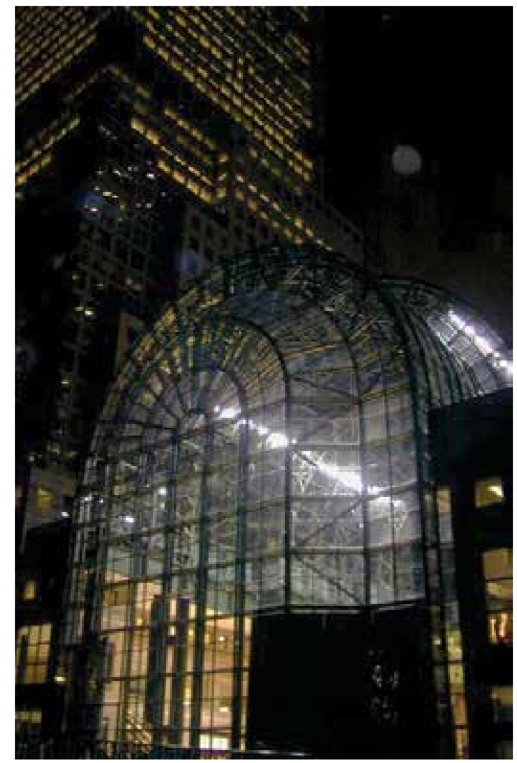
Patterns of light intensity seem to play a role in the distribution of collisions in the built environment, however. Birds may land in patterns dictated by the pattern of light intensity in an area, so the brightest buildings are the most likely to cause collisions early in the day. As birds move through the landscape seeking food, patterns related to distribution of vegetation appear. Studies using radar to map movement of birds through the built environment are starting to appear, but we need information at the level of species and individuals to truly understand how light is impacting birds.

It is often said that birds are attracted to lights at night (Gauthreaux and Belser, 2006; Poot *et al.* 2008). However, we do not have direct evidence that birds are, in fact, attracted to lights; they may simply *respond* to lights they encounter. Gauthreaux and Belser quote Verheijen as suggesting that "capture" might be a better word for birds' response to night lighting. While "capture" does seem appropriate to describe the phenomenon of birds circling drilling platforms, or in the lights of the 9/11 Memorial's Tribute in Light in Manhattan, "disorientation" is a term that covers more of the spectrum of behaviors seen when birds interact with light at night. Gauthreaux and Belser (2006), reporting unpublished data, stated that "exposure to a light field causes alteration of a straight flight path (for example hovering, slowing down, shifting direction, or circling)," and this has been reported by other authors.

Larkin and Frase (1988, in Gauthreaux and Belser, 2006) used portable tracking radar to record flight paths of birds near a broadcast tower in Michigan. Birds showed a range of response, from circling to arcs to linear flight. Haupt and Schillemeit (2011) described the paths of 213 birds flying through up-lighting from several different outdoor lighting schemes. Only 7.5% showed no change in behavior, while the remainder deviated from their courses by varying degrees, from minimal course deviation through circling. It is not known whether response differences are species related.

Bolshakov *et al.* (2010) developed the Optical-Electronic Device to study nocturnal migration behaviors of songbirds. Inspired by the more limited techniques of moon watching and watching birds cross ceilometer light beams, the device uses searchlights to illuminate birds from the ground, while a recording unit documents the birds' movements. With this technique, they can study 1) ground- and airspeed; 2) compensation for wind drift on the basis of direct measurements of headings and track directions of individual birds; 3) wing-beat pattern and its variation depending on

Swainson's Thrush. Photo by Owen Deutsch



The glass walls of this atrium, coupled with nighttime illumination, create an extreme collision hazard for birds. Photo courtesy of New York City Audubon

Canada Warbler. Photo by Ted Ardley

wind direction and velocity. In some cases, species can be identified. Bolshakov *et al.* (2013) examined the effects of wind conditions on numbers of birds aloft and flight trajectories of birds crossing the light beam from the apparatus. They determined that numbers of birds do differ with wind strength, but that birds may be attracted to the light beam under calm conditions. They also found that the light beam disturbs straight flight trajectories, especially in calm wind conditions. Regression models suggest that the probability of curved flight trajectories is greater for small birds, especially when there is little or no moon.

Bulyuk *et al.* (2014) used the same device to compare behaviors of night-migrating passerines under natural nocturnal illumination (at the Courish Spit of the Baltic Sea) with birds passing through an urban light environment (inside the city limits of St. Petersburg, Russia). Songbirds were distinguished as either small passerines or thrushes. The illuminated background caused a decrease in image quality. The shape of flight tracks was compared for the two groups, and a larger proportion of small songbirds changed flight path while crossing the light. This could be explained by flight type or flight speed. The proportion of songbirds changing flight trajectory in the lighted condition was much smaller than under the dark condition.

To understand exactly how light affects birds and what actions must be taken to reduce those effects, we need to know much more. For example, at what range (horizontal and vertical) and under what conditions do birds feel disruption from light, and of what intensity and wavelength composition? How do these factors change their behavior? Does night lighting have any effect on birds departing at the beginning of migratory stages? Do we ever actually see birds changing course to move toward a bright light source?

Light Color and Avian Orientation

Starting in the 1940s, ceilometers—powerful beams of light used to measure the height of cloud cover—came into use and were associated with significant bird kills. Filtering out long (red) wavelengths and using the blue/green range greatly reduced mortality, although we don't know whether the intensities of these two colors of lights were equal. Later, replacement of fixed-beam ceilometers with rotating beams essentially eliminated the impact on migrating birds (Laskey, 1960). A complex series of laboratory studies in the 1990s demonstrated that birds required light in order to sense the Earth's magnetic field. Birds could orient correctly under monochromatic blue or green light, but longer wavelengths (yellow and red) caused disorientation (Rappli *et al.,* 2000; Wiltschko *et al.,*1993, 2003, 2007). Wiltschko *et al.* (2007) showed that above intensity thresholds that decrease from green to UV, birds showed disorientation. Disorientation occurs at light levels that are still relatively low, equivalent to less than half an hour before sunrise under clear sky.

Poot *et al.* (2008) demonstrated that migrating birds exposed to various colored lights in the field responded the same way as they do in the laboratory. Birds responded strongly to white and red lights and appeared disoriented by them, especially under overcast skies. Green light provoked less response and minimal disorientation; blue light attracted few birds and did not disorient those that it did attract. Birds were not attracted to infrared light. Evans *et al.* (2007) also tested different light colors but did not see aggregation under red light. However, they subsequently determined that the intensity of red light used was less than for other wavelengths, and when they repeated the trial with higher intensity red, they did see aggregation (Evans, pers. comm. 2011).

Scientists working in the Gulf of Mexico (Russell, 2005), the North Atlantic (Wiese *et al.* 2001), and the North Sea (Poot *et al.* 2008) report that bright lights of oceanic drilling rigs induce circling behavior and mortality in birds at night. Working on a rig in the North Sea, Marquenie *et al.* (2013), estimated that birds were affected up to five kilometers away. Replacing about half the lights with new bulbs emitting minimal red light reduced circling behavior by about 50%. The authors speculate that completely re-lamping the platform would reduce bird aggregation by 90%. Gehring *et al.* (2009) demonstrated that mortality at communication towers was greatly reduced if strobe lighting was used as opposed to steady-burning white, or especially red lights. At the 9/11 Memorial Tribute in Light in Manhattan, when birds aggregate and circle in the beams, monitors turn the lights out briefly, releasing the birds (Elbin, 2015, pers. comm.). Regular, short intervals of darkness, or replacement of steady-burning warning lights with intermittent lights, are excellent options for protecting birds, and manipulating light color also has promise, although additional field trials for colored lights are needed.

Research: Deterring Collisions

Systematic efforts to identify signals that can be used to make glass visible to birds began with the work of Dr. Daniel Klem in 1989. Testing glass panes in the field and using a dichotomous choice protocol in an aviary, Klem (1990) demonstrated that popular devices like "diving falcon" silhouettes were effective only if they were applied densely, spaced two to four inches apart. Owl decoys, blinking holiday lights, and pictures of vertebrate eyes were among items found to be ineffective. Grid and stripe patterns made from white material, one inch wide, were tested at different spacing intervals. Only three were effective: a 3 x 4-inch grid; vertical stripes spaced four inches apart; and horizontal

Glass panes are being tested at the Powdermill Tunnel, as seen from the outside. Photo by Christine Sheppard, ABC

Susan Elbin tests a bird in the tunnel at the Carnegie Museum's Powdermill Banding Station in southwestern Pennsylvania. Photo by Christine Sheppard, ABC

The tunnel: an apparatus for safely testing effectiveness of materials and designs for deterring bird collisions. Photo by Christine Sheppard, ABC

A bird's-eye view of glass in the tunnel. Photo by Christine Sheppard, ABC stripes spaced about an inch apart across the entire surface. (A summary of Klem's results can be found at collisions.abcbirds.org).

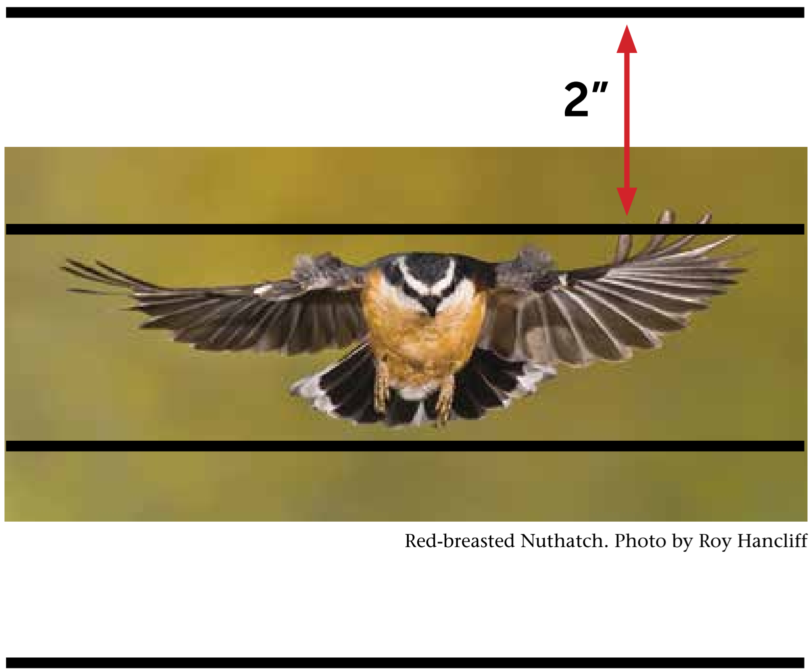
Building on Klem's findings, Rössler developed a testing program in Austria starting in 2004 and continuing to the present (Rössler and Zuna-Kratky, 2004; Rössler, 2005; Rössler, *et al.,* 2007; Rössler and Laube, 2008; Rössler, 2010; Rössler, 2012; Rössler, 2013). The banding center at the Hohenau Ringelsdorf Biological Station outside Vienna, Austria, offered a large sampling of birds for each test, in some instances permitting comparisons of a particular pattern under differing intensities of lighting. This program has focused primarily on geometric patterns, evaluating the impact of spacing, orientation, and dimensions. Birds are placed in a "tunnel," where they can view two pieces of glass: one unmodified (the control) and the other with the pattern to be tested. Birds fly down the tunnel and are scored according to whether they try to exit through the control or the patterned glass. A mist net keeps the bird from hitting the glass, and it is then released. The project focuses not only on finding patterns effective for deterring collisions, but also on effective patterns that cover a minimal part of the glass surface. To date, some patterns that cover only 5% of the glass have been found to be highly effective. (A summary of Rössler's results can be found at collisions.abcbirds.org).

The tunnel at Powdermill, showing the framework where the background will be mounted. Photo by Christine Sheppard, ABC

Building on Rössler's work, ABC collaborated with the Wildlife Conservation Society, New York City Audubon, and the Carnegie Museum to construct a tunnel at Powdermill Nature Reserve's banding station, primarily to test commercially available materials. Results from the first season showed that making an entire surface UV-reflective was not an effective way to deter birds. With UV materials, contrast seems to be important. Glass fritted in patterns conforming to the 2 x 4 rule, however, scored well as deterrents. (A summary of results from Powdermill can be found at collisions.abcbirds.org).

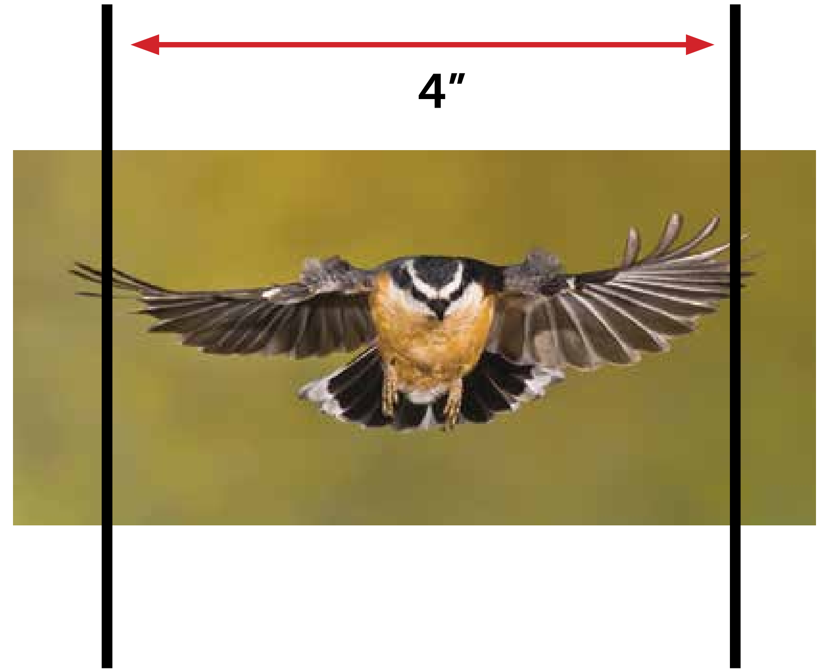
Most clear glass made in the United States transmits about 96% and reflects about 4% of light falling perpendicular to the outside surface. The amount of light reflected increases at sharper angles: clear glass reflects about 50% of incident light at angles over 70 degrees. Light on the inside of the glass is also partly reflected and partly transmitted. The relative intensities of light transmitted from the inside and reflected from the outside surfaces of glass combined with the viewing angle determine whether the glass appears transparent or mirrors the surrounding environment. Patterns on the inside surfaces of glass and objects inside the glass may not always be visible. These changeable optical properties support the argument that patterns applied to the outer surface of glass are more effective than patterns applied to the inner surface. Efforts have been made to model freestanding glass, glass installed on a building, and reflections on glass in some trials. (The testing protocol for freestanding glass, developed at Hohenau, and the testing protocols used at Powdermill can be found at collisions.abcbirds.org).

Horizontal lines with a maximum spacing of 2 inches



Red-breasted Nuthatch. Photo by Roy Hancliff

Vertical lines with a maximum spacing of 4 inches



The 2 x 4 Rule

Research on songbirds, the most numerous victims of collisions, has shown that horizontal lines must be two or fewer inches apart to deter the majority of birds. Vertical spaces must be four or fewer inches apart. This difference presumably has to do with the shape of a flying bird. (Narrower spacing is required to deter collisions by hummingbirds.) Schiffner *et al.* (2014) showed that budgies have a very precise understanding of their own physical dimensions. Trained to fly in a tunnel, the birds were then challenged to pass through ever narrowing gaps. They were able to assess the width of the gaps relative to their body size and adjust their flight behavior accordingly. It seems likely that this is a general avian trait, useful for navigating complex environments at flight speed. Bhagavatula *et al.* (2011) used the same tunnel setup to investigate how optical flow cues guide flight. It appears that birds balance the speeds of images perceived by both eyes, in this case, images to the birds' sides. This reinforces the suggestion of Martin (2011) that humans experience the world as something ahead of them, while for birds in flight, what is ahead of them is not necessarily their primary focus.

Evaluating Collision Problems—A Toolkit for Building Owners

American Woodcock are often victims of collisions. This bird hit a window in Washington, D.C., in March, 2011, and was recovered by ABC's Jason Berry. Photo by Dariusz Zdziebkowski, ABC

Often, only part of a building is responsible for causing most of the collisions. Evaluation and documentation can help in the development of a program of remediation targeting that area. Remediation can be almost as effective as modifying the entire building, as well as less expensive. Documentation of patterns of mortality and environmental features that may be contributing to collisions is essential. Operations personnel are often good sources of information for commercial buildings, as they may come across bird carcasses while performing regular maintenance activities. People who work near windows are often aware of birds hitting them.

Regular monitoring not only produces data on the magnitude and patterns of mortality, but also provides a baseline for demonstrating improvement. The best monitoring programs feature consistent effort, careful documentation of collision locations, and accurate identification of victims. Effective monitoring should document at least 18 months of collisions before mitigation is attempted, unless collision rates are especially high. (Resources for monitoring, from simple to sophisticated, can be found at collisions.abcbirds.org).

Solutions

Many factors come into play in selecting how to make glass safe for birds. The table below compares common solutions according to their effectiveness, appearance, relative cost, ease of application, longevity, and required maintenance. Effective patterns on the exterior surface of glass will combat reflection, transparency, and passage effect. Within the 2 x 4 guidelines, however, considerable variation is possible when devising bird-friendly patterns. We recommend that lines be at least ¼-inch wide, but it is not necessary that they be only vertical or horizontal. Contrast between pattern and background is important, however, and designers should be aware that the background—building interior, sky, vegetation—may change in appearance throughout the day.

This security grille creates a pattern that will deter birds from flying to reflections. Photo by Christine Sheppard, ABC

COMPARISON OF RETROFIT OPTIONS

Material	Effectiveness	Cost	Application	Appearance	Longevity	Upkeep
Seasonal, temporary solutions	*****	$	*	*	na	na
Netting	*****	$$	**	***	****	***
Window film	*****	$$$	****	*****	***	****
Screens	*****	$$	***	****	*****	****
Shutters	*****	$$$	***	****	*****	****
Grilles	*****	$$$	****	*****	*****	****
Replace glass	*****	$$$$$	*****	*****	*****	****
5 stars/dollars =	**highly effective**	**expensive**	**easy**	**attractive**	**long-lasting**	**minimal**

The following questions can guide the evaluation and documentation process by helping to identify features likely to cause collisions and other important factors.

Seasonal Timing

Do collisions happen mostly during migration or fledging periods, in winter, or year round? If collisions happen only during a short time period, it may be possible to apply inexpensive, temporary solutions during that time and remove them for the rest of the year. Some birds will attack their own reflections, especially in spring. This is not a true collision. Territorial males, especially American Robins and Northern Cardinals, perceive their reflection as a rival male. They are unlikely to injure themselves, and temporarily blocking reflections in the offending window (and those nearby) from the outside should resolve the problem. Taping up paper and smearing a soap paste can both be effective.

Weather

Do collisions coincide with particular weather conditions, such as foggy or overcast days? Such collisions may be light-related, in which case an email notification system, asking building personnel to turn off lights when bad weather is forecast, is advisable.

Diurnal Timing

Do collisions happen at a particular time of day? The appearance of glass can change significantly with different light levels, direct or indirect illumination, and sun angles. It may be possible to simply use shades or shutters during critical times.

Fog increases the danger of light both by causing birds to fly lower and by refracting light so it is visible over a larger area. Photo by Christine Sheppard, ABC

Lower-floor windows are thought to be more dangerous to birds because they are more likely to reflect vegetation. Photo by Christine Sheppard, ABC

Location

Are there particular windows, groups of windows, or building façades that account for most collisions? If so, it may be cost effective to modify only those sections of glass. Is glass located where birds fly between roosting or nesting and feeding sites? Are there areas where plants can be seen through glass—for example, an atrium, courtyard, or glass building connectors?

Are there architectural or landscaping features that tend to direct birds toward glass? Such features might include a wall or rock outcropping or a pathway bordered by dense vegetation. Solutions include using a screen or trellis to divert flight paths. Are there fruit trees, berry bushes, or other plants near windows that are likely to attract birds closer to glass? These windows should be a high priority for remediation. The glass itself can be modified, but it may also be possible to use live or inanimate landscaping elements to block the view between food sources and windows.

Local Bird Populations

What types of birds are usually found in an area? Local bird groups or volunteers may be able to help characterize local and transitory bird populations, as well as the most likely routes for birds making short flights around the area. The American Birding Association, *Bird Watchers Digest*, Audubon chapters, and Birding.com are good places to start finding such resources. Universities, colleges, and museums may also be helpful.

Post-Mitigation Monitoring

Monitoring efforts should continue for at least 18 months after mitigation efforts are made, and for at least two peak collision seasons (often the fall in urban areas, but spring and summer may also be peak seasons in more rural locations). Collision rates vary along with local bird populations, so a year of high population and high collisions may be followed by a year of low populations and low collisions, regardless of the effectiveness of any mitigation.

This Ovenbird survived a collision and was recovered alive during a Lights Out monitoring effort in Baltimore, Maryland. Photo by Daniel J. Lebbin, ABC

Use of glass with a highly effective horizontal frit pattern, together with sunshades, earned this retrofitted building on the SUNY Brockport campus the LEED “collision deterrence” credit. Photo by Paul Tankel

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A dramatic use of glass block characterizes the Hecht Warehouse in Washington, D.C., designed by Abbott and Merkt. Photo by Sandra Cohen-Rose/Colin Rose

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The World Trade Center of New Orleans, designed by Edward Durrell Stone, uses a simple bird-friendly strategy; almost all windows have exterior shutters. Photo by Christine Sheppard, ABC

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For the Langley Academy in Berkshire, U.K., Foster + Partners used louvers to control light and ventilation, also making the building safe for birds. Photo by Chris Phippen Ofis

Authors and Editors

Written by Dr. Christine Sheppard, Bird Collisions Campaign Manager and Glenn Phillips, Bird Collisions and Development Officer

Additional contributions by: Anne Law, and Mike Parr.
Edited by: George Fenwick, Clare Nielsen, Mike Parr, Darin Schroeder, Mary Jane Kaplan, Barbara Kancelbaum
Designed by: Gemma Radko

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Disclaimer

The Institut Arabe du Monde in Paris, France, provides light to the building interior without using glass. Photo by Joseph Radko, Jr.

American Bird Conservancy is the Western Hemisphere's bird conservation specialist—the only organization with a single and steadfast commitment to achieving conservation results for native birds and their habitats throughout the Americas. With a focus on efficiency and working in partnership, we take on the toughest problems facing birds today, innovating and building on sound science to halt extinctions, protect habitats, eliminate threats, and build capacity for bird conservation.

AMERICAN BIRD CONSERVANCY

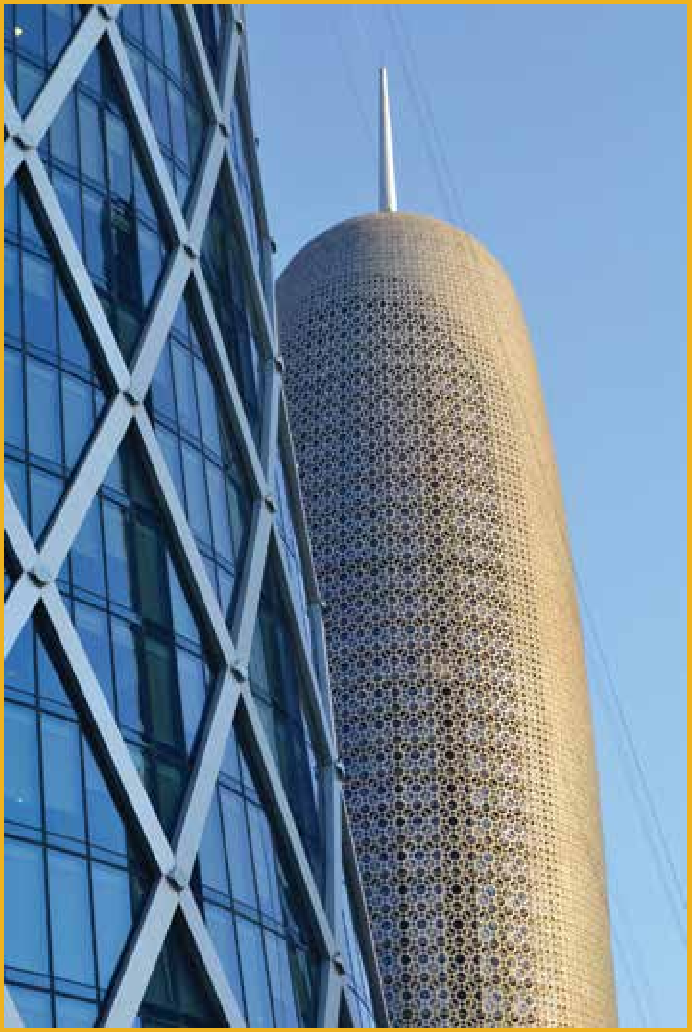
American Bird Conservancy
4249 Loudoun Avenue, P.O. Box 249
The Plains, VA 20198
540-253-5780
abcbirds.org

The Orange Cube, a commercial and cultural complex, was designed by Jacob + McFarlane Architects as part of redevelopment of the harbor in Lyons, France. The external skin virtually eliminates threats to birds while permitting natural illumination of the interior and sightlines for those inside. Photo © Nicolas Borel

American Bird Conservancy's Bird-Friendly Building Standard

Briefly, a bird-friendly building is one where:

- At least 90% of the material in the exposed façade from ground level to 40 feet (the primary bird collision zone) has a threat score of 30 or less, derived from controlled experiments.
- At least 60% of material in the exposed façade above the collision zone meets the above standard.
- All glass surrounding atria or courtyards meets the above standard.
- There are no "see through" passageways or corners.
- Outside lighting is appropriately shielded and directed to minimize attraction to night migrating or nocturnal birds.
- Interior lighting is turned off at night if not in use and designed to minimize light escaping through windows during night operation.
- Landscaping is designed without features known to increase collisions.
- Actual bird mortality is monitored and compensated for (for example, in the form of habitat preserved or created elsewhere, mortality from other sources reduced, etc.).



The Burj Qatar, designed by Jean Nouvel, was named Best Tall Building Worldwide in 2012. The façade, created with multi-layered screens, expresses local culture while providing protection from high temperatures and sand. Photo by Marc Desbordes

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David Chipperfield's expansion of the Anchorage Museum has a surface of mirror glass, made bird-friendly by a frit pattern that conforms with 2 x 4 recommendations. Museum staff confirm that while collisions do occur in the area, the museum sees few, if any. Photo by Larry Vincent