Issue 03 • November 2023
acumen.architecture.com.au/environment

ISSN 2651-9828

Ecological connectivity design strategies

Cristina Hernandez-Santin, Jane Toner and Bethany Kiss

Cover image. Land undergoing restoration area beside the Mon Repos Turtle Centre by KIRK. (Image: Scott Burrows)

Abstract

The Indigenous Ecosystem Corridors and Nodes Project (IEC+N) was launched in 2016 by the International Union of Architects (UIA) and the International Federation of Landscape Architects (IFLA). IEC+N aligns with 'designing for connectivity' as a critical component of Biodiversity Inclusive Design (BID), and responsiveness to the biodiversity emergency. One of the aims of IEC+N is to advocate for architects, landscape architects, and allied professionals to purposefully adopt design strategies and practices that enable species to freely move through urban landscapes and beyond. Designing for connectivity encourages the mindful curation of mobility pathways for biodiversity in conjunction with the creation of high-quality habitat nodes. This note aims to empower designers to design for connectivity by identifying practical strategies to create 'corridors' and high-quality 'nodes' for biodiversity within the built environment. Readers of this note will 1) learn foundational concepts of 'ecological connectivity' and how it supports urban biodiversity, 2) understand three key dimensions fundamental to 'designing for connectivity' and 3) access practical strategies to deliver Indigenous Ecosystem Corridors and Nodes.

Keywords: biodiversity, urban-greening, rewilding, multi-species design, Biodiversity Inclusive Design (BID), biodiversity sensitive urban design

Background – Biodiversity and the built environment

The Australian Architects Declare Climate & Biodiversity Emergency network urges architects and allied professionals to deliver built projects 'to create architecture and urbanism that has a more positive impact on the world around us' (Australian Architects Declare n.d.). Recognising the interdependence and interconnection of human and non-human life and the critical role biodiversity plays in creating liveable built environments, architects have an implicit responsibility to design in ways that will enable species long-term survival.

Sustaining the long-term survival and viability of biodiversity requires supporting the ability of species to move across the landscape (Taylor et al. 1993). Species mobility allows wildlife to access resources (ie food, water, shelter), disperse and maintain the genetic diversity of species populations (Taylor et al. 1993, Rudnick et al. 2012). Even plants rely on the free movement of wind, water or wildlife to disperse pollen and seeds (Nathan et al. 2008). Species mobility facilitates energy exchange across different ecosystems by shifting nutrients and beneficial microbes (Earl and Zollner 2017; Rudnick et al. 2012).

Built environments profoundly modify the ecosystems in which they are situated (Pickett et al. 2011). The hard, impermeable surfaces of urban and suburban landscapes alter microclimates. Rivers are re-routed, land is cleared, and soil compressed to provide space and material resources for buildings and their supporting infrastructure. The built environment fragments the landscape, reducing ecosystems into isolated habitat patches that act like islands (Hilty et al. 2012). These alterations disrupt landscape connectivity, hampering species' movement and modifying their behaviour. The built environment introduces barriers such as roads, light, noise, built structures (ie buildings) and land use intensity that exacerbate impacts on biodiversity (Kirk et al. 2022).

The spatial distribution of barriers can permanently alter species diversity and composition within urban areas. Fine scale changes can result in the decline of native species richness while invasive species increase (McKinney and Lockwood 2001; McKinney 2008). Unable to overcome barriers, less-mobile species begin to disappear leaving behind those that can adapt to novel resources offered by urban areas. Many of these species are territorial and aggressive, leading to further biodiversity decline. The noisy miner, a native Australian bird, provides a clear example of this phenomenon. In defending their territory, noisy miners drive out smaller, more vulnerable birds such as scarlet honeyeaters, brown honeyeaters, and eastern spinebills (Stone 2022). Noisy miners' competitive dominance is facilitated by the sparse canopy cover present in urban environments.

Biodiversity often concentrates in resource-rich nodes further emphasising the importance of facilitating clear passage across the fragmented urban landscapes.

Planners have a clear role to play in delivering connected urban landscapes within the broad-scale patterns of the city. Architects, landscape architects, urban designers and engineers can also intentionally design to increase connectivity. This entails careful consideration of the pathways currently available and those missing at every scale of the urban landscape. However, 'for many building industry professionals, the world of ecology and living systems can seem dauntingly complex' (Mang and Reed 2015: 8).

Designing for connectivity is a valuable skill for architects, landscape architects and urban designers. One of the fundamental principles of Biodiversity Inclusive Design (BID), designing for connectivity requires design professionals to learn related ecological concepts to facilitate productive collaboration with experts (Hernandez-Santin et al. 2022). It also requires gaining skills and knowing design strategies that promote ecological connectivity. This note presents information to support designing for connectivity organised in three overarching sections that:

1. Define ecological connectivity and its role in BID.
2. Describe three dimensions relevant to designing for connectivity: spatial, structural, temporal.
3. Identify four 'designing for connectivity' strategies: being locally attuned and responsive, facilitating species movement, creating high-quality habitat nodes and being culturally respectful.

Ecological connectivity and its role in Biodiversity Inclusive Design (BID)

Ecological connectivity is a measure of landscape continuity, defined by the degree to which genes, species and natural processes can flow across the landscape without encountering obstacles (Hilty et al. 2012; Taylor et al. 1993). Connectivity implies that the resources essential for a species' survival are available and accessible via pathways that allow unrestricted movement. The more fragmented a landscape is, the more important these pathways become.

Ecological corridors are the 'roads' and 'highways' for non-humans. An ecological corridor provides a route that facilitates species' movement between two ecologically diverse areas, or nodes (Hilty et al. 2012).

Synonyms include wildlife corridors, biological corridors, conservation corridors, landscape corridors and more. While nuances differentiate each term, they all describe pathways that enable species movement and dispersal across fragmented landscapes. In conservation science, ecological corridors are a popular strategy for connecting two or more protected areas and remnant habitats.

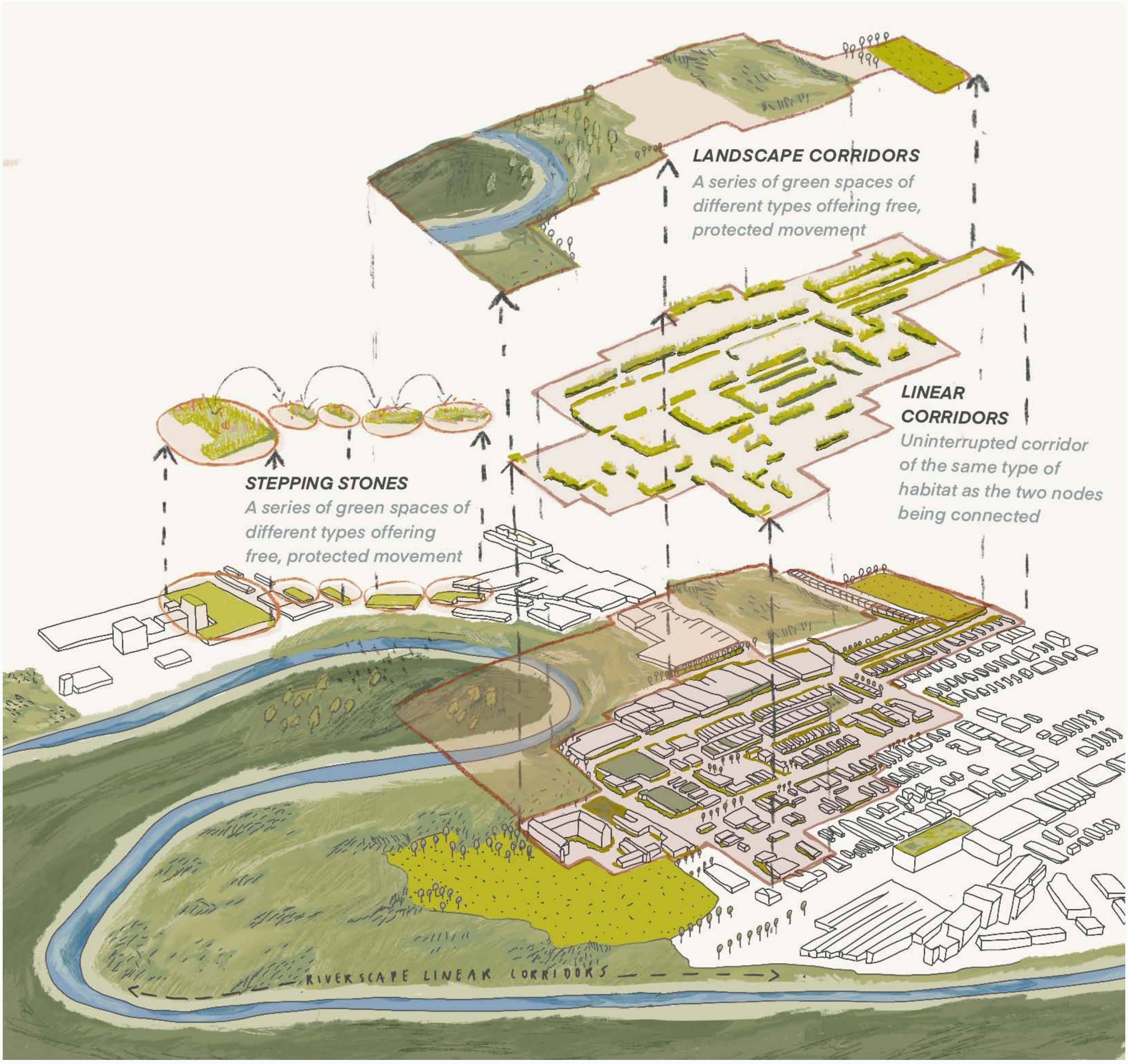

Figure 1. Elements and corridor typologies of an Urban Ecological Network. Drawing by Bethany Kiss. (Source: Authors)

Figure 2. Birds-eye view of the Pasadena Biodiversity corridor. (Image: Don Brice Photography and Outerspace Studios)

Corridors are becoming a popular planning strategy to support biodiversity within urban areas, where biodiversity-rich nodes might include wetlands, lakes, remnant habitat patches and golf courses (Hilty et al. 2012; Kirk et al. 2023; Kirk et al. 2018). In urban areas, ecological corridors might include streetscapes, riverways and even small parks or gardens. Depending on their characteristics, ecological corridors can be categorised as: linear corridors, steppingstones or landscape corridors (Figure 1). The combination of multiple corridors delivers an ecological 'transport network' of interconnected available pathways between existing nodes. As such, ecological connectivity is mediated by the structure of the urban matrix and the ecological 'transport' network within it.

Connectivity is also species-specific (Hilty et al. 2012; NatureServe 2023). Species have different physical characteristics, ecological requirements (habitat, resources) and movement capabilities that define how far they can travel and what comprises a barrier to their movement. Built environments introduce physical barriers that prevent species' movement between nodes even when the distance separating them is below a species dispersal distance (Kirk et al. 2022; Shepard et al. 2007). A species' mobility strategy – walking, hopping, swimming or flying – makes them resilient to some barriers and vulnerable to others. For example, roads and traffic intensity present more challenging barriers for non-flying organisms like frogs, reptiles and many mammals (Charry and Jones 2009). These obvious examples highlight that there is not one-size-fits-all strategy for connectivity.

Linear corridors provide the most straightforward way of connecting habitats. A linear corridor has the same characteristics as the remnant habitats it connects, offering a continuous 'natural highway'. The Pasadena Biodiversity Corridor in Kaurna Country, South Australia, shows how designers can retrofit an urban area into a wildlife corridor achieving multiple benefits for non-human and human inhabitants. This project de-culverts a stormwater drain restoring natural flows and supplies water for vegetation and wildlife through the creation of a series of ephemeral ponds and swales that link three green reserves (Green Adelaide 2022). The previous monoculture landscaping has been structurally enhanced and enriched with water-sensitive plants, an understorey and a more diverse native plant palette creating multiple niches and resources for wildlife. Strategies such as this serve as guides for residents within the area to adopt similar planting palettes in their gardens.

Figure 3. Pasadena Biodiversity Corridor. A diverse palette of understorey planting offers multiple niches and varied resources. (Image: Don Brice Photography and Outerspace Studios)

Figure 4. Pasadena Biodiversity Corridor. Water-sensitive urban design features create access to water and microclimates that benefit non-human and human inhabitants. (Image: Don Brice Photography and Outerspace Studios)

The pitfalls of connectivity

Creating natural corridors for local biodiversity is not without risk. Well-known risks include the spread of unwanted species, fire and predators (Haddad et al. 2014; Ogden 2015). While pathways can be used by invasive species, Haddad et al. (2014) found no evidence that ecological corridors significantly increase their presence. Corridors are also effective pathways for predators, enabling them to move more quickly, and potentially increasing the potential for predator-prey encounters (Dickie et al. 2020). An example of this is the Toowoomba bypass, Queensland, where animal crossings are most frequently used by feral cats, wild dogs and foxes (Daly and Sanders 2021). The potential risks of ecological corridors are currently under-researched but there is no known case study where the negative impacts outweigh the benefits (Ogden 2015).

Awareness of these risks should not detract from the critical need cities have for interconnected natural landscapes. In fact, being aware of the risks, can help design more successful solutions to support the movement of more vulnerable species. For instance, integrating many stopping points and potential shelters can give refuge and protection to prey species as they move across the landscape. Additionally, planning multiple ecological corridors provides a 'connectivity redundancy', allowing species multiple pathways to choose from while reducing predation opportunities. These and other examples constitute design responses emerging from careful consideration on how to design for connectivity.

Designing for connectivity

Designing for connectivity is the intentional act of designing and delivering 'highways' for local flora and fauna. Connectivity is simultaneously dependent on landscape structure and responsive to the characteristics and behaviour of individual species. At a species-specific level, the iterative design process for connectivity requires mindful consideration of how species move, the existing barriers to that movement and enablers for connectivity. Natural and built features within the urban landscape can be adapted to enable species movement (Figure 3).

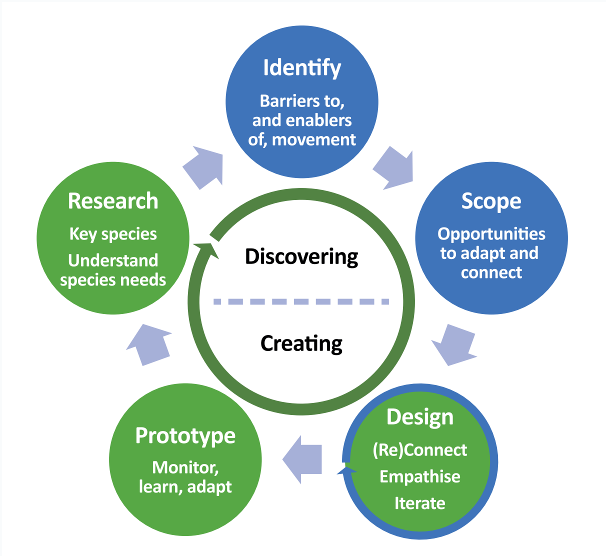

Figure 5. Integrating connectivity thinking into the iterative design cycle. (Source: Authors)

Connectivity is a multi-dimension and multi-scale concept. There are three key dimensions that influence ecological connectedness: structural, spatial and temporal (Figure 7 and 8). Each dimension is multi-scalar as it expands from micro- to macro-levels (ie from wall, to garden, to streets, to neighbourhoods, to local councils). For macro-scale ambitions to be realised, micro-scale connectivity must also be enacted. In a well-connected habitat, the resources available for a particular species coincide across all dimensions. The following sections discuss how species-specific requirements influence decisions to design for connectivity as well as providing examples of how considerations at each scale can occur in practice.

Structural dimension

Pathways for species movement occur at more than one habitat layer. A three-dimensional cross-section of a habitat has five broad layers: soil, ground cover, mid-story, canopy cover and the air layer above the canopy. Each of these layers can act as separate 'highways' catering to different kinds of species. Some organisms depend solely on the soil while others consistently move through the air.

A biodiversity connectivity study in Melbourne by Kirk et al. (2018) identified seven different species groups or biodiversity communities. Each group has different habitat needs which affect connectivity considerations (Table 1). While this is not a definitive list, it highlights how different biodiversity communities may rely on one layer more than another. Reptiles and amphibians are more dependent on the ground level while woodland birds rely on canopy cover. Tree-hollow using birds and bats need old trees with hollows to nest in but can fly above the tree canopy in search of resources. This has implications for what built features will act as a barrier to, or facilitator of, movement.

Understanding the structural needs of particular species within a landscape is fundamental to designing connectivity pathways for each structural layer. For instance at mid-storey level, tree-hollow using birds require refuge for roosting and nesting. This need could be catered for by design practices that retain hollow-bearing trees and incorporate artificially made hollows (Goldingay and Stevens 2009). Artificial refuges that are tailored to the specific functional requirements of targets species are important in restoring lost habitat (Cowan et al. 2021). For example, nesting boxes for small gliders and small parrots have small diameter entries that prevent access by larger tree-hollow users, such as bats and possums (Goldingay et al. 2020). Other aspects that influence which species take up residence in a nesting box include the orientation and shape and location of entry, texture, materials and tree species on which the nest is situated (Cowan et al. 2021; Lawton et al. 2022). Some designers are taking a proactive approach in this area. For example, a group at the University of Melbourne are testing the effectiveness of 3D-printed tree hollows designed specifically for the Powerful Owl (Parker et al. 2022). This innovative effort exemplifies how targeted design can create suitable habitats for endangered species.

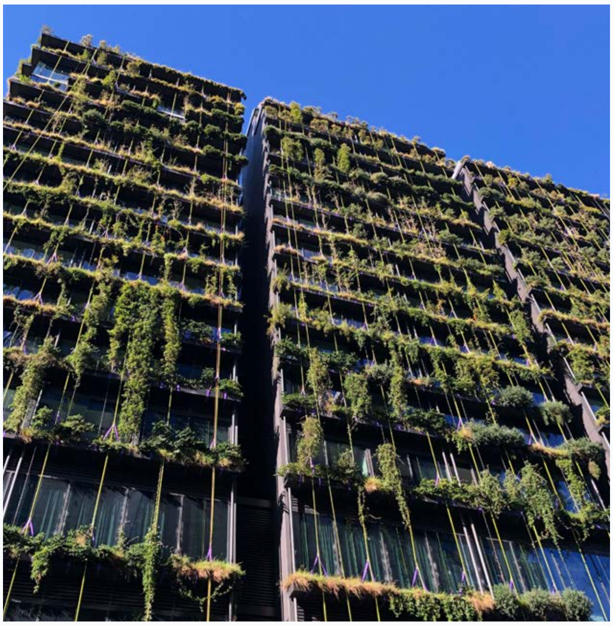

Figure 6. View of One Central Park, Chippendale, Sydney. Design architect: Ateliers Jean Nouvel - Collaborating architect: PTW Architects. Green Walls: Patrick Blanc. (Image: Jane Toner)

Once in-situ ecological requirements of a species are understood, designers can evaluate if site characteristics meet species' connectivity needs. A green roof might remain unreachable for some species where there are no vertical pathways stepping up the building. Even for flying organisms, green roofs high above the landscape may be outside of their movement range (Lepczyk et al. 2017). For example, a productive green roof (food produce) on an 8-storey building was inaccessible for Australian Native Bees but recorded European honeybees (Berthon 2022). Integrating green walls as vertical steppingstones that connect the ground level with a roof garden can potentially resolve this barrier to connectivity. A well-known and well-regarded example of vertical connectivity is One Central Park building in Sydney where vegetated balconies offer opportunities for birds, butterflies and other insects to find food and refuge at high altitudes (Narwal 2022) (Figure 6).

Biodiversity groups	Ecological dependencies	Applicable building types
Amphibians	▪ Access to waterbodies ▪ Waterbodies protected by a buffer area ▪ Early life stages are entirely confined to aquatic environments ▪ Adults have a limited ability to remain outside aquatic environments ▪ Access to starlight ▪ Key layers: water, ground cover	▪ Integrate raingardens, wetlands, water features, etc ▪ Frog hotels and havens designed for specific species' needs ▪ Buffer areas planted with reeds and rushes for protection ▪ Consider connectivity between nearby waterbodies ▪ Avoid artificial lighting
Aquatic insects	▪ Suitable waterbodies, particularly in the early stages of life ▪ Access to starlight ▪ Key layers: water, ground cover	▪ Diversity of aquatic and terrestrial micro-habitats ▪ Avoid artificial lighting
Insect pollinators	▪ Flowering resources ▪ Food plants for juvenile stage ▪ Suitable nesting sites ▪ Access to starlight ▪ Key layers: all layers	▪ Plant selection to consider nectar diversity, flowering seasonality and which species might benefit from different plants ▪ Insect hotels with diversity of insect scale holes and insect-friendly materials ▪ Avoid artificial lighting (Hunter and Hunter, 2008)
Reptiles	▪ Groundcover and organic litter for refuge ▪ Access to sunlight ▪ Shallow water sources ▪ Key layers: soil, groundcover	▪ Plant native grasses and ground cover ▪ Integrate 'sun-basking' rocks, logs and large pieces of bark to hide under
Tree-hollow using (micro) bats	▪ Tree hollows for safe, dry refuge during daylight hours ▪ Dark night skies ▪ Key layers: mid-storey, canopy, air	▪ Integrate artificial hollows (roost and nest boxes) designed with consideration for the particular species' needs ie size, shape, position, entrance location (Goldingay and Stevens, 2009) ▪ Refer to Bat Conservation International designs (Further resources) ▪ Avoid artificial lighting
Tree-hollow using birds	▪ Tree hollows for nesting and shelter ▪ Note: tree hollows usually form in trees that are 80 – 120 years old ▪ Key layers: mid-storey, canopy, air	▪ Integrate artificial hollows (roost and nest boxes) designed with consideration for the particular species' needs ie size, shape, position, entrance location (Goldingay and Stevens, 2009; Lawton et al., 2022) ▪ Avoid artificial lighting
Woodland birds	▪ Mid-story vegetation to nest, find food resources and hide from predators ▪ Key layers: mid-storey, canopy, air	▪ Indigenous and native plant selection ▪ Retain coarse woody debris (Walsh et al., 2023)

Table 1. Seven biodiversity groups in Melbourne. Biodiversity group allocation based on Kirk et al. 2018.

Spatial dimension

Pathways can be long or short depending on the species they are catering for. Every species has different mobility capabilities and behaviours, dispersal mechanisms and dispersal distances, which influence the relevant design dimension for connectivity.
For highly mobile species, like migratory shorebirds, large scale regional pathways are necessary to facilitate their migration (Commonwealth of Australia 2017).
For less mobile species, like superb fairy wrens, connectivity acts at smaller dimensions.

Designers who know the dispersal mechanisms and distances of their non-human stakeholders can prioritise the scale of pathways that need to be addressed (see Figure 7). For example, a peregrine falcon can maintain a territory of 20-30km^2 (Australian Museum, 2019) while a growling grass frog might take a day to hop one kilometre between two water bodies (DCCEEW n.d.). Optimising connectivity opportunities for these two species might require a focus on regional scale and neighbourhood scale respectively.

Figure 7. Structural and spatial connectivity. Drawing by Bethany Kiss. (Source: Authors)

A family of superb fairywrens conducts their foraging and social activities within a territory of half a hectare (Adams 2015), equivalent to about 10 private gardens. At an even smaller scale, small invertebrates and soil micro-organisms might stay within the same garden their whole life. While these examples represent a few different species from different biodiversity groups (amphibians, birds, invertebrates), it should be noted that there can be large differences between different species within the same group. As a highly mobile frog, the aforementioned growling grass frog, surpasses the dispersal distance for many frog species.

Adulthood marks a spike in the mobility of most species. For some, this is a response to natural dispersal strategies to establish new territories, while for others it is a response to physical changes experienced across their life cycle. For example, when male superb fairy wrens reach maturity they move to a neighbouring area, avoiding competition for limited food resources and maintaining genetic diversity. Conversely, other taxonomic groups, such as amphibians, undergo dramatic transformations between their juvenile and adult forms, each with vastly different mobility needs. It is important to note that mobility capabilities and behaviours are as diverse as life itself.

To design for connectivity at micro-scales, think about your dining and grocery shopping habits. How far do you go to get your food? Do you regularly go to a restaurant or market store that is more than one hour from your house or workplace? Most people get their groceries from the closest markets and will regularly go to the same coffee shops and restaurants close by. Animals do the same. Regardless of the maximum dispersal distance for a species, movement is more frequent where there are many steppingstones in close proximity. For example, urban birds move more frequently when the travel distance is ~10m (Silva et al. 2020). This results in healthier populations that are genetically diverse. Design decisions made by architects and landscape architects can facilitate or hinder the ability of species to find resources and in return pollinate plants. Within the project boundary, architects and allied professionals can intentionally integrate the resources a species needs to survive and create clear linkages between their 'home' and 'supermarkets'.

Temporal dimensions

Pathways can also be rendered inaccessible depending on temporal changes in the landscape. The ecological requirements of a species may change over their lifecycle (ie frogs and butterflies), or relate to their foraging habits, habitat preferences and peak times of activity (ie diurnal or nocturnal species). Resources offered within a landscape vary between day and night, seasonally, or even over cycles of multiple years, such as La Nina and El Nino.

Just like when people encounter a flooded road, temporal environmental changes can render biodiversity pathways temporarily inaccessible. Imagine that you are a woodland bird living in the suburbs of Canberra. Your preferred habitat has evergreen trees that offer food and refuge all year round, but now you are in the suburbs. A series of parks and streets with continuous canopy cover enables you to move freely between your favourite roosts, but 50% or more of the trees are exotic (Brack and Schirmer 2020) and lose their leaves over the cold season. As exotics lose their leaves, the refuge they offer is diminished and your habitat becomes temporally disconnected. Similarly for pollinators dependent on flowering vegetation, landscapes dominated by Spring flowering plants can pose a challenge to survival once flowering season ends (Figure 8).

To design for temporal connectivity, architects and allied professionals should actively reflect on resource availability and how it varies over time. Are the species I am designing for active during the day or at night? Are there available pathways all year round? Do the plants that I am incorporating into my building or garden offer food, shelter or resources for local biodiversity?

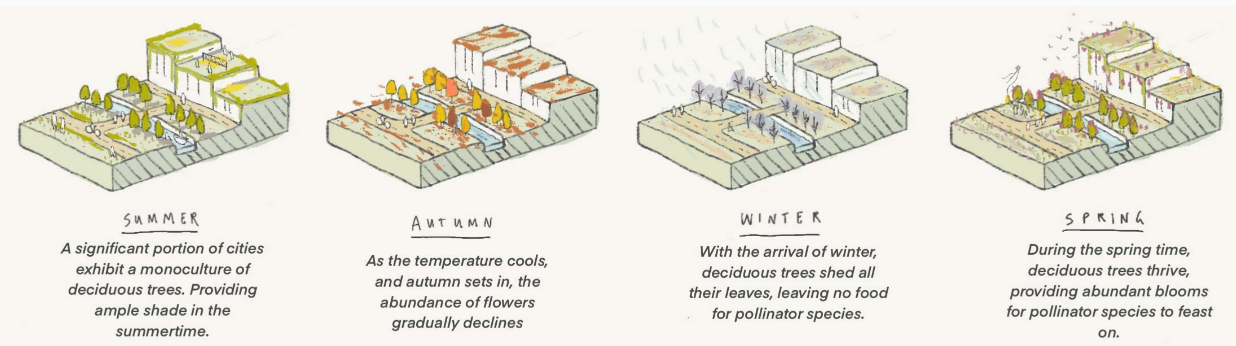

Figure 8. Temporal connectivity (seasonal). Drawing by Bethany Kiss. (Source: Authors)

Strategies to design for connectivity: The IEC+N lens

It is not enough to protect the species that remain within urban landscapes, we also need to invite nature to return (Mata et al. 2020). Connectivity offers opportunities to support the survival of urban biodiversity while enabling re-colonisation by locally extinct species.

Designing for connectivity is an ambitious practice-led response that requires designers to simultaneously think about landscape-level structural patterns and species-specific characteristics and behaviours.

Designers should mindfully incorporate the types of resources and structures that each species needs to survive from micro- to macro-spatial scales, designing in three dimensions (structural dimension) and considering temporal variations. As such, strategies to design for connectivity require the integration of bespoke solutions adapted to the specific requirements and abilities of individual species or biodiversity communities.

This section proposes a series of recommendations and strategies to design for connectivity. Responding to the call posed by the IEC+N Project (see IFLA and UIA 2019 for project launch statement), the section is arranged around four key elements that architects, landscape architects and allied professionals should *design for*: [indigenous] Ecosystem, Corridors, Nodes and Culturally respectful practice.

Note: The IEC+N project was launched within a European context where the term 'indigenous' referred to species, habitats and ecosystems native to a particular place. The intention being to advocate for hyper-local responses. In Australia, the term indigenous or Indigenous has different meanings: indigenous (lower case) to describe locally native species or ecosystems and the capitalised form 'Indigenous Australians' has been used as a broad term referring to First Nations peoples.

[indigenous] Ecosystem – Be locally attuned and responsive

Biodiversity Inclusive Design (BID) is inherently a place-based design process (Hernandez-Santin et al. 2022). BID encourages designers to learn about the ecosystems that once existed in a project's location and the changes through time. BID is an invitation for built environment practitioners to collaborate with ecologists and use their learnings to foster biodiversity within urban areas.

Good design recognises the history of a place and interweaves its story into the future.

An ecological understanding of living systems is fundamental (Mang and Reed 2015), as is exploring the past, present and future roles of individual projects and their potential to regenerate biodiversity. For example, the Mon Repos Turtle Centre, Queensland (refer cover image), is a research and environmental education and conservation centre for loggerhead turtles (see Thomson 2020). Recently redeveloped, the architects of Kirk Studio reorganised the built structures to respond

Figure 9. People participating in a turtle encounter at Mon Repos Conservation Park. (Image: © Tourism and Events Queensland)

Australian Institute of Architects

to place (Figure 9). The carpark along the foreshore was relocated with the land returned to sand dunes, providing refuge for turtles looking for suitable nesting grounds. This project also offers lessons on minimising impacts during construction and post-occupancy phases of design by scheduling construction activities around the turtles' lifecycle and eliminating light pollution. The latter strategy is of vital importance as turtles use moonlight to orient themselves towards the sea and bright lights near beaches can disorient turtles causing them to move inland rather than head towards the ocean (Silva et al. 2017). Bright lights also reduce nesting success and lead to higher predation (Silva et al. 2017). The architects showcased what careful consideration of the place for its non-human users can achieve in both design and construction.

Key activities for architects and allied professionals to incorporate connectivity as a place-based response include researching, mapping, creating connections and planning for change (Table 2).

Temporal dimension	Design activity	Recommendations
PAST	**Researching**	▪ Identify and understand key ecological patterns and processes within the site and its surroundings. ▪ Gather information on biodiversity and key species. Look for resources with First Nations peoples, local council, local environmental community groups, and species' profiles by reputable science communication outlets such as Bird Life Australia, Atlas of Living Australia, state government websites, etc. ▪ Identify species that have been displaced (which species used to live here but are not here anymore?).
PRESENT	**Mapping**	In relation to your site, identify and map: ▪ Species presence and distribution on the site and nearby surrounding area. ▪ Biodiversity-rich nodes – remnant habitats, conservation areas, and parks with high levels of biodiversity. ▪ Existing pathways for movement – linear corridors, landscape corridors, and steppingstones, along with formal and informal green spaces that contribute to the ecological network. ▪ Existing barriers that prevent species movement – roads, fences, light, noise, land-use intensity (ie traffic, busy parks, etc). ▪ Flows of, and barriers to, ecological processes – water cycle, soil cycle. Compare with ecological processes of the past (what is missing?). ▪ Potential for species movement at spatial, structural and temporal dimensions.
	Creating connections	▪ Identify opportunities to create connectivity. ▪ Determine key species or biological communities to design for. ▪ Establish the role the site might play in enhancing ecological networks (is your project a steppingstone or a linear corridor?).
FUTURE	**Planning for change**	▪ Consider the impacts of climate change. This may include selecting a planting palette with species adapted to future climate conditions and zoning the land in response to environmental risks (ie flooding, fire, etc). ▪ Allow for adaptation. ▪ Practice multifunctional design.

Table 2. Recommendations to incorporate connectivity as a place-based response by considering long-term temporal dimensions. Recommendations can be completed directly by the design team or by engaging biodiversity consultants. Collaborative pathways are recommended.

Corridors – Facilitate species movement

Architects and allied professionals should explore opportunities to remove barriers preventing species' movement and to integrate corridors that facilitate their dispersal. Garden House, in Western Port, Victoria, offers an example of how barriers can be removed by touching the earth lightly (see Dodd 2015; Baracco and Wright 2014). Designed by Barraco and Wright, this holiday home has a raised wooden platform 'covered by a transparent 'shed', the interior perimeter 'veranda' is garden space' (Baracco and Wright 2014). By opting for a raised platform, the architects retain the topography and continuity of the site allowing water and ground-dwelling creatures to flow across the landscape with minimal interruption (Figure 10). Another way to promote flow is to remove physical barriers that restrict access. Removing picket fences, integrating wildlife doors, and opting for living or permeable fences are examples of small-scale strategies that can strengthen larger-scale ecological networks.

Designers can integrate living and non-living infrastructure that facilitates species movement. Corridors delivered through living infrastructure include formally designed streetscapes, road median strips, drainage lines (vegetated swales), vegetated biodiversity bridges and informal green spaces such as vacant lots, nature strips and vegetation on railway verges. Informal green spaces are critical in delivering an interconnected ecological network in the city (Rupprecht et al. 2015; Rudd et al. 2002). Non-living infrastructure can also support species' movement (eg tension cables, biodiversity bridges and tunnels). While some structures can help multiple species simultaneously (ie large natural bridges and tunnels), others use bespoke solutions designed with species characteristics and preferences in mind (Figure 12). Examples of this include a bridge constructed along the overland migration route of red crabs on Christmas Island which uses a mesh that allows crabs to climb up and over a road (Standen 2017) and tunnels for frogs and other reptiles like those installed in Cape Town, South Africa to reduce road mortality (Woltz 2008; TMKsouth 2021). Awareness of successful solutions can help designers identify those that can feasibly be integrated into their projects.

Synergy between micro- and macro-scales of connectivity is critical. Local governments across Australia provide resources to support design for connectivity. For example, many Victorian councils are associated with the 'Gardens for Wildlife' initiative which positions individual gardens as habitats and steppingstones for local flora and fauna (Gardens for Wildlife Victoria 2021). Councils associated with the program offer resources to support the design and delivery of wildlife havens.

Figure 10. Garden House by Baracco and Wright Architects depicting a transparent tent-like structure with an elevated wooden platform on the inside. (Image: Rory Gardiner)

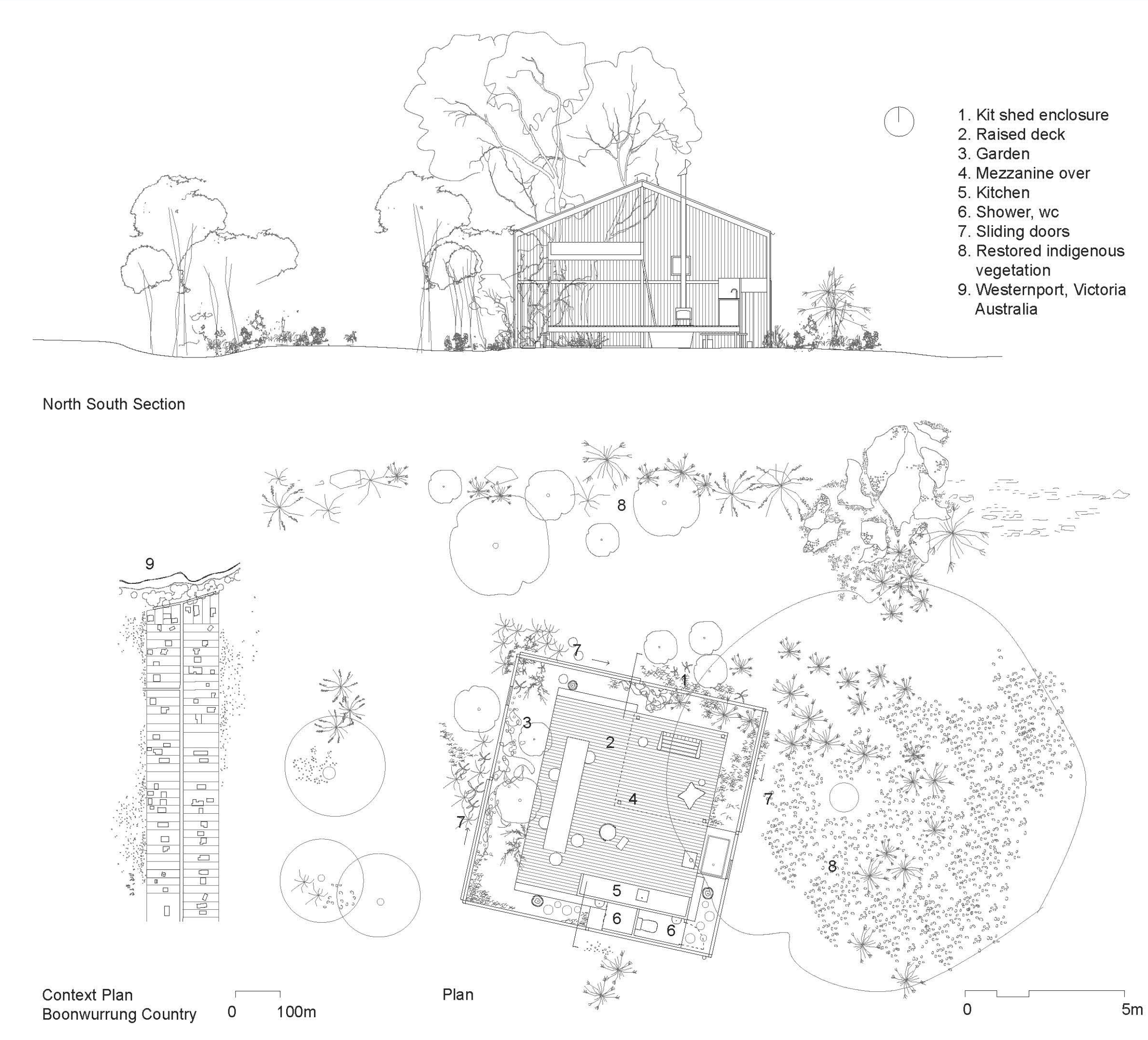

Figure 11. Garden House by Baracco and Wright Architects site plan. The house is located in a space within the property that was vacant and where water accumulated. Raised stilts allow for ongoing continuity of the landscape at a site scale. (Image: Baracco and Wright Architects)

Figure 12. Wildlife bridge. (Image: Brisbane City Council)

Figure 13. Red crab migration across a road through a specially constructed bridge on Christmas Island. (Image: Yvonne McKenzie / © Wondrous World Images 2023)

Design activity	Recommendations across multiple dimensions
Facilitate movement	Remove spatial barriers: ▪ Design for walkability – reducing car dependency minimises roads and their usage intensity. ▪ Remove fencing, integrate wildlife doors or opt for living or highly permeable fences. ▪ Lower speed limits. This includes planning-led responses such as 'dusk to dawn' speed limits or design-led responses to reduce traffic speed to increase walkability. Remove structural barriers: ▪ Emulate vegetation cover patterns of native habitats. ▪ Establish consistent vegetation coverage at ground, midstory and canopy layers. ▪ Integrate steppingstones suitable for target species. Remove temporal barriers: ▪ Supply a variety of resources available at different times. ▪ Consider changes in diurnal-nocturnal resources. ▪ Integrate biodiversity-friendly lighting to reduce light pollution. ▪ Consider changes in seasonal resources. ▪ Integrate 'lights off' programs during migratory seasons.
Design corridors	▪ Large-scale biodiversity bridges or tunnels. ▪ Incorporate vegetation cover in proximity. ▪ Tension cables for canopy-dependent organisms. ▪ Integrate amphibians and reptile tunnels. ▪ Integrate multiple pathways to connect two nodes.
Connect with local programs	Examples of potential programs available locally: ▪ Consult with local environmental community groups (ie "Friends of" groups, Rewilding initiatives). ▪ Find council-led biodiversity plans and connectivity initiatives (ie Urban forestry strategies, Biodiversity strategies. ▪ Find relevant council or community-led programs (ie Gardens for Wildlife).

Table 3. Recommendations to facilitate species movement by removing barriers, designing corridors and connecting with relevant local programs.

Nodes – Create high-quality habitats

Enabling ecological connectivity is a well-regarded biodiversity conservation strategy, but creating high-quality habitats is another critical element in designing for biodiversity. Hodgson et al (2009) warn about the risks of focusing all efforts on connectivity. Some organisms depend upon fine-scale characteristics more than they are affected by large-scale connectivity. This applies, for instance, to ants and spiders where artificially made structures are strong barriers preventing their movement (Peng et al. 2020).
In this sense, designing for connectivity also requires designers to focus on delivering high-quality habitats for local biodiversity.

The characteristics of a space determine the quality of the habitat for each species. A designer can integrate living and non-living infrastructure that offers valuable resources to local biodiversity including food, water and refuge. From small to large, every green space can act as a 'biodiversity rich node'. Private gardens can have high insect diversity (Braschler et al. 2020). Green roofs and green walls rich in native plantings can attract native wildlife (Lepczyk et al. 2017).

Built structures also offer refuge opportunities for biodiversity (Figures 14-18). Bricks designed to house different species are now available as viable materials integrated into building facades (ie bee bricks, bird bricks and bat bricks). Students at the University of Buffalo, USA, designed 'Elevator B' (Figure 14), a bee-hive tower as a structural art piece that supports pollination (Tan 2022). Walls (Figure 15), and even walkways (Figure 16), can provide structures and crevices for different animals including land-based and marine organisms (Metcalfe 2015; Living Seawalls 2022; Tan 2022). The integration of nesting boxes can be specifically designed for different organisms (Figures 17 and 18). Be aware that different organisms have different requirements, characteristics and preferences for their homes (ie see Lawton et al. 2022); making it important to target structures that are designed for Australia's native fauna.

Figure 14. Built structures providing refuge for different species. Elevator B project. (Image: Hive City Design Team (Courtney Creenan, Kyle Mastalinski, Daniel Nead, Scott Selin, Lisa Stern))

Figure 15. Built structures providing refuge for different species. Living Seawalls. Emulating reef characteristics to provide habitat for marine organisms. (Image: Reef Design Lab)

Figure 17. Bee and insect hotel at the University of Melbourne. Built structure providing refuge for different species. (Image: Courtesy of the University of Melbourne)

Figure 16. Built structures providing refuge for different species. Walkway tiles for marine organisms. (Image: Daniel Metcalfe)

Figure 18. Built structures providing refuge for different species. A Krefft's glider in a glider nest box. (Image: Jess Lawton)

Architects and allied professionals wishing to foster biodiversity within their design practice must find opportunities to create habitats for a diversity of species.

A habitat comprises all the resources -alive and not- that are present in a locality, and which support a species' ability to survive and reproduce.

By definition, habitat calls for species specificity as the type of resources each species needs will vary. Critical resources include food, water and refuge (ie nesting); but these resources vary depending on the species. Working through individual key species – often called 'focal' species, or grouping species according to the groups of biodiversity they belong to, architects and allied professionals can deliver habitat nodes that attract native wildlife. Some things to consider are included in Table 4.

Resources	Recommendations across multiple dimensions
FOOD	▪ Curate a planting palette that offers valuable resources for non-humans. ▪ Enable availability of food resources all year round. ▪ Prioritise a 'natural' look and native plantings (Berthon et al., 2021). In relation to focal species, integrate food resources available all year round. ▪ Integrate flowering resources available every season. ▪ Integrate flowers of different morphologies (small, large, colour variety, shapes, etc).
WATER	In relation to focal species, integrate water features that are accessible: ▪ Integrate permanent or semi-permanent water sources at ground level for amphibians, water-dependent organisms and ground dwellers. ▪ Integrate bathing fountains for birds.
REFUGE	In relation to focal species, integrate nesting opportunities: ▪ Where possible, retain old trees with hollows for hollow-dependent fauna. ▪ Incorporate built structures designed for the focal species (ie habitat walls, bee bricks, bee hotels, bird bricks, bat bricks, nest boxes). In relation to focal species, integrate coverage to hide from predators: ▪ Integrate groundcover, mid-story and canopy cover emulating coverage patterns of a reference habitat. ▪ Incorporate rocks and organic litter as a design feature for lizards and insects. ▪ Add aquatic vegetation to water bodies including emergent, floating and submersed vegetation (as suitable to locality). Emergent vegetation have their root system on the soil and need to be partially underwater to survive (ie grass sedge). Floating vegetation has leaves that float above the water (ie water lily). Submersed vegetation is completely underwater (ie seagrass).

Table 4. Recommendations to provide critical resources for different species or biodiversity communities.

Be culturally respectful

As shapers of the built environment, architects are responsible for designing and delivering projects that 'respect, conserve and enhance, the natural and cultural environment' (Australian Institute of Architects 2006: 2). The Australian working group of the IEC+N project has embraced the different meanings ascribed to the terms indigenous or Indigenous, as outlined above, and encourages designers to practice design that connects to Country as a local response. This was evidenced in the Australian Institute of Architect's IEC+N Masterclass (1 and 15 July 2021) where Wailwan|Kamilaroi architect Jefa Greenaway shared his work. The 'Being culturally respectful' strategy of the IEC+N project argues that designers cannot truly be designing for ecological connectivity in Australia without recognising, valuing and integrating the deep cultural relationship that First Nations peoples have with Country through design.

There is a growing movement within the architectural profession to embrace culturally sensitive and respectful approaches to Designing for Country (Page and Memmott 2021). Inherent within these approaches is the need to develop an understanding of the deep ecological relationships and knowledges held by First Nations peoples. The dominant development practices that have shaped the built environment have directly contributed to the erasure of First Nations cultural narratives (Rees 2018). The decolonisation of design practice is already in progress (Mouritz and Breedon 2022), but non-Indigenous practitioners have much to unlearn and learn towards developing cultural competency – authors of this publication included. This includes critical attention to countering the privilege, power and exclusion embedded within colonisation by collaborating and co-creating design solutions with the traditional Knowledge Holders of the place (Page and Memmott 2021; Government Architect New South Wales 2020; Rees 2018).

Developing cultural competency is not the focus of this paper, and as non-Indigenous authors, we are not qualified to comment, but we can invite all designers to engage with First Nations authors and practitioners actively working in this field of knowledge. For example, Danièle Hromek, a spatial designer and Budawang/Yuin woman, along with her colleagues, crafted 14 principles that guide non-Indigenous practitioners in designing with Country (Hromek 2023). The 'Reconcile yourself and your practice' principle, proposed by Michael Mossman – a Kuku-Yalanji man with deep roots in Cairns on Yidinji Country, highlights the architect's role in cultural reconciliation. This principle requires non-Indigenous practitioners to establish respectful partnerships with Knowledge Holders to ensure that the distinct stories and characteristics of Country are reflected in architectural work.

An example of these partnerships in action is demonstrated by the Puntukurnu Aboriginal Medical Service (PAMS) Rammed Earth Health Hub, East Pilbara, Western Australia by Kaunitz Yeung Architecture. Through an extensive and iterative co-design process, this wellness centre is culturally connected to Country through art, local materials and landscaping. The central courtyard brings Country into the building through landscaping which flows through to a public park that was regenerated with over 2000 endemic plants (Figures 19 and 20).

Deep engagement between First Nations and non-Indigenous peoples delivers many co-benefits including an active exchange of knowledges and the physical and cultural connection between the built project and Country (Hromek 2023; Woodward et al. 2020; Kennedy et. al 2018). Engaging with communities across cultures can be difficult, but it is not new and can deliver high social value within design projects (Edmonds 2021). In engaging with First Nations peoples, Woodward et al. (2020) offers key principles and case studies of engagement. This body of work inspired the Three-Category Approach which outlines three levels of engagement between ecology researchers and First Nations peoples: communicate, collaborate and co-design (see CAUL n.d.).

Figure 19. Rammed Earth Health Hub by Kaunitz Yeung Architecture integrates Indigenous Ecological Knowledges and indigenous vegetation to connect to Country. (Image: Robert Frith)

Figure 20. Rammed Earth Health Hub by Kaunitz Yeung Architecture integrates Indigenous Ecological Knowledges and indigenous vegetation to connect to Country. (Image: Robert Frith)

Conclusion

This publication acknowledges the profound impacts that built environments impose on biodiversity and architects' responsibility to design for species survival. Built environments that support species survival involves recognising the need for connected landscapes that enable both free movement across the landscape and refuge. However, landscapes are not static and uniform, they are everchanging dynamic and diverse mosaics.

Designing for connectivity offers a pathway to design for non-humans in the urban fabric. It requires architects and allied professionals to learn how to look at the project site and its surrounding context through the perspectives of the various species who might live there with an awareness of their movement strategies, behaviours and needs. This awareness must extend across three key dimensions: spatial, structural and temporal, which need to be addressed in combination and at multiple scales.

Designing for connectivity is part of a place-based design process. To ensure a comprehensive understanding of the ecology of place and effective integration of ecological principles, collaboration with ecologists and transdisciplinary design processes are needed. Additionally, authentic engagement and partnerships with Knowledge Holders should be sought to add meaning and depth to the design response, ensuring that it is culturally respectful. This paper presents concepts and strategies for architects and allied professionals to design for ecological connectivity by being locally attuned and responsive to place, creating habitat nodes, facilitating species movement and collaborating with Knowledge Holders.

Further resources

Activity	Useful tools and research resources*
Identify local biodiversity	▪ Atlas of Living Australia: a database collating all species recorded through scientific research and citizen science (ie birdwatchers).
Scope opportunities and case studies.	▪ Urban Nature Atlas: a collection of more than 1000 nature-based solutions from European cities and beyond – map based and allows new projects to be added.
Guides to design for different organisms	▪ How to Build a frog hotel: an online guide to frog-friendly structures in the backyard as provided by the Wildlife Preservation Society of Queensland. ▪ A frog pond for the backyard: a checklist of features to incorporate into your garden ponds provided by the RSPCA in Queensland. The article linked above has a factsheet to download to help Queenslanders design for their amphibian neighbours. ▪ Attracting Lizards: an informative guide on how to attract and care for lizards in your garden. ▪ How to build bat boxes: a resource created by Bat Conservation International to build bat homes for tree dependent bats. Please note that some Australian species may require some differences in design. ▪ Installing bat boxes: a resource specific to designing bat roosting boxes in an Australasian context.
Connect with local programs	▪ 'Gardens for Wildlife' Victoria: a voluntary program where councils provide aid and resources to private dwellers wishing to deliver a biodiversity-friendly garden. See here for participating councils. ▪ Land for Wildlife: a voluntary property registration scheme for landholders who wish to manage areas of wildlife habitat on their property.
Evaluate	▪ Green Factor Tool: A tool for architects, landscape architects and allied professionals to evaluate a project's green infrastructure. This tool is site-specific and was created for the City of Melbourne.

* Please note that this is not an exhaustive list of resources.

What is IEC+N

The International Union of Architects (UIA) and the International Federation of Landscape Architects (IFLA) have a long association. They also have a Memorandum of Understanding providing for engaging together in joint projects. The Indigenous Ecosystem Corridors and Nodes (IEC+N) project supports such cooperation between the professions and offers an open invitation for the participation of other professions and relevant organisations. Please share your projects with the IEC+N team.

Acknowledgements

We acknowledge and pay respect to the Traditional Owners of the lands from which we have written this paper, the Wurundjeri people of the Kulin Nations (RMIT, Melbourne CBD campus) and the land of the Yugarabul, Yuggera, Jagera and Turrbal peoples (Griffith University, Nathan campus). This paper is written from the perspective of non-indigenous women who live, work and play on unceded lands.

We acknowledge the contributions of professionals associated with the IEC+N Project who have contributed time and thinking to conceptualise the project and its intention. Particular acknowledgement goes to Tony Williams (IFLA) and Professor Allan Rodger (UIA) for the pivotal role they played initiating the IEC+N project internationally.

We also acknowledge the substantial contribution made by the Clean Air and Urban Landscapes Hub (CAUL Hub), funded by the National Environmental Science Program (NESP) and the Interdisciplinary Conservation Science Research Hub (ICON Science) at the Centre of Urban Research, RMIT. The work of this publication draws heavily from the work of authors associated with these hubs. We acknowledge that there are other noteworthy research hubs across Australia contributing to this field of knowledge; however our authorship team intimately knows the research being produced by CAUL-NESP and ICON which resulted in showcasing the work produced by these hubs, such as the use of resources from Biodiversity Sensitive Urban Design. While we have attempted to balance references and case studies throughout Australia, there is some weighting towards the case studies we are personally familiar with.

We acknowledge the valuable contribution in clarity of expression provided by anonymous peer reviewers as well as Sarah Bekessy (ICON Science), and Belinda Strickland (National Editor Knowledge Services, Australian Institute of Architects) for the thoughtful feedback provided on earlier versions of this note. Additionally, we thank writing coach Karyn Gonano (KLG Communications) and the writing circle led by Cities Research Institute (Griffith University) for enabling the authors to undertake a sense-checking discussion of the language and structure used in the paper through a regular writing circle (March 2023).

References

Adams G (2015) Birdscaping Australian Gardens.

Australian Architects Declare (n.d.) Australian Architects Declare Climate and Biodiversity Emergency, Australian Architects Declare website, accessed 12 November 2023.

Australian Institute Of Architects (2021) Masterclass: Indigenous Ecosystem Corridors and Nodes, Australian Institute of Architects website.

Australian Institute Of Architects (2006) Code of Professional Conduct [PDF], accessed 9 November 2023.

Australian Museum (2019) Peregrine Falcon, Australian Museum website, accessed 29 May 2023.

Baracco M and Wright L (2014) Garden House, Baracco Wright website, accessed 12 Aprril 2023.

Berthon K (2022) 'Greenspace design for plant-insect interactions in the city', PhD Thesis, RMIT, Melbourne.

Berthon K, Thomas F and Bekessy S (2021) 'The role of 'nativeness' in urban greening to support animal biodiversity', *Landscape and Urban Planning*, 205 (103959).

Brack C and Schirmer J (2020) Social, *Economic and Environmental Value of Street Trees in the Urban Environment*, ACT Government Publishing Services.

Braschler B, Gilgado JD, Zwahlen V, Rusterholz HP, Buchholz S and Baur B (2020) 'Ground-dwelling invertebrate diversity in domestic gardens along a rural-urban gradient: Landscape characteristics are more important than garden characteristics', *PloS one*, 15 (e0240061).

CAUL Hub (Clean Air And Urban Landscapes Hub) (n.d.) Three Category Approach, CAUL Hub website, accessed 08 November 2023.

Charry B and Jones J (2009) *Traffic volume as a primary road characteristic impacting wildlife: a tool for land use and transportation planning.*

Commonwealth of Australia (2017) 'Celebrating Australia's Migratory Waterbirds and their habitats - Showcasing Australia's Flyway Site Network', *Department of the Environment and Energy* (ed).

Cowan MA, Callan MN, Watson MJ, Watson DM, Doherty TS, Michael DR, Dunlop JA, Turner JM, Moore HA and Watchorn DJ (2021) 'Artificial refuges for wildlife conservation: what is the state of the science?', *Biological Reviews*, 96 (2735-2754).

Daly J and Sanders B (26 October 2021) *Wildlife corridors study of $1.6b bypass reveals feral animals the biggest users.*

DCCEEW (Department of Climate Change, Energy, the Environment and Water) (n.d.) 'Litoria raniformis – Growling Grass Frog, Southern Bell Frog, Green and Golden Frog, Warty Swamp Frog, Golden Bell Frog', *Species profile and Threats Database*, Australian Government, accessed 29 May 2023.

Dickie M, Mcnay SR, Sutherland GD, Cody M and Avgar T (2020) 'Corridors or risk? Movement along, and use of, linear features varies predictably among large mammal predator and prey species', *Journal of Animal Ecology*, 89 (2):623-634.

Dodd M (2015) 'Garden House', *Architecture Australia*, 104:66-71.

Earl JE and Zollner PA (2017) 'Advancing research on animal-transported subsidies by integrating animal movement and ecosystem modelling', *Journal of Animal Ecology*, 86:987-997.

Edmonds A (November 2021) 'Supporting social value through the design process', *Acumen Practice Notes*, Environment Issue 4, Australian Institute of Architects.

Gardens for Wildlife Victoria (2021) Programs and Affiliates, Gardens for Wildlife Victoria website, accessed 13 April 2023.

Green Adelaide (2022) Everything you need to know about a new biodiversity corridor in Adelaide's south, Green Adelaide website, accessed 29 May 2023.

Goldingay RL and Stevens JR (2009) 'Use of artificial tree hollows by Australian birds and bats', *Wildlife Research*, 36:81-97.

Goldingay RL, Rohweder D and Taylor BD (2020) 'Nest box contentions: are nest boxes used by the species they target?', *Ecological Management & Restoration*, 21(2):115-122.

Government Architect New South Wales (2023) 'Connecting With Country: Good practice guidance on how to respond to Country in the planning, design and delivery of built envionment projects in NSW', Issue 2.

Haddad NM, Brudvig LA, Damschen EI, Evans DM, Johnson BL, Levey DJ, Orrock JL, Resasco J, Sulilivan LL, Tewksbury JJ and Wagner SA, (2014) 'Potential negative ecological effects of corridors', *Conservation Biology*, 28(5):1178-1187.

Hernandez-Santin C, Amati M, Bekessy S and Desha C (2022) 'A Review of Existing Ecological Design Frameworks Enabling Biodiversity Inclusive Design', *Urban Science*, 6(95).

Hilty JA, Lidicker Jr WZ and Merenlender AM (2012) *Corridor ecology: the science and practice of linking landscapes for biodiversity conservation*, Island press.

Hodgson JA, Thomas CD, Wintle A and Moilanen A (2009) 'Climate change, connectivity and conservation decision making: back to basics', *Journal of Applied Ecology*, 46:964-969.

Hunter MR and Hunter MD (2008) 'Designing for conservation of insects in the built environment', *Insect Conservation and diversity*, 1:189-196.

Hromek, D (2023) Indigenizing practice: What can non-Indigenous designers do? Architecture AU website, accessed 8 November 2023.

IFLA and UIA (Internation Federation of Lanscape Architects and International Union of Architects) (2019) Indigenous Ecosystem Corridors and Nodes, IFLA website, accessed 12 April 2023.

Kaunitz Yeung Architecture (2023) Rammed Earth Health Hub, Kaunitz Yeung Architecture website, accessed 29 May 2023.

Kennedy R, Kelly M, Greenaway J and Martin B (2018) International Indigenous Design Charter: Protocols for sharing Indigenous knowledge in professional design practice [PDF], accessed 8 November 2023.

Kirk H, Soanes K, Amati M, Bekessy S, Harrison L, Parris K, Ramalho C, Van De Ree R and Threlfall C (2023) 'Ecological connectivity as a planning tool for the conservation of wildlife in cities', *MethodsX*, (101989).

Kirk H, Soanes K, Amati M, Bekessy S, Harrison L, Parris K, Ramalho C, Van Der Ree R and Threlfall C (2022) 'Urban ecological connectivity as a planning tool for different animal species', *bioRxiv*, (2022.11.06.515356).

Kirk H, Threlfall C, Soanes K, Ramalho C, Parris K, Amati M, Bekessy S and Mata L (2018) *Improving connectivity for biodiversity across the City of Melbourne: A framework for evaluating and planning management actions.*

Lawton JA, Holland GJ, Timewell C, Bannon A, Mellick E and Bennett AF (2022) 'Citizen science and community action provide insights on a threatened species: nest box use by the brush-tailed phascogale (Phascogale tapoatafa)', *Wildlife Research*, 49(6):513-528.

Lepczyk CA, Aronson MF, Evans KL, Goddard MA, Lerman SB and Macivor JS (2017) 'Biodiversity in the city: fundamental questions for understanding the ecology of urban green spaces for biodiversity conservation', *BioScience*, 67:799-807.

Living Seawalls (2022) Design, Living Seawalls website, accessed 29 May 2023.

Mang P and Reed B (2015) 'The nature of positive' *Building Research & Information*, 43:7-10.

Mata L, Ramalho CE, Kennedy J, Parris KM, Valentine L, Miller M, Bekessy S, Hurley S and Cumpston Z (2020) 'Bringing nature back into cities', *People and Nature*, 2:350-368.

Mckinney ML (2008) 'Effects of urbanization on species richness: a review of plants and animals', *Urban ecosystems*, 11:161-176.

Mckinney ML and Lockwood JL (2001) 'Biotic homogenization: a sequential and selective process', *Biotic homogenization, Springer*.

Metcalfe D (2015) *Multispecies Design*, University of the Arts London in collaboration with Falmouth University.

Mouritz L and Breedon A (2022). 'Country-Led Approaches in Land Management and Design', *Architectural Design*, 92(1):96-103.

Narwal HT (2022) *Engaging in more-than-conservation in multispecies cities: A study of One Central Park*, Sydney, Macquarie University.

Nathan R, Schurr FM, Spiegel O, Steinitz O, Trakhtenbrot A and Tsoar A (2008) 'Mechanisms of long-distance seed dispersal', *Trends in ecology & evolution*, 23:638-647.

Natureserve (2023) Clarifing the Terminology, LandScope America website, accessed 29 May 2023.

Ogden LE (2015) 'Do Wildlife Corridors Have a Downside?', *BioScience*, 65:452-452.

Outerspace Landscape Architects (2023) Pasadena Biodiversity Corridor, AILA Awards and Competitions website, accessed 29 May 2023.

Page A, Memmot P (2021) *Design: Building on Country*, Thames & Hudson, Australia.

Parker D, Roudavski S, Jones T and Soanes K (2022) *New design tech offers hope for urban wildlife*, Pursuit: The University of Melbourne website, accessed 25 May 2023.

Peng MH, Hung YC, Liu KL and Neoh KB (2020) 'Landscape configuration and habitat complexity shape arthropod assemblage in urban parks', *Scientific reports*, 10:1-12.

Pickett ST, Cadenasso L, Grove JM, Boone CG, Groffman PM, Irwin E, Kaushal SS, Marshall V, Mcgrath BP and Nilon CH (2011) 'Urban ecological systems: Scientific foundations and a decade of progress', *Journal of environmental management*, 92:331-362.

Rees SL (2018) Our cities reflect the denial of history. Blak design aims to change that. Sarah Lynn Rees for IndigenousX, The Guardian website, accessed 11 November 2023.

Rudd H, Vala J and Schaefer V (2002) 'Importance of backyard habitat in a comprehensive biodiversity conservation strategy: a connectivity analysis of urban green spaces', *Restoration Ecology*, 10:368-375.

Rudnick DA, Ryan SJ, Beier P, Cushman SA, Dieffenbach F, Epps CW, Gerber L, Hartter J, Jenness JS and Kintsch J (2012) 'The role of landscape connectivity in planning and implementing conservation and restoration priorities', *Issues in Ecology*, 1-23.

Rupprecht CDD, Byrne JA, Garden JG and Hero JM (2015) 'Informal urban green space: A trilingual systematic review of its role for biodiversity and trends in the literature', *Urban Forestry & Urban Greening*, 14:883-908.

Shepard DB, Kuhns AR, Dreslik MJ and Phillips CA (2008) 'Roads as barriers to animal movement in fragmented landscapes', *Animal conservation*, 11:288-296.

Silva CM, Pereira JAC, Gusmões JDSP, Mendes BEP, Valente H, Morgan AP, Goulart D and Hasui E (2020) 'Birds' gap-crossing in open matrices depends on landscape structure, tree size, and predation risk', *Perspectives in Ecology and Conservation*, 18:73-82.

Silva E, Marco A, Da Graca J, Perez H, Abella E, Patino-Martinez J, Martins S and Almeida C (2017) 'Light pollution affects nesting behavior of loggerhead turtles and predation risk of nests and hatchlings', *Journal of Photochemistry and Photobiology B: Biology*, 173:240-249.

Standen S (2017) Christmas Island red crab migration challenges filmmaker, equipment and subject, *ABC News*.

Stone L (16 September 2022) 'Noisy miners are one of Australia's 'most hated birds'. How do we manage their booming population?' *ABC Radio Brisbane*.

Tan D (2022) Designing for Other Species, MoMA website, accessed 12 April 2023.

Taylor PD, Fahrig L, Henein K and Merriam G (1993) Connectivity is a vital element of landscape structure, *Oikos*, 571-573.

Thomson S (2020) 'Another 50 years' of research and conservation: Mon Repos Turtle Centre', ArchitectureAU webiste, accessed 20 May 2023.

TMKsouth (2021) South Africa Builds Tunnels To Help Endangered Frogs Cross Busy Roads, Nairland Forum website, accessed 6 June 2023.

Walsh JC, Gibson MR, Simmonds JS, Mayfield HJ, Bracey C, Melton CB, Reside, AE and Maron M (2023) 'Effectiveness of conservation interventions for Australian woodland birds: A systematic review', *Biological Conservation*, 282 (110030).

Woltz HW, Gibbs JP and Ducey PK (2008) 'Road crossing structures for amphibians and reptiles: informing design through behavioral analysis', *Biological Conservation*, 141(11):2745-2750.

Woodward E, Rosemary H, Harkness P, Archer R (eds) (2020) *Our Knowledge, Our Way in caring for country: Indigenous-led approaches to strengthening and sharing our knowledge for land and sea management. Best Practice Guideline from Australian experiences*, NAILSMA and CSIRO.

About the Authors

Cris Hernandez-Santin

School of Global, Urban and Social Studies, RMIT

Interdisciplinary Conservation Science Research Hub, Centre of Urban Research

Cristina is an ecologist, designer and placemaker who seeks to translate ecological knowledge to support 'place' for both humans and non-humans to coexist. She aspires to merge the idea of participatory design with ecology by incorporating the voice and needs of the non-human stakeholders into the design process. With a background in ecology (B.Biology, University of the Americas, Puebla, Mexico) and sustainable design (MEnv. The University of Melbourne), she is currently undertaking her PhD on Biodiversity Inclusive Design (BID) (RMIT University).

Jane Toner

Cities Research Institute, Griffith University

Jane Toner is a registered architect (BArch, AIA), certified regenerative design practitioner, and certified Biomimicry Professional (Biomimicry 3.8) holding a MSc in Biomimicry. In 2017, Jane founded Biomimicry Australia, an emerging collaborative network that applies lessons from nature to solve human design challenges. Jane is active in the Australian Institute of Architect Victorian Sustainable Architecture Forum and is a lead member of the Australian working group for the Indigenous Ecosystem Corridors and Nodes Project (IEC+N). She is currently a PhD Scholar at Griffith University exploring how enhancing community ecoliteracy through nature (re)connection practices can contribute to a regenerative future where all life thrives.

Bethany Kiss

School of Global, Urban and Social Studies, RMIT

Interdisciplinary Conservation Science Research Hub, Centre of Urban Research

Beth has a background in Architecture and Planning, with B.Arch and M.URP degrees from the University of Sydney. With several years of experience across private and public practice, she is now pursuing her PhD as part of the ARC Discovery Grant project 'Beyond Green Facades' at RMIT University. The project aims to bridge the knowledge and design gap between ecologists and built environment designers. As a design practitioner, Beth is focusing on design solutions that enhance biodiversity consideration in practice.

Australian Institute of Architects