

Implementing Architectural Features of Bird Nests To Enhance Bird Conservation

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The bird population has been declining globally over the last few centuries in response to human disturbances. Several populations including grassland birds in Southeast Asia and forest birds in South America are subject to habitat loss and fragmentation. In particular, the urban bird population is in immediate danger of being exposed to large human-built structures and light pollution which alter the bird's behavior. Several bird conservation projects have taken action to reintroduce endangered bird species back into their respective ecosystems through breeding and experimentation but not all of them are successful. A few selective bird species such as the weaverbirds have adapted strategies to build intricate nests which has a positive impact on their survival rate. This literature search will analyze attempts at bird conservation and explain ways that architectural features of intricate bird nests can be adapted to buildings to enhance bird conservation of endangered species in urban areas.

Introduction

The conservation of biodiversity, both flora and fauna, is critical in maintaining intact and healthy ecosystems. In particular, bird species play an important role in ecosystem ecology. Birds both directly and indirectly affect other organisms in their ecosystem. For example, birds directly prey upon other wildlife, or act as prey themselves, within their food chain. Alternatively, if a species of bird were to be locally exterminated, it could lead to multiple indirect effects: first, predators that prey upon the exterminated species might suffer population decline. Second, the food chain could be further imbalanced through an increased prey population because of the loss of natural predators; This could subsequently lead to the increased prey population overutilizing natural resources in the area – ultimately leading to ecosystem degradation. The balance of these interactions between species is crucial to maintain biodiversity in ecosystems, but if a group of species were to be eradicated, there would be an imbalance in how the ecosystem functions.

However, the increasing rates of human-induced habitat loss and other human disturbances such as noise and light pollution have led to bird population declines¹. This is especially prominent in urban areas. Over the last few decades, more areas have been cleared to make way for development within cities as the human population increases which, in turn, exacerbates the “human impact gradient.” The human impact gradient is a theoretical concept that describes the ever-changing magnitude of human impacts on the environment along the ecological gradient². In this case, human activities have a more prominent impact on birds in urban areas compared to rural areas. The human impact gradient has a significant impact on bird conser-

vation. In areas with minimal human impact, the bird population thrives so there is limited need for intervention². Contrastingly, in areas where human impact increases, human involvement in the form of altering urban structures is necessary to reintroduce endangered bird species with some exceptions. For example, some bird species, such as the rock pigeon (*Columba Livia*), are adapted to thrive in cities, while others are more negatively impacted by urban light pollution, which, in turn, suboptimally alters their vocal features and nesting habits³.

Over the past few decades, bird conservation projects have taken action to address these threats with the objective of increasing the population of threatened bird species. In most cases, projects suggest the addition of vegetation and artificial bird nests as conservation tactics. For example, the local government in Germany enforce the application of green roofs in the building code⁴. Research suggests that bird reintroduction benefits from practices that comprehensively consider species' ecological needs. The reintroduction of endangered birds is not simple because, in addition to supporting species ecology, one must simultaneously consider a species' vulnerability to human disturbances and how these disturbances can alter a bird's behavior. Despite continuous efforts, current approaches to bird conservation and reintroduction aren't sufficient to address the complexity of the situation posed by human disturbances⁵. Conservation projects such as the Waldrapp Project is an example that will be explored in the paper to demonstrate the behavioral changes affected by the attempt to reintroduce migratory routes.

In this paper, I review bird nest-building ecology and describe current and potential approaches to support bird conservation efforts. Specifically, my objective is answer the question: Can the architectural features of bird nests be adapted to human-

built structures to enhance endangered bird conservation? I first explore various threats posed against birds, followed by an exploration of elaborate nests made by weaver birds, flycatchers and blue tits. Next, I describe the efforts and solutions around bird conservation in relation to human-built structures in urban cities. I assess the methodological approaches in which architectural features of bird nests can be adapted to buildings in order to reintroduce a bird population. It is crucial that people take on the task of conserving or reintroducing a bird population in urban areas, and specifically do so in consideration of the features that birds themselves have adapted. Certain bird species, such as the blue tit and flycatcher, use defining materials to build elaborate nests. By redefining these features, people can implement processes that reintroduce the bird population in cities, thereby restoring biodiversity in the ecosystem and promoting coexistence between humans and birds.

Literature Search

For the literature search, the journal databases: Google Scholar (www.scholar.google.com), Jstor (www.jstor.org), and Plos One (www.journals.plos.org) were used and consideration was limited to articles focused on the topic of bird conservation, bird nests and bird collisions. To achieve this, articles ranged from case studies, experimental research, and other original data collection in relation to bird conservation. Articles are included if they involve a specific species of bird that built elaborate nests and various attempts to solve bird conservation. Examples of articles used include “The Evolution of Nests and Nest-Building in Birds” and “The Social Network: Tree Structure Determines Nest Placement in Kenyan Weaverbird Colonies” to investigate the nesting behaviors of certain bird species. Furthermore, specific studies such as “After a 400-Year Absence, a Rare Ibis Returns to European Skies” were used to highlight the potential impacts of bird conservation efforts. The collection of data comes in the form of interviews, statistics, and graphs. Articles were excluded if they focused heavily on the biological aspects of birds and strayed away from the main objectives of my literature search (e.g., lacked nest information or conservation perspectives). Specific bird species were noted, along with the threats that the species is facing. Various attempts and solutions were recorded so that they could be evaluated for their strengths and limitations.

Goals and Methods of Bird Conservation

Bird conservation is a subfield in the science of conservation biology that focuses on the protection of endangered birds and explores the profound impact that humans have on birds. Since the 19th century, bird populations have generally declined worldwide due to human disturbances, which include poaching, log-

ging, invasive species, bird collisions, and light pollution. This has resulted in some species becoming extinct, while other remaining species are now classified as endangered⁶.

An emblematic example of these human disturbances is the introduction of invasive species. Humans have brought predators to the islands that birds live which in turn, introduce a new threat that birds don't have a defence mechanism for. Furthermore, cameras in forests have shown monkeys and lizards invading nests, decreasing the population of the species. The scientists believe that these predators, such as snakes, would eventually move uphill to where the birds live⁷. In addition to invasive species, logging is one of the main threats to bird species in rural areas. Over two-thirds of the bird population lives in forest habitats, but since the 1900s, approximately half of the forests around the world have been exterminated due to the need for trees to be harvested⁶. This has a profound impact on forest birds are habitat specialists that rely on pristine forests to live.

Alternatively in urban areas, collisions and light pollution are the most prominent issues to bird conservation. Around 20% of recognized bird species live in urban areas, with the common species being the house sparrow, rock dove, house finch, eurasian tree sparrow, common starling, and feral pigeon⁸. These individuals are usually spotted in large gardens, parks, and other green spaces. The starling, sparrow, and pigeon, in particular, are species that have adapted to exploit a potential food source or a suitable nesting site in human-altered environments. However, other bird species, such as parrots and songbirds, are not as adaptable as the three species mentioned above and are readily exposed to obstacles through bird collisions and light pollution.

Bird collisions are a common problem in populated cities with large skyscrapers and tall buildings. Through migration, bird species can collide directly with buildings, which leads to birds being severely injured, unable to fly, or even lying dead on the ground. Needless to say, skyscrapers are not the only human-built structures that are the cause of bird collisions. A study done in 2019 also looked at stadiums in comparison to buildings. Through monitoring 21 buildings in Minnesota, including the U.S. Bank Stadium, the results showed that a majority of the collisions are caused by stadiums made of glass⁹. The study explored different building features that contributed to total collision fatalities, fatalities by species, and fatalities by season. Examples of features that were explored were the height, glass area, nighttime lighting, and surrounding forms of vegetation. Surprisingly, vegetation near the glass buildings actually manages to confuse the bird's migratory patterns even more as they can see through reflective glass or are attracted to the vegetation without realizing that there is glass in the way. Bird's vision differs from that of humans. It is speculated that bird turn their heads pitch and yaw to look with their lateral view which in turn, results in certain species being blind in the direction of travel¹⁰.

One prominent example of bird strikes is the case study of the School of Management's Evans Hall at Yale University. Since April 2018, a total of 262 stunned, injured or dead birds have been found near the building by groundkeepers⁵. Keep in mind that data in relation to the number of bird strikes can be misleading as some birds manage to fly away after getting hit by buildings. Many of these bird strikes involve imperiled species, making them have a population-level effect. Despite this, efforts to prevent further strikes have been inadequate. In 2017, the University decided to collect a year's worth of data to further understand the problem and identify areas of concern before implementing a solution. There were plans to add ultraviolet film to the glass building, but no further action was taken because the coating would be visible to humans and require frequent application⁵.

The effects of light pollution on birds follow a similar process in human disturbances. In this instance, light pollution is the light source produced by human-made objects such as street lamps and interior lighting. These artificial light sources have a tremendous impact on migratory bird's behavior. This is especially notable in migratory birds at night, who rely on the light source from the moon and stars but mistakenly are attracted to streetlamps and buildings. Inevitably, light pollution alters the bird's nesting habits, migratory routes, and mating calls. Evidence also points out that light affects bird's internal clocks and disrupts the timing of behaviors like dawn song and mating³. Not only do the consequences advance dawn song in species such as the eurasian blue tit (*Cyanistes Caeruleus*), but early singing associated with lights was shown to be positively correlated with the amount of offspring that males were able to sire, hinting at potential reproductive consequences of light pollution¹¹. Building collisions are also associated with light pollution, meaning that birds gravitate towards buildings that are lit up, eventually resulting in strikes. Overall, the conservation of birds still faces multiple challenges, both in urban and rural areas, that require further strategic action. Following the trend of habitat destruction, invasive species, bird collisions, and light pollution, implementing solutions to monitor and reintroduce bird populations still needs proper consideration.

Architectural Features in Bird Nests

A large effort dedicated to bird conservation has been proposed to change the structure of human buildings. The problem around bird collisions points back to the material that is being used when creating structures. Most of the bird strikes are caused by glass buildings that have transparent glass which in turn, confuses the bird's flight patterns. Creating bird-friendly structures isn't straightforward, as in order to create structures that are companionable to birds, humans need to consider the bird's behavior patterns. This involves an in-depth analysis of how birds interact with the ecosystem. Researching the use of materials in

bird nests and their effectiveness is a way to incorporate features of birds into structures as a form of mimicry. By studying the designs created by birds, humans can take inspiration from them to create structures that, in turn, assist birds in urban areas.

Weaverbirds (Ploceidae) are a species of bird that work together as a colony to locate an area that is suitable to build nests¹². Male builders adapt their behavior depending on their surrounding environment. They use a hierarchical method of building by redefining materials when they don't stick. This trial and error process corresponds to the way that architects restructure their designs if they don't work out¹². The strategy that weaverbirds have adapted in response to the environment is worth further investigation to be applied to architectural design. Essentially, the weaverbird is known for creating unique and intricate nests that are pendant-shaped and have long tunnels. The species' creations are often seen dangling from telephone poles and high branches of treetops. Environmentalists believed that the nests were shaped in this particular way as a defense mechanism against predators like snakes and brood parasites invading their nests¹³. Field reports have indicated that snakes struggle to climb down the slim branches to get to the nests, which supports the theory that pendant shaped-nests provide protection for the infants when the parents are out hunting for food. In addition, experiments revealed that these unique nests have a correlation to slow development in infants, especially in the incubation phase¹³. Without the need to defend themselves against predators, infant birds hatch later compared to other infant birds that are threatened by predators.

Using a similar method, the flycatcher family of birds constructs intricate nests using specific materials that they forage. In this case, flycatchers use fungal fibers as the primary medium for their nests. The majority of birds primarily use grass fibers for their nests compared to the flycatchers. A particular example would be the Yellow-Olive Flycatcher species which uses black *Marasmius* fibers for constructing their nest¹⁴. The reason behind choosing this particular material has been debated by ornithologists. The phenomenon behind this unusual preference was explored in the study published by the University of Arkansas. Two hypotheses were tested to understand if flycatchers specifically chose to use fungal fibers because they are more durable and physically stronger than grass fibers. Furthermore, they wanted to explore if fungal fibers have a control in the temperature exchange of the interior and exterior of the nests¹⁴. To confirm this theory, they compared the strength of the black *Marasmius* fungal fibers that were collected from six nests of Yellow-Olive Flycatchers with the grass fibers that were obtained from Yellow-Tailed Oriole nests. However, the results of the study contradicted both hypotheses, revealing that the *Marasmius* fungal fibers were not superior in strength to the grass fibers. The assumption is that the fungal fibers are merely used for water resistance and more flexibility for the Yellow-Olive Flycatchers that live on the forest edges of Central/South

America, where fungal fibers are more common to forage. This may just be exclusively for that particular species, varying in others.

Ultimately, there are several interacting influences that impact how and why birds build nests. In most bird species, the primary instinct that drives nest construction is protection against predators. Other factors include protection against parasites, bacteria and nurturing the development of hatchlings. Unique species have individual preferences regarding the composition of the nests and the vegetation that surrounds it, as demonstrated above with the flycatcher. In Corsican populations of blue tits (*Cyanistes Caeruleus*), the females regularly add fragments of several aromatic plants in their nests during the breeding season. The selected plants that are present in the environment have been shown on several occasions to have positive effects on the nestlings¹⁵. It was suggested that sprigs of aromatic plants are added onto nests primarily because of the ability to reduce ectoparasite loads. A large number of infectious diseases are caused by ectoparasites such as ticks, fleas, lice, and mites who attach themselves to the feathers of birds for a long period of time, sucking on the blood of the host. As a result, the infected birds are often itchy with damaged feathers and weak from the blood loss¹⁶. In turn, the avian disease could spread easily to other birds that come into contact with the ectoparasite or the hosts. Blue tits majorly use the three main aromatic shrubby species: Hophbush (*Dodonaea viscosa*), French Lavender (*Lavandula Dentata*) and Morocanna (*Cynara baetica*), suggesting that the females actively search for plants in means of protection from parasites and bacteria¹⁵. In particular, the French Lavender emit an intense fragrance that repels parasites. The fragrance itself is produced by oils rich in beta-pinene which is a chemical compound known as a potent insect repellent¹⁷. In this instance, the aromatic plants reduce the effect that ectoparasites have on the birds and nestlings, thus providing a useful material in nest construction.

Nest building is a crucial and essential part of bird behavior as a whole, being vital in the reproduction of the species as well as regulating the growth of nestlings. Like humans, birds also apply architectural features when constructing their homes therefore, illustrating the cognitive similarities between the two families. The assembly of nest materials in an appropriate composition is within the species' variation. Although, the majority of a particular species use certain materials for their nests, the selection process can be adapted to the environment in which they live in. Nature is always changing due to global warming, which in turn, affects the abundance of nest materials in varying habitats. The distribution of certain plant species are limited to a range of environmental conditions, making some conditions unsuitable under climate change which in turn, leads to a decrease in the availability of certain plant materials¹⁸. This would force the individual to change the proper nest material to fit what is available. As demonstrated, intricate nests are constructed to

prevent predators from invading the nests. Both the weaverbird and flycatcher built carefully designed pendant-shaped nests, evidently making it so that predators struggle to climb into the nest. Sequentially, the flycatcher and the blue tit use certain materials when constructing nests for resistance. It is important to note that the development of the nests can have underlying effects on the hatchlings. Although intricate nests increase the survival rate of infants, they decrease the development rate. Studies have demonstrated that infant development periods are negatively correlated with nest predation¹³. The complex nest provides better protection for the hatchlings, reducing the risk of predation and eliminating the urgency for development. Despite this drawback, it is important for humans to understand bird behavior in order to develop ways to protect and reintroduce endangered bird species.

By studying the nesting habits of these birds, architects can design buildings that incorporate certain features that reflect the natural nesting sites such as providing crevices and ledges where urban birds can build their nests. The choice of nesting materials used by flycatchers can be incorporated into building designs. This includes using a mixture of artificial and natural materials such as wood and fiber. Creating bird-friendly spaces accommodates their nesting needs, promoting their survival and contributing to bird conservation efforts.

Bird Conservation: Efforts with Increasing Consideration for Infrastructure

Taking action to conserve and reintroduce bird species is a daunting task. The conservation of a declining bird population requires extensive research and experimentation that can be difficult to achieve in the wild, as well as competitive funding to earn. Several notable bird conservation efforts have taken place across the globe in the past few centuries. Until recently, a generalized observation shows that many conservation efforts have focused on restoring population sizes and habitats, but have lacked strong consideration for the link between bird ecology, population threats, and human infrastructure. Nevertheless, unifying such efforts is the primary goal to bolster the population of endangered birds in their respective ecosystems through minor adjustments. If the endangered bird population increases to a stable size, it has the potential to restore and balance the ecosystem to its proper function.

Conservation strategy can be implemented in several different forms, for example, the Waldrapp Project aims to reverse the events that took place 400 years ago on the northern bald ibis. Back in ancient times, the northern bald ibis was considered an afterworld divinity, however, over the last few centuries, the population has dwindled due to hunting¹⁹. Recently, a population within Syria has been presumed locally extinct but due to effects from the nation's civil war. All that remains is a small

population (800 individuals) in Morocco, southern Turkey, and East Africa. Unlike other conservation projects that focus on breeding endangered birds species, the Waldrapp Project took a unique approach by specifically aiming to establish a new migratory route for the species. In turn, the new migratory route is intended to lower anthropogenic risk (e.g., poaching) while ibises migrate. To achieve this, they first bred the bald ibis before training them in a new migratory route. Through the project's ultralight aircraft, the pilot led the way for the ibises¹⁹. Although the training took years, the project was successful and the number of birds completing the migration, roundtrip, has increased since 2014. Though future testing is needed, this success could be replicated to reintroduce other endangered species without potential threats from hunting. However, the project has drawn criticism in the nature of promoting conservation, with claims that this new method disrupts natural bird behavior by forcing the birds to adapt to modern landscapes occupied by humans. In other words, by integrating the ibis into the modern landscape, humans are altering the bird's natural behavior and migratory pattern¹⁹. However, such efforts bolster the concept that human infrastructure should take into account bird ecology.

In urban areas, human-built structures often contribute to bird collisions due to their large size and capacity. These collisions are primarily caused by buildings made up of reflective glass. To counteract this, conservationists have made plans to adhere films to the glass, but such effort would require constant re-application⁵. On the other hand, some buildings and stadiums have minimized their use of reflective glass by replacing it with a different type of glass that can be distinguished by birds⁹. This would allow the birds to differentiate a structure to clear air, decreasing the rate of bird strikes.

A large number of birds rely on vegetation to survive as a means of protection against predators and a place to roost. Bird species such as the weaverbirds and flycatchers are dependent on plants to build nests and use their materials to construct nests. These reasons support the common suggestion to add more forms of vegetation in buildings. By planting more trees in gardens and parks, birds are able to nest while coexisting with humans. Conservation of green spaces is valuable to the reintroduction of birds in urban cities. However, this further requires consideration on the strategic locations for where vegetation should be restored. Simply planting gardens on top of buildings and around the area could risk further confusion for the birds. The research on the impact of glass stadiums on birds ultimately concluded that vegetation near glass can, in fact, confuse a bird's movement patterns because the bird can see the vegetation through reflective glass⁹. The research study assessed how building features such as vegetation and lighting could impact collision fatalities. The results showed that the effect of glass area and the amount of surrounding vegetation contributed to collisions in 4 buildings and stadiums. Thus, a sweeping effort to plant more vegetation is not universally

beneficial, having the potential to exacerbate the issue of birds colliding with glass. It requires strategic spatial planning, or else the greenery can become an ecological trap by attracting the bird to the vegetation without realizing that there is a glass in the way. A more effective approach would be to create green spaces further away from human structures in addition to minimizing the use of reflective glass and light during night hours.

The conservation services provided by stakeholders is vital to alter the designs of human-built structures to increase the bird population in urban cities. A stakeholder is a party that has interest in a project and work to see the outcome of its actions. To deal with planning biodiversity maintenance, stakeholders such as urban designers and architects need to determine the city's layout, thus the availability of green space. Similarly, homeowners and industry owners focus on the management of residential gardens⁴. All values above need to be estimated before a final decision. Furthermore, most of the actions suggested by stakeholders include adding more forms of vegetation and using more bird-friendly construction materials when creating structures. Essentially, the key to urban bird conservation is to increase efforts toward designing intricate, diverse gardens that connect to existing greenspaces both inside and outside of buildings. This form of action would be beneficial to both birds' and humans' health while restoring habitat fragmentation.

Within personal households, a common social interaction between birds and humans is the application of the bird feeders. Many homeowners utilize their gardens as an area for birds to rest and access food, with the intention to care for nature. Through wooden built bird nest boxes and feeders, humans are able to observe bird behavior which, in turn, provides individuals with an opportunity to be resourceful in enhancing bird conservation projects. These nest boxes have been used to support bird populations that nest in holes (e.g., the common house sparrow (*Passer domesticus*)) because the nest box can compensate for shortages of nesting sites in built-up areas. This includes support for locations that have experienced loss of breeding site due to the removal of dead and decaying trees in forests, which are important materials for nests²⁰. The scarcity of hollows due to the lack of trees of large diameters and natural damage to the holes can indirectly impact the survival rate of these bird species which in turn are exposed to predators²⁰. As concluded by a study done in residential buildings of Olsztyn, Poland, nest boxes were effective in increasing the population of house sparrows and most of them preferred the medium and larger sized boxes as they could lay eggs²¹. The study looked at species that were associated with buildings such as the House Sparrow (*Passer domesticus*) and Common Starling (*Sturnus vulgaris*) which showed a decline in population after losing access to their nesting sites in buildings. After nest boxes were provided, five years of monitoring showed that nest boxes compensated for the loss of nesting sites. The population recovered to 50% of its original population²¹. Furthermore, a study conducted in

Table 1 This table is an organizer representing the statements argued for attention to urban bird conservation that are targeted towards specific stakeholders. Further action and arguments are addressed for each statement, demonstrating the limitations and strengths. Graph Credit to: Snep et al. 2016

Statements	Key stakeholders						Action perspective for stakeholders	Argument for main stakeholder	Addressed urban bird survival challenges
	Urban planners and designers	Urban developers and engineers	Homeowners and tenants	Companies and businesses	Landscaping and gardening firms	Education staff (school and NGOs)			
I. Support for nature conservation starts in cities.	X	X	X	X	X	X	Include urban birds in wildlife education, outreach and communication	Make general conservation aims more recognizable by linking with the daily perception of citizens, businesses and urban professionals (Miller 2005; Snep and Clergeau 2012)	Habitat fragmentation; vegetation composition and structure
II. People need education and messages to increase the value of bird conservation			X			X	Provide tailor-made advice for wildlife-friendly management of gardens	Tailor-made advice increases success rates in conservation practice (Goddard et al. 2013; van Heezik et al. 2012), increase support for NGOs	Vegetation composition and structure at the garden scale
III. Citizens can make a difference when it comes to habitat quality for urban birds			X			X	Design structurally diverse gardens (vegetation and landforms), with native vegetation, and minimal paved surfaces, collar cats with bells and feed birds—if appropriate in the local context (Fuller et al. 2008)	The actions proposed will attract birds to gardens, enabling people to enjoy them, increase citizens' well-being.	Vegetation composition and structure (Goddard et al. 2010; Lerman and Warren 2011); habitat fragmentation (Rudd et al. 2002); predation by domestic cats (Van Heezik et al. 2010).
IV. Both people and birds benefit from green cities			X	X		X	Green built-up areas where health problem prevention and recovery is important: hospitals, schools, elderly homes.	A green environment may prevent people from illness and speed up the healing process (De Vries et al. 2003; Ward Thompson et al. 2012)	Vegetation composition and structure of utility areas
V. Incorporating wildlife habitat quality into urban planning and design substantially increases urban bird	X	X	X			X	Maximize the amount of green in urban developments, and connect new green areas with existing green structures inside and outside cities	People prefer a green living environment with abundant wildlife, increases the well-being for the planners/designers' client (the citizen)	Habitat fragmentation and availability at the larger scale (Stagoll et al. 2010; Ikin et al. 2012; Asikainen and Jokinen 2009); zoning of human presence (recreation paths) in urban green
VI. Incorporating wildlife habitat quality into building design and development increase urban bird abundance	X	X	X			X	Apply bird-friendly construction materials; select green roof/wall types with added value for birds. Use checklists for bird-friendly buildings (e.g. http://www.checklistgroenbouwen.nl/).	Accounting for biodiversity is an increasingly popular issue within green building practices (Hostetler 2012).	Bird-friendly buildings: green walls (Chiquet et al. 2012); green roofs (Fernandez-Canero and Gonzalez-Redondo 2010); built-in nesting boxes
VII. Incorporating wildlife habitat quality into urban green design and management substantially increases urban		X	X		X	X	Combine aesthetical and cost-effectiveness aims with habitat creation (Lovell and Johnston 2009). Establish native vegetation with sufficient variety in green design and maintenance (Murgui and Macias 2010; Wilkinson 2006).	Offering habitat opportunities for wildlife may appeal to land owners and users (Kaplan 2007), the (indirect) clients of the designers and landscape managers	Vegetation composition and structure; habitat availability; zoning of human presence (recreation paths) in urban green
VIII. Both employees and birds benefit from green business and office parks.			X	X			Companies may utilize various options to physically green corporate environments, e.g. green walls and roofs.	A green outdoor environment at work appears to be an asset for employees' wellbeing and level of stress (Kaplan 2007; Lottrup et al. 2013)	Habitat availability at business areas (Snep et al. 2009), bird-friendly corporate buildings
IX. Urban bird conservation can help companies to express their corporate social/environmental responsibility				X		X	Companies may employ activities to stimulate wildlife presence and wildlife experience at their corporate land (Snep et al. 2009)	Increased employee commitment, improved relationships with environmental NGOs, positive effect on community relations, improved relationship with regulators, annual cost savings (Cardskadden and Lober 1998)	Habitat availability, composition and structure at business areas
X. Corporations can make a difference when it comes to habitat quality for urban birds				X		X	Companies may explore how their corporate land (e.g. left-over land) can contribute to regional conservation aims (Snep and Ottburg 2008; Snep et al. 2011).	Companies can move beyond current corporate biodiversity practices and make a profile at the next CSR-level of conservation (CSR: Corporate Social Responsibility).	Habitat fragmentation and availability at the city region scale

Sivakasi, India, investigated the effect of artificial bird nests on house sparrows in an attempt to escalate the population. Artificial bird nest boxes constructed from available paper boards were placed in 10 sites and monitored for a period of time. The results were similar, showcasing that house sparrows occupied 30 out of 50 of the nest boxes when building sites weren't available. The house sparrows stayed in the nests for a period of time, nurturing their young with plant materials gathered²². However, adding nest boxes should also be built when it is necessary as it requires periodic cleaning from ectoparasites. Essentially, the conservation of endangered bird species requires an interdisciplinary approach that encompasses various stakeholders and strategies. The challenge of balancing nature with human infrastructures demands collaboration from architects, urban planners and homeowners to address the necessities to alter the construction of buildings without disturbing the birds' natural behavior.

Discussion

It is critical to understand and recognize that there are different methods for bird conservation that prioritize the protection of elaborate nests. A variety of other bird species, such as the bowerbirds (Ptilonorhynchidae) and the oven birds (Seiurus Aurocapilla) exist in varying habitats. Bowerbirds in particular are known for their courtship structures during mating season where they gather a variety of materials from leaves to bottle caps²³. Their nests can give further insight into materials that can be provided in urban buildings. On the other hand, oven birds construct dome-shaped nests that serve a variety of functions including protection and incubation, thus further research can be explored so that their architectural adaptations can be mimicked²⁴. The structural intricacies of elaborate nests not only portray functionality but indeed, act as a defence mechanism to ensure the survival of nestlings from predators. Moreover, the nests themselves are living examples of natural architecture, from the variety of materials to design choices. Simply,

understanding the significance of elaborate nests, can provide insight into the behavior, ecology, and conservation of birds. By evaluating certain aspects and features of the elaborate bird nests, they can be mimicked onto human-built structures to enhance bird conservation in the form of biomimicry. Replicating the design principles processed by birds, fellow architects and engineers can use it to create bird-friendly structures. Below, I detail the methods that can be trialed to potentially create bird-friendly structures:.. mainly, the shape of the nest and the material provided.

1. Placement of Vegetation

As proposed by garden firms and other stakeholders, it is essential to conserve vegetation in urban cities. Simply planting more trees in addition to clearing land for creation of greenspaces is influential to the survivability of birds in urban areas. Vegetation is vital to the bird's shelter in cities so implementing gardens on buildings would save the average population that are exposed to predators such as dogs and cats. In a similar area to Central Park in New York, large scale green spaces are home to several bird species that hole up in trees and interact with humans on a daily basis. However, planting more vegetation isn't a simple task. The placement of vegetation must be taken into consideration because the closure to glass buildings can lead to further confusion in birds. Surrounding vegetation near buildings can be reflected through the glass, resulting in bird strikes. A moderate approach to placement lies in planting vegetation further away from buildings, forming a separate greenspace in the form of parks. Similarly, adapting green spaces onto the roofs of buildings themselves can reorient the direction of bird attraction. For example, the New York's Jacob Javits Center was transformed into a sanctuary for birds after recovering from bird collisions. The center was adapted to be bird-friendly by incorporating fritted glazing and a 6.75-acre rooftop garden where birds can recharge³. Other limitations need to be considered. This includes the potential risk of attracting invasive species, such as insects which pose a health risk for people, in these re-vegetated areas. This also includes, the required regular upkeep to maintain the vegetation including watering, weeding, and pruning. This can be time-consuming and expensive, especially in urban areas where there is limited space.

2. Adding Nest Boxes

The pendant-shaped nests of weaverbirds can be mimicked when constructing nest boxes. This can be further adapted onto trees in urban greenspaces to accommodate birds, such as the house sparrows, to nest in²². In particular, house sparrows find shelter in crevices near buildings, so further research needs to be conducted to ensure whether the weaverbird nests can be adapted by house sparrows. The holes in the bottom of the nest boxes

would provide protection from potential predators and parasites. Furthermore, the installation of the hole could act as a drainage point as it is difficult for the rain to reach the interior of the box. Besides common woodwork, the nest boxes can be constructed using a variety of materials. Taken inspiration from the blue tits, implementing specific aromatic vegetation around the greenspace given as a nesting site for birds would provide a flexible option for urban birds to choose their preferred nesting material, which in turn, further decrease the rate of parasites invading the nests. A study that was carried out at the Pirió site in Corsica, looked at the effect of aromatic vegetation on bacteria and parasites. During the nestling period, they removed the fresh plants brought by the blue tits before adding aromatic plants. The results showed that aromatic plants significantly impact bacterial communities on nestlings hence, incorporating aromatic vegetation and providing necessary materials can be a valuable tool in addition to nest boxes¹⁵. In addition, both fungal and grass fibers should be provided for certain birds that prefer water resistance, creating a hospitable environment where birds can build their own nests in addition to nest boxes. On the contrary, artificial bird nests require constant sanitation, which some structures aren't able to provide. While weaverbirds construct their pendant-shaped nests, it is not guaranteed that other bird species will adopt these structures, so further research is needed to assess the adaptability of other urban bird species to these nest boxes. Additionally, the impact of artificial nest boxes on nesting behavior needs to be considered, as relying heavily on nest boxes could potentially risk altering the natural nesting behavior of urban birds. Lastly, research must also determine whether, over time, the birds may become less inclined to seek out natural nesting sites for themselves

The construction of these artificial nest boxes can range from simplistic (Fig. 1a) to more complex (Fig. 1b). Simple constructed bird boxes are replicated from common nest boxes, while the complex constructed bird boxes are architecturally developed. The simple constructed boxes serve as an efficient approach to mass production with their easy designs that can be replicated. With their design and size, they require less maintenance than the complex constructed boxes. Though the complex constructed boxes require more labor to construct, they can be more durable and long-lasting. Ultimately, the best type of nest box to use will depend on the specific needs of the birds in the area and the available resources. Simple nest boxes are a good choice where the goal is to attract a wide range of bird species, while complex nest boxes are a good choice to attract a particular species of bird with specialized nesting habits like those of the weaverbirds. Complex nest boxes may also offer aesthetic value, as it strays from traditional linear human infrastructure.

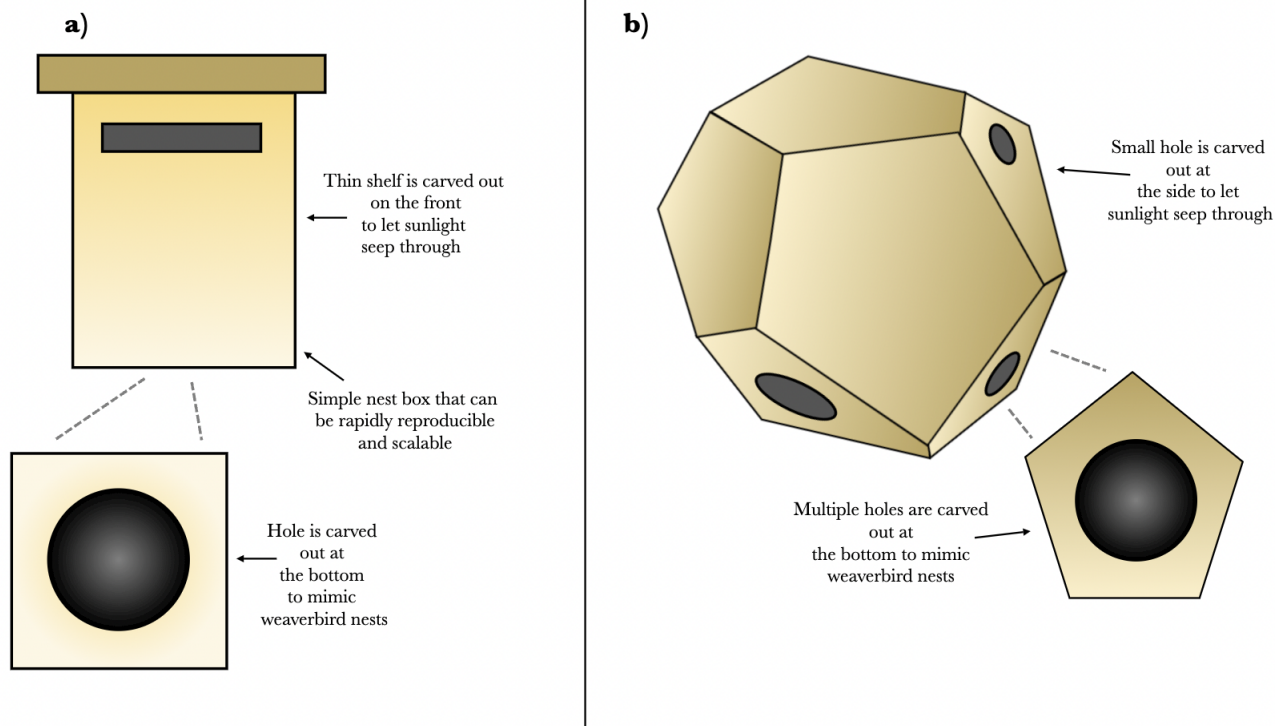


Fig. 1 (A): [Simple nest box that can be easily reproduced in quantities.] **(B):** [Complex nest box that requires additional time and effort to assemble.]

3. Constructing Nesting Towers

Nesting towers are another form of shelter that can be constructed. Nesting towers are similar in structure to nest boxes but take shape as multiple nest boxes are compiled on top of each other to establish a tall tower. Natural materials such as branches, grass and fungal fibers can be used to construct the towers, providing a familiar environment for the endangered birds looking for shelter. For example, the study above demonstrated multiple ways of reintroducing Northern Bald Ibises. One option was the construction of artificial shelves attached to a cliff face. The ibises would nest and breed in the concave shelves. This methodological approach could be adapted for nesting towers (Fig. 2). Individual shelves can be edged out on the walls of the tower, providing shelter for multiple endangered species. It has been well-established that bird species are attracted to tall structures, if not solely based on the continued pattern of birds colliding into tall glass buildings. Beyond the mortality risks of some tall structures, bird species have also been observed utilizing tall spaces in order to thrive. For example, the pied crow (*Corvus albus*) use cellular telecommunication towers as their nesting sites, taking use of artificial infrastructure²⁵. In this case, the colossal height of the telecommunication towers can be mimicked onto nesting towers with a limited range to

support the area. While the concept of nesting towers can provide shelter for multiple individuals, it is a daunting structure to construct, especially with limited time and cash. Nesting towers can be expensive to construct, especially if they are made from durable wood that can accommodate for multiple species while requiring sturdy structures for suspension. Furthermore, regarding the safety of birds, they need to be constructed with durable wood that can withstand heavy wind and rain so that the tower doesn't collapse. Depending on the size, the towers need to be ventilated to prevent the buildup of moisture and heat, as it could lead to the growth of mold or fungus, which can harm birds. Nevertheless, the construction of these nest boxes and nest towers is important to the endangered bird species in urban cities, acting as a method of shelter from disturbances. They provide nesting habitat for endangered bird species in urban environments, playing a significant role in advancing bird conservation efforts.

Conclusion

Human infrastructure, particularly high-rise buildings, poses significant mortality risks to the global bird population. The most prominent risks include bird collisions and light pollution

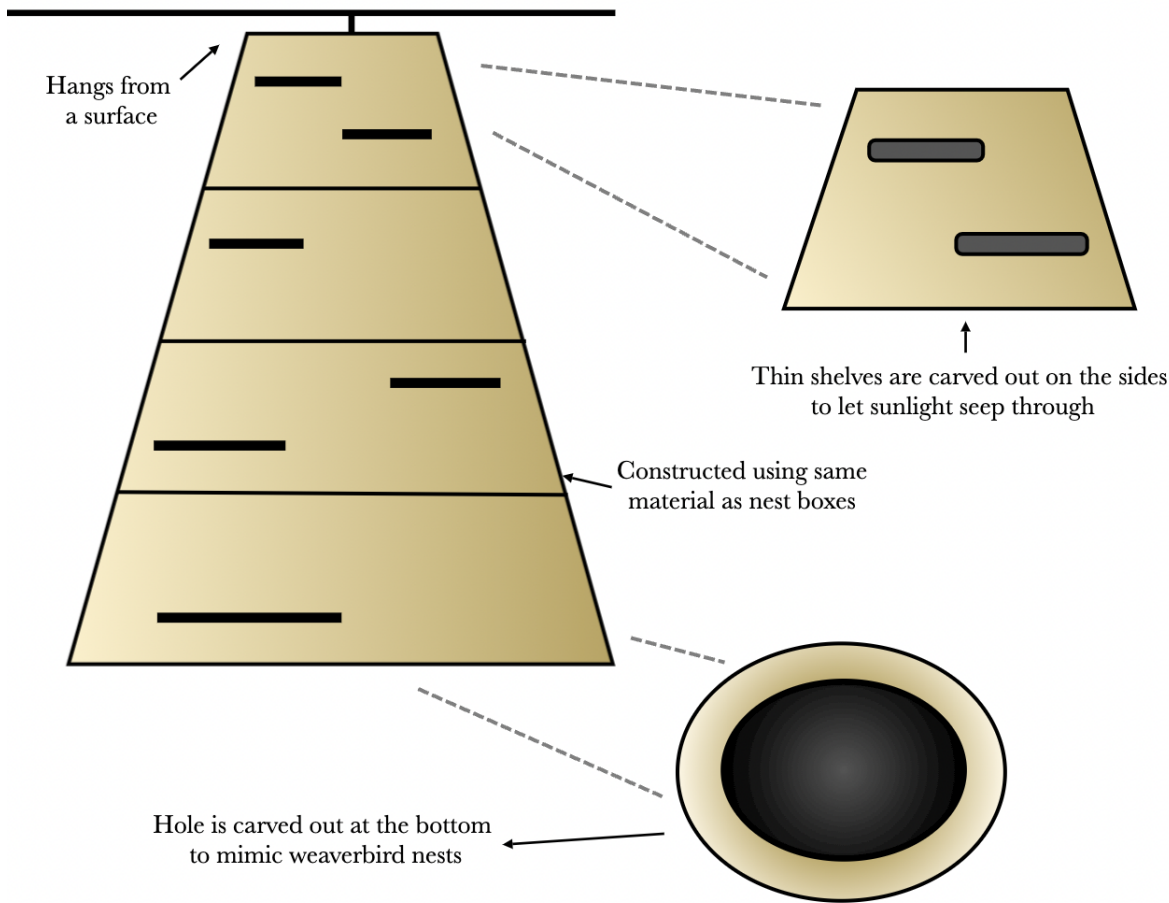


Fig. 2 [Nest towers that are layered to host a variety of bird species inside. A hole is carved out at the bottom for bird species that nest in holes while the thin shelves allow entry for smaller bird species in addition to sunlight.]

caused by human built-structures. Previous attempts at bird conservation have wavered on their commitment to take action and have focused primarily on restoring population sizes. Solutions to enhance the population of endangered bird species are only recently drawing inspiration from the analysis of elaborate bird nests such as that of weaver-birds, flycatchers and blue tits. The architectural features adapted by these species can be carefully imitated on human structures in the form of artificial nests to provide shelter for the endangered birds in urban cities which in turn, decreases the number of birds affected by buildings. Beyond this review of previously collected data, it is critical that future research is conducted in a timely manner because endangered bird conservation projects can take many years to accomplish, especially with the appropriate inclusion of stakeholders, governments, and current economic requirements. Potential avenues of future research include an in-depth study to investigate if urban birds can adapt to weaverbird nests and evaluating the compatibility of different urban

bird species living in shared nest towers to assess the possibility of competition, answering questions such as: Can urban birds successfully adapt to nests inspired by natural designs? How does the varying compatibility of different urban bird species affect their ability to coexist in shared nesting towers? How does the provision of artificial nests contribute to the overall urban biodiversity? The execution of such research, as well as the gathering of relevant resources, are critical in order to implement informed future plans. Human-built structures are an enduring landmark in cities, so it is crucial that bird conservation efforts seek to adapt green space in these areas. The practicality of this research can be applied to real-world urban planning and architecture. In collaboration with ornithologists, architects, and urban planners should consider incorporating artificial nests that provide optimal conditions for bird habitation into the design of new buildings and green spaces to enrich the urban bird population. Thus, the provision of nest materials for nest for bird species, as well as the construction of artificial nests

itself, will be useful in making an area adaptable. Ultimately, the mimicry of bird nest features can be generalized beyond bird conservation to the conservation of other wildlife species, as the implementation of key nest sites, rest sites, or other crucial habitat features can significantly enhance conservation in areas where these elements are being rapidly lost to human activity.

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