Landscape Institute Technical Guidance Note

Green Bridges

Technical Guidance Note 09/2015 December 2015

Contents

This Guidance Note guide provides information and guidance on planning for a green bridge, the different types of green bridge that can be used and example case studies. It also highlights some of the wider multi-functional benefits that green bridges can provide.

Foreword

Fragmentation of the landscape, loss of its patterns and features and disruption to ecosystem connectivity are major problems. Green bridges can play a part in ensuring connectivity is retained or reinstated. As just one recent example, Euan Maharg's award-winning concept for two green bridges in the Seven Lochs Wetland Park in Scotland has been an inspiration.

The report on which this guidance note is entirely based, without substantive alteration, was written by Land Use Consultants for and following research commissioned by Natural England. Understandably references are to the regulatory environment in England but the study is based on research internationally and in particular principles and practice developed in the Netherlands. It is of course possible that different regulations, landscape patterns and features and climatic conditions in other countries may require adjustments to practice but the Landscape Institute believes that the principles are well-established and widely applicable. The Institute therefore commends this guidance to practitioners on this basis.

Mark Turnbull FLI, Chairman of LI Technical Committee, December 2015

Introduction

It is well documented that transport infrastructure can have a negative impact on the environment. Road and rail schemes can fragment habitats and create a barrier to species movement causing direct impacts through species collisions with vehicles. Roads and railways can cause habitat fragmentation because they break large habitat areas into small, isolated habit patches which support fewer individuals. However, research has shown that when managed appropriately existing transport corridors have the potential to be enhanced to provide connecting corridors through otherwise biodiverse poor landscapes such as urban areas and intensively farmed landscapes.

In landscape and visual terms linear transport corridors can sever and fragment cohesive areas of valued landscape; having a detrimental effect on the special qualities that underpin the natural beauty of our designated landscapes (e.g. National Park and Areas of Outstanding Natural Beauty) and adversely affecting the character of our valued landscapes, both nationally designated landscapes and others. Such schemes can result in extensive scarring from cut and fill or embankments, and notches on the skyline, conflicting with the local landform; severing and disrupting the local pattern and detail of the landscape such as important field boundary patterns, and imposing associated urban infrastructure, including lighting, in otherwise rural, tranquil places. The time depth and historic character of the landscape can be changed and historic patterns, linear features and routes may be severed. The significance and setting of historic assets may also be changed.

Road and rail infrastructure also impacts on the local connectivity and accessibility of the landscape severing links between places. Infrastructure can act as a barrier to access to greenspace and may sever existing walking, cycling and horse riding routes. However some road or rail infrastructure if sensitively designed may present opportunities for iconic landscape features such as green bridges.

Wildlife crossing structures have been used in Europe and North America to facilitate movement through landscapes fragmented by roads. These structures include wildlife overpasses and green bridges, bridges, culverts, and pipes. Green bridges are relatively new within the UK, with only a small number in existence. This guide is designed to provide information on when it may be appropriate to consider installing a green bridge as part of a project. As well as new infrastructure schemes, retrofitting green bridges on existing schemes may be an option to alleviate known blackspots for wildlife collisions or where there is a wider goal to join up landscapes and ecosystems. Such retrofitting may enhance wildlife connectivity and increase the permeability of the landscape, while potentially enhancing the attractiveness and visual character of an existing crossing. Through creating high quality, visually attractive and convenient crossings for pedestrians, cyclists and horse riders, green bridges can encourage more people to use these routes with resulting health, wellbeing and other benefits.

This guide provides information on planning for a green bridge, the different types of green bridge that can be used and example case studies. The guide also highlights some of the wider multi-functional benefits that green bridges can provide for people and communities.

For the purposes of this guide a green bridge is defined as an:
Artificial structure over road or rail infrastructure which is either vegetated or provides some wildlife function

This guide is based upon a literature review on green bridges undertaken for Natural England by Land Use Consultants:

Natural England (2015) Green Bridges – Literature Review. Natural England Commissioned Report

In summary, the literature review found that green bridges do provide mitigation for ecological severance, with evidence of wildlife use recorded on a large number of bridges. Green bridges were found to provide habitats in their own right, with established bridges complementing and connecting the surrounding habitat. Some evidence was also found to show that green bridges can be used to address landscape and access severance. Beyond these aspects some evidence was also found to demonstrate a role in providing wider ecosystem services, for example by recycling rainwater to irrigate the bridge structure. In the literature reviewed green bridges are also referred to as ecoducts, landscape bridges, wildlife bridges and wildlife crossings. The review did not include cut and cover tunnels[1]. It is acknowledged that much of the literature has concentrated on the role of green bridges as wildlife crossings, and to date there is relatively little information on the effectiveness for landscape and visual mitigation.

Guide structure

This guide is designed to give a clear pathway on planning and designing a green bridge structure. It is not intended to be a detailed design guide, covering technical engineering aspects as these will largely be site specific. The guide aims to identify the broad design principles for green bridges so that they are able to provide ecological, landscape and access functions, depending on the aims.

In terms of planning, the guide lays out the key considerations to take into account when deciding if a green bridge is an appropriate approach for project specific mitigation or wider biodiversity/ landscape/access goals. Once the construction of a green bridge is identified as a suitable option then details are given on the work required to position the bridge and develop the design. Design options are then provided along with case study examples.

The approach within this guide has largely been developed from the information gathered within the literature review. However, where the literature review only provided limited or no information on an aspect then LUC's views are presented. This is clearly referenced in the text.

Limitations of the guide

The international literature review of green bridges has revealed that there are knowledge gaps, for example, in terms of assessing if green bridges are successful in maintaining gene flow of populations where populations have been severed by road and rail infrastructure. This is largely due to a lack of long term monitoring data.

[1] i.e. constructing a tunnel by excavating a cutting to the required depth and then backfilling the excavation over the tunnel roof down to a depth

The majority of literature focuses around bridges over roads; however it is considered that the concepts used for these bridges are applicable over railways.

There is limited information regarding green bridges built for purposes other than wildlife, for example, to bring landscape benefits.

In terms of ascertaining typical costs for green bridges, there are some details regarding costs of constructed bridges but these are limited and as such only rough indications of likely costs of new bridges are provided in the guidance below. It is noted these are heavily caveated as local site aspects will influence costs, such as topography, geology and hydrology.

This guide does not consider the visual impacts of green bridges on landscape, but more specifically relates to the way they mitigate for landscape severance from road and railway infrastructure.

This guide solely focuses on green bridges and does not include tunnels or cut and cover structures.

Aims of green bridge structures

When planning for a green bridge, it is important that project aims are clear from the outset. Green bridges can either be built as part of new projects or retrofitted in to existing infrastructure where a need is identified. The aims of a green bridge may be to:

- Maintain, restore or enhance ecological connectivity (to reduce species fragmentation and mitigate ecological severance)
- Provide habitat enhancement and reduce habitat fragmentation
- Reduce species mortality from collisions
- Maintain, restore or enhance historical links
- Maintain, restore or enhance access and recreational links
- Maintain, restore or enhance a connected landscape resource or feature
- Reduce visual effects and fragmentation
- Provide ecosystem services
- Provide all or some of the above

When to consider a green bridge

When contemplating a green bridge, care should be taken to understand the advantages and disadvantages it may offer compared to other engineering solutions (p.5). Also, a green bridge may provide a localised benefit for landscape, but will not mitigate the impacts of linear transport infrastructure over a wide area.

Green bridges may be installed for new road and rail schemes, but may also be retro-fitted over existing infrastructure. When considering if a green bridge is an appropriate option the key drivers will be ecological, landscape and access considerations. The requirement for a green bridge may be driven by one of these, or by multiple drivers. Even where a project has only one main driver, the use of a green bridge may provide multiple benefits beyond that of the driver. The table below identifies the key drivers and likely triggers in relation to these.

Ecological	Landscape	Access
Severance of a designated site, or infrastructure between two designated sites	Severance of an approach to/ or setting of/ or within an historic landscape	Severance of access route, e.g. national or regional trail, cycle route or bridleway
Severance of species commuting routes (e.g. bats)	Infrastructure to be sited within a statutory designated landscape (e.g. National Park or AONB)	Severance of two areas of public open space
Severance of rare habitats or habitats of local importance	Severance of a highly valued or sensitive feature of importance to landscape character (e.g. small lanes) or to address other landscape severance/connectivity issues (e.g. to avoid an unbroken skyline)	Severance between residential areas and greenspace or rural areas
Identification of local biodiversity benefits that a green bridge could provide, e.g. connecting local wildlife sites	Identification of local landscape benefits that a green bridge could provide, e.g. creating an iconic structure (in keeping with landscape character)	Identification of access benefits that a green bridge could provide, e.g. addressing local deficiencies in access to greenspace through linking to public rights of way and other greenspaces

Wider Benefits

Green bridges may be able to provide a range of benefits beyond that of their initial drivers. For example the main drivers of a project may be to provide access and by adding green features to a bridge a project can deliver additional functions. A mixed use green bridge can provide wider ecosystem services such as cultural services, allowing for recreational activities by joining up a severed path and providing cultural services in relation to aesthetic values and creating a sense of place.

Incorporating structures such as green bridges into scheme design to address ecological, landscape and access severance is in line with a number of government policy documents including:

- the National Policy Framework (NPPF) which identifies the need to minimise impacts on biodiversity while providing net gains where possible. It also details that local planning authorities should set out a strategic approach in their Local Plans, planning positively for the creation, protection, enhancement and management of networks of biodiversity and green infrastructure and advocates a landscape scale approach to biodiversity. With respect to access, the NPPF details that planning policies should protect and enhance public rights of way and access. With respect to landscape it identifies the importance of protecting and enhancing valued landscapes, and the weight should be given to conserving landscape and scenic beauty in National Parks, the Broads and Areas of Outstanding Natural Beauty

- the National Networks National Policy Statement, which cites green bridges as a way of enhancing existing habitats and creating new habitats of value.
- the Natural Environment White Paper which aims to establish coherent ecological networks that are more resilient to current and future pressures.
- the Natural Environment and Rural Communities (NERC) Act 2006, which details that

"*Every public authority must, in exercising its functions, have regard, so far as is consistent with the proper exercise of those functions, to the purpose of conserving biodiversity*" Section 40, NERC Act, 2006

Other key documents include Lawton's Making Space for Nature (2010). This report provides an independent review of England's wildlife sites and the connections between them along with recommendations to help achieve a healthy natural environment. The report identifies the need for greater joined up thinking and provisions of connections across our landscape for wildlife to function. Lawton identifies that "the essence of what needs to be done to enhance the resilience and coherence of England's ecological network can be summarised in four words: more, bigger, better and joined". One of the five key approaches identified in the review is to *enhance connections between, or join up, sites, either through physical corridors, or through 'stepping stones'*. Green bridges can be a key step in achieving this vision to prioritise biodiversity networks.

Alternatives to green bridges

It is important to ensure that mitigation and enhancement measures are proportionate. Green bridges are one of a number of measures that could be considered to address ecological, landscape and access severance issues. As part of the consideration of options it may be necessary to consider alternative options, which may include the following:

- Modified grey bridges
- Multifunctional overpasses
- Cut and cover tunnels
- Pedestrian, cyclist and equestrian bridges
- Underpasses for medium-sized and large animals
- Underpasses for small animals
- Modified and multifunctional underpasses
- Modified culverts
- Fish passages
- Amphibian tunnels
- Fences (e.g. where mammal collisions are a key consideration)
- Warning signs/ warning systems with sensors
- Clearing vegetation/ Planting vegetation
- Escape ramps from drains, fauna exits in waterways
- Artificial lighting (e.g. to deter species from crossing in a certain area)

When planning a green bridge, this should not be done in isolation, but should form part of a wider and integrated design and mitigation strategy addressing wildlife, landscape, access and broader ecosystem services considerations. Particularly of relevance for long linear schemes a green bridge may be used in combination with underpasses, tunnels and ledges to increase the permeability of the road or railway to wildlife.

Further guidance on alternatives can be found within the following sources:

Design Manual for Roads and Bridges, Volume 10 (sections 3 and 4) Volume 11 (sections 3 and 4)

Great Crested Newt Mitigation Guidelines (English Nature 2001)

Bat Mitigation Guidelines (English Nature 2004)

The Dormouse Conservation Handbook 2nd Edition (English Nature 2006)

Water Vole Conservation Handbook 3rd Edition (Strachan 2011)

Common Toads and Roads: Guidance for highways planners and engineers in England (ARC 2011)

Guidance on Building Development (England) With Respect to Amphibians and Reptiles, Amphibian and Reptile Conservation, Sep 2010

Recording Aims and Objectives

If the early scheme planning stages identify that a green bridge could provide a mitigation solution, it is important that the aims and objectives of constructing a green bridge are clearly recorded.

As the project progresses the aims and objectives should be regularly revisited and updated in the light of any new information, i.e. data gathered through surveys, stakeholder consultation. It is important that robust data is collected at early stages so this can be compared with the findings post construction and should be tied into the future management and maintenance plan post construction.

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Planning for a green bridge structure

When planning for a green bridge, it is important that this is included with the early design stages. This is to allow sufficient surveys to be undertaken to provide a pre-construction base line as well as to allow for wider consultation to take place and to ensure that the design is fully integrated into the wider transport network and surrounding landscape and is appropriately located.

It is recommended that the following steps are taken during the planning process:

Step 1: Develop a Communication Plan

In order to engage with stakeholders it is recommended that a communication plan is developed at the project outset. This should help smooth the consenting process. The communication plan should contain the following actions:

- Establish a diverse project steering committee with broad representation including: local authority, local community groups, local wildlife groups, local access groups, project neighbours, statutory consultees.
- Encourage and record stakeholder/participant contributions from public meetings,
- Develop a communication plan to publicise meetings and workshops in local and regional media,
- Maintain a visible, accessible public record including meeting and workshop minutes to assure that information and comments are part of the official project record/process,
- Maintain an up-to-date project website, including: project summary, schedule, contact information, downloadable draft documents, maps and images, and address for email.

Step 2: Information Gathering

In order to decide on the best location to position a green bridge a wide range of information should be collected. It is recommended that this information is then overlaid in Geographical Information System (GIS).

The following information should be collected:

- Aerial photography
- Landownership maps and adjacent land management
- Potential future changes in land management
- Landscape Character Assessments
- Phase 1 habitat maps (and where appropriate National Vegetation Classification maps)
- Greenspace and green infrastructure maps showing public access including open access, common land etc.
- Definitive Map of Public Rights of Way
- Amenity use
- Road kill data
- Topography data
- Geology data
- Flood risk zone
- Utilities
- Local biodiversity opportunity maps
- Local strategies and management plans e.g. protected landscape management plans, green infrastructure /open space strategies and plans, local biodiversity action plans
- Designated nature conservation sites, protected landscapes and protected species information

This data gathering process is likely to require surveys to be undertaken. It is important that these surveys are undertaken in a systematic and repeatable way. Surveys should follow best practice guidelines and full survey results should be presented. For some species (for example bats) it is noted that two years of survey data may be required to provide robust indication of site use; this should be considered in project timescales.

Step 3: Choosing a location

Using the data identified above, a short list of locations should be created. When siting a bridge, consideration needs to be given to areas beyond a project's immediate boundary to identify optimum locations at a landscape scale. This approach is needed to ensure that bridges deliver the greatest possible benefits.

Once a short list has been created this should be subject to further screening based on topography, obstacles present, geology and geography, maintenance, safety, flood risk and utilities all of which can ultimately influence the location. When siting a green bridge the landscape context *and local landscape character* should be considered.

Key points which should be considered when selecting a location are:

- Outcomes of consultation with statutory consultees, environmental partnerships, local communities, land owners and other relevant parties.
- Avoid areas with large differences in topography (between level ground and embankments); this is likely to be especially important when addressing landscape severance.
- Where target species rely on a habitat, select a site where the habitat can be connected to the bridge.
- If targeting species use, locate along traditional commuting routes
- When planning a bridge for wildlife use, consider if a mixed use bridge is appropriate in terms of disturbance levels. Consider selecting locations with low levels of human disturbance, taking account of future proposed development.
- Don't create 'dead ends' i.e. don't build a bridge to nowhere, the bridge needs to connect into a wider permeable landscape
- Consider the location of other features in the landscape that can enhance connectivity and how the bridge location interacts with these i.e. watercourses, hedge lines, greenways, parks and greenspaces, sites etc.
- For a mixed use bridge consider connections with strategic access routes such as public rights of way, National Trails, strategic cycle network, horse riding trails and other local access routes

Step 4: Specific Design Considerations

The overall function of the green bridge will drive most of the decisions, as the size of the structure must be determined based on the requirements of the expected use (i.e. species specific, mixed etc.) and the degree of need for separation between wildlife and human access.

Once the preferred location for the green bridge has been selected then a list of specific design considerations should be created to allow the most suitable type of structure to be selected.

Specific design considerations will need to take account of the following:

- Existing and proposed level of the road in relation to the surrounding landscape
- Shape of green bridge, e.g. hourglass or straight
- Width
- Length
- Suitable vegetation to be in keeping with local landscape and habitats
- Soil depth and substrate type
- Screening and fencing
- Target species
- Other users (pedestrians, equestrian, cyclists); access for all
- Ecosystem services benefits (such as pollination, cultural heritage, recreation and tourism, aesthetic experience, water management, wild species diversity)
- Engineering considerations
- Drainage and water (for example, ponds)
- Ease and cost of maintenance/management
- Ability of wildlife to access and exit from the bridge into the surrounding landscape
- Lighting
- Connectivity with surrounding features in the wider landscape i.e. for wildlife bridges, vegetation will need to connect into surrounding landscape features such as watercourses, hedge lines.

[Specific Design Considerations continued:]

Width and length

Bridges aiming to achieve connections at a landscape/ ecosystem level should be over 80m in width. Bridges aiming to achieve connections for species at a population level should be around 50m (published guidance recommendations range from 25m-80m, with an average of 50m). Bridges below 20m in width are not recommended as frequency of use has been found to be lower. The length will largely be determined by the number of roads/ railway lines that are crossed. The length will also be influenced by topography as the access ramps should not be too steep. A width to length ratio over 0.8 is recommended.

Vegetation

The vegetation should complement the habitats either side of the structure, using plant species native to the local area. In terms of seeding, options including natural establishment and use of the local seed bank (from topsoil or hay cutting) should be considered. Hedge structures can be used to provide a guiding line, for species such as bats, and should be continuous and connect with established foraging routes. When targeting small vertebrates and invertebrates then the aim should be to resemble the habitat adjacent to the bridge as far as is possible. The planting should be designed to create a mosaic with tree and shrub planting at the end and the middle section left open with grasses and smaller vegetation. Depending on the species that may use the bridge it may also be appropriate to leave patches of bare ground or gravel. If such micro-habitats are created then within the management plan measures should be included to ensure that these remain open areas rather than allowing colonisation by vegetation. Brash, tree stumps and piles of rubble may also be used to create refuges for small animals.

To account for the time it takes for vegetation to establish, other features may be needed to provide cover following bridge construction. This may include tree stumps, piles of brash and stones (it may be possible to use leftover construction materials for this purpose), as well planting more mature shrub, hedge and tree saplings.

Water features can be created on bridges to provide "stepping stones" for species using the bridge and can also provide a habitat in their own right. These have been successfully created on the continent and used by a number of amphibian species and dragonflies. This can be achieved by creating a series of wet depressions across the bridge itself, with deeper ponds either side. Water recycling can be used to transport rain water run-off to the top of the bridge, which can then run down the bridge through a series of small pools/ wet depressions. It is noted that the wet habitats on the bridge do not need to contain water at all times, and will be dependent on rain water.

Soil

The amount of soil used will affect the bridge load. It may be possible to achieve deeper depths at the edges of the bridge with shallow depth in the centre. The variation in soil depths can be used to create a mosaic of vegetation, including maintaining areas of bare ground, and creating a varied topography. As a guide the following depths might be appropriate:

Grass and herbs: 0.3m, Shrubs: 0.6m, Trees: 1.5m.

In some cases top soil may not be required, depending on the target vegetation, for example crushed aggregate may be used to create a substrate suitable for species associated with brown field sites.

Advice from an engineer should be sought if necessary.

Screening and fencing

Screens can be used to reduce disturbance on the bridge from light and noise. These should be located as close to the outer edge of the bridge as possible to maximise the amount of the bridge available for use.

On wider bridges, hedges on mounds may be used to provide screening. Where earth mounds are used these should be designed to extend along the transport infrastructure. Side screens should be around 2m in height and should be connected into any other screening present along the infrastructure (such as noise barriers). If screens are not used then fencing must be placed along the outer edge of the bridge and fencing on the bridge must tie into fencing along the infrastructure.

Lighting

If the main driver of the bridge is wildlife use then it is recommended that lighting is avoided. If a mixed use bridge is designed, where lighting is required, this should be designed to minimise disturbance to wildlife. Guidance on the Bat Conservation Trust website should considered: http://www.bats.org.uk/pages/bats_and_lighting.html

Target species

The target species for use may be critical in determining the width, design and vegetation. For examples amphibians may require a "wet zone" across the bridge. For larger animals, the width and location can be more important than the vegetation, but for smaller animals such as bats the vegetation is more important.

Other Users (Mixed use)

In general the literature focuses on bridges with a wildlife function and as such guidance recommends avoiding mixed use structures where wildlife use is the primary objective. However in two studies on mixed use bridges, where wildlife use was investigated, evidence of species use was recorded and as such it is considered in certain circumstances, mixed use bridges may be appropriate. At the Zanderij Crailoo green bridge in Holland recorded 180,000 walkers and cyclists and 17,000 horse riders in a year and 13 species were recorded using the bridge, including 6 species of amphibians and 2 species reptiles.

To determine the width of a mixed use bridge, the width of any paths should be added to the width required for faunal passage to give the total width of the bridge.

For bridges, where the main objective is species use (particularly for species sensitive to disturbance) it is recommended that any paths used should be positioned on an outer edge to ensure the width of the natural area is retained. Where the main function is to provide access, with a secondary biodiversity benefit, then it may be appropriate to consider the use of paths in other areas of the bridge. The needs of people of all abilities should be considered to ensure access for all.

If greening a low use road bridge (e.g. an accommodation overbridge), a vegetated strip along one edge may be used. This should have a minimum width of 1m, with soil of around 0.3m (again this may depend on the target vegetation and it may be possible to used crushed aggregate). The strip may be planted or left to naturally vegetate, although it is important that a management plan is in place to ensure that the verge is well maintained. Appropriate information and interpretation will add to users' understanding and appreciation of the green bridge.

Ecosystem service benefits

In designing a green bridge consideration should also be given to what ecosystem services the structure can provide. For most bridges, if the design is for wildlife purposes or has a secondary wildlife function, then the bridge will naturally provide the function of wild species diversity. Examples of other ecosystem services that may be provided include the use of plant species with high nectar sources to provide a resource for pollinating insects; this may be achieved through planting a wildflower meadow mix of local providence or through local self-seeding.

The method of drainage should also consider water recycling to irrigate the bridge structure. This may also be used to provide resilience to climate change, for example by using basins within the bridge deck to retain water for use in drought periods.

Mixed use bridges and those that are designed to maintain cultural and recreational links will provide cultural heritage, recreational and tourism services. If appropriately landscaped and well maintained, such structures should also provide an aesthetic experience and the users' view point should be considered during the design process.

Engineering considerations

Load and drainage are the main engineering aspects which will influence the design of the bridge in terms of what vegetation it can support and as such should be considered at the initial design stage.

The build materials will also affect the aesthetics of the bridge and how well it merges into the surrounding landscape.

Other key considerations

Cost is a key factor. Costs can be reduced or minimised by decreasing the load, span, and/or width of the structure. Shorter spans can be obtained through the provision of intermediate supports, though this can interfere with road safety and aesthetic concerns. The foundations for the structure have a significant impact on cost and requirements are related to soil conditions and topography at the site.

The bridge load will depend on the target vegetation. Larger vegetation (trees) will require deeper soil to support its root structure which will have a higher load than shallower rooted vegetation. Consideration could be given to containing larger vegetation (such as trees and shrubs) at distinct locations along the span rather than placing over the entire area. The drainage system under the soil and control of soil build up, will also affect the load and needs to be considered in design.

Green bridges can be complex engineered structures and the advice of an engineer should be sought.

Choosing a green bridge structure

Four types of green bridge structure have been developed in this guide based on examples of green bridge structures from around the world. (It is noted that this guide does not include cut and cover style bridges which may be appropriate to address large-scale landscape impacts). These have been termed as follows:

- Natural Bridge
- Wildlife Bridge
- Mixed Use Bridge
- Modified Grey Bridge

The type of green bridge selected should be based on the aims and objectives of the project (which in turn is influenced by landscape, biodiversity and access needs) although it is also noted that the selected design may be heavily influenced by engineering aspects. The descriptions of each design type below are intended as guides. When designing a green bridge on a site, this will be a collaborative process between the road and bridge engineers and the environmental consultants, with input from a wide range of stakeholders. The structural requirements of the design will be key in terms of what is achievable in establishing vegetation growth.

Costs

The table below provides examples of green bridges and their costs. Within the green bridge literature review, limited information was found on costs and as such no detailed costs for each bridge type identified above are provided. Furthermore costs will be heavily influenced by local aspects such as geology and topography.

Bridge name, location	Cost[2]	Details on structure
Mile End, UK	£5,800,000	25 m width of landscaped parkland. Rainwater runs off the bridge and down into tanks on either side. It is then pumped back onto it and reused.
Kootwijk, Netherlands	£2,187,621 (3 million euros)	150m long, hour glass shape structure, 80m wide at its entrances and 30m wide in the middle. 1.5m walls planted with trees and shrubs
Laarder Hoogt, Netherlands	£8,385,588 (11.5 million euros)	Not yet constructed. Two bridges, one 70x40m and one 40x30m
Natuurburg Zeepoort	£4,008,493 (5.5 million euros)	Scheduled for construction in 2016
Zanderij Crailio	£10,569,588 14.75 million euros	300m long, 50m wide
Aspiholz and Fuchswies, Switzerland	5% of project cost	Concrete of 0.4m and a minimum soil layer of 1.5m. Native bushes were planted only at critical spots and the rest has been left for natural succession.
A556, Cheshire, UK	Estimated cost of 'greening' the access bridge £366,000, with total bridge cost estimated at £1.14m.	Not yet constructed. Proposal is for an 11m green bridge, with a farm track and a 7m green verge.

[2] Exchange rate calculated using www.xe.com on 27/02/15 rate of 1 GBP = 1.37209 EUR

Natural Bridge

These are the largest of the four bridge types defined in this guide, with widths of 70m to 100m or greater. By being of a larger size the aim is to provide an ecosystem level of connection. The larger size allows for the recreation of habitats and ideally the planting should be designed and integrated so there is habitat continuity from one side of the bridge to the other. By providing habitat continuity this should facilitate use by a wide range of species. It is recommended that human use is carefully considered, depending on the sensitivity of the target wildlife.

Width – 70m to 100m

Soil – Where possible avoid importing from outside the area. Aim for depths between 1.5m to 2m in areas with tree planting. Shallower depths may be used in the centre for grasses and herbs (0.3m) and shrubs (0.6m). Soil must be deep enough to allow water retention. A variation in soil depths can be used to create a mosaic of vegetation, including maintaining areas of bare ground, and creating a varied topography.

Habitat creation – Aim to create habitat as found either side of the bridge. Native species local to the area should be used. Tree and shrub planting should be used to guide species movement across the bridge and to provide cover. The planting should be designed to create a mosaic with tree and shrub planting at the end and the middle section left open with grasses and smaller vegetation. Brash, tree stumps, for example, may also be used to create refuges for small animals. If creating habitat for amphibians a series of pools/ wet depressions should be created across the structure, with a larger deep pool either side. Boulders (embedded) may also be used either side of the bridge to prevent vehicle access.

Fencing/ screening – Earth mounds with hedges planted on top can be used along the bridge edges to reduce noise and light pollution on the bridge. These mounds should extend along the approach ramps to tie into wildlife fencing. The mound plus vegetation should aim to be around 2m in height. Alternatively wood fencing could be used as screening; where this is done then fencing should be placed on the outer edge of the bridge.

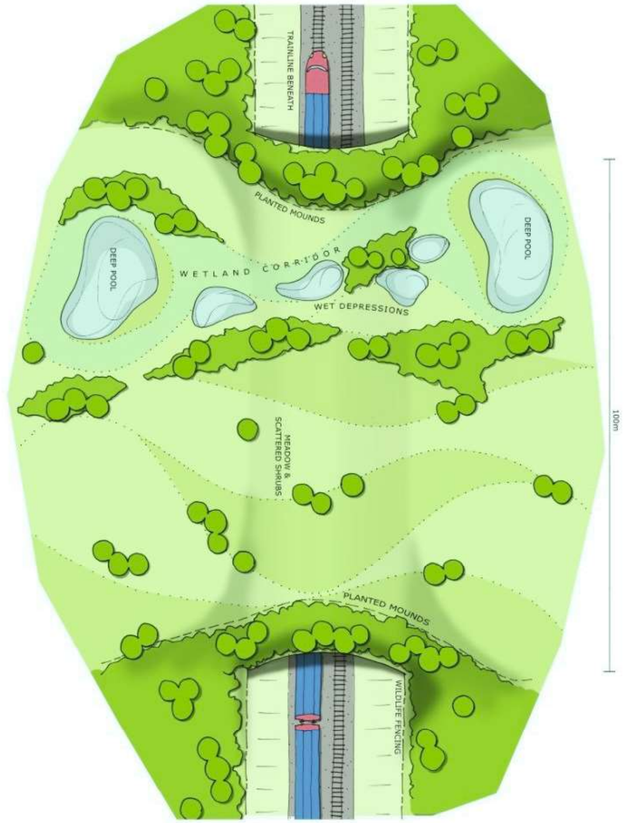

Figure 1: Example sketch of a Natural Bridge

Wildlife Bridge

These are very similar in design to a Natural Bridge, but are smaller in size. This type of bridge is intended primarily to facilitate species crossing the infrastructure. Design specifics may target particular species. Ideally an hourglass shape should be used as this is better for wildlife locating the ramps to cross the bridge. It is recommended that human use is carefully considered, depending on the sensitivity of the target wildlife.

Width - 40m-50m

Soil - Where possible avoid importing from outside the area. Aim for depths between 1.5m to 2m (may need to be shallower in centre). Soil must be deep enough to allow water retention. A variation in soil depths can be used to create a mosaic of vegetation, including maintaining areas of bare ground, and creating a varied topography.

Habitat creation – Aim to create a habitat mosaic, for example with trees on either side, hedgerows on mounds along edges, then in the middle meadow and scattered tree stumps. The vegetation should consider the surrounding habitats and look to reflect these. Any hedgerows planted should tie into the trees either side to create a flight corridor for bats. Other aspects as detailed for the Natural Bridge can be considered. Boulders may also be used either side of the bridge to prevent vehicle access.

Fencing/ screening – Earth mounds with hedges planted on top can be used along the bridge edges to reduce noise and light pollution on the bridge. These mounds should extend along the approach ramps to tie into wildlife fencing to create a barrier to animals accessing the road/railway. The mound plus vegetation should aim to be around 2m in height. Alternatively wooded fencing could be used as screening.

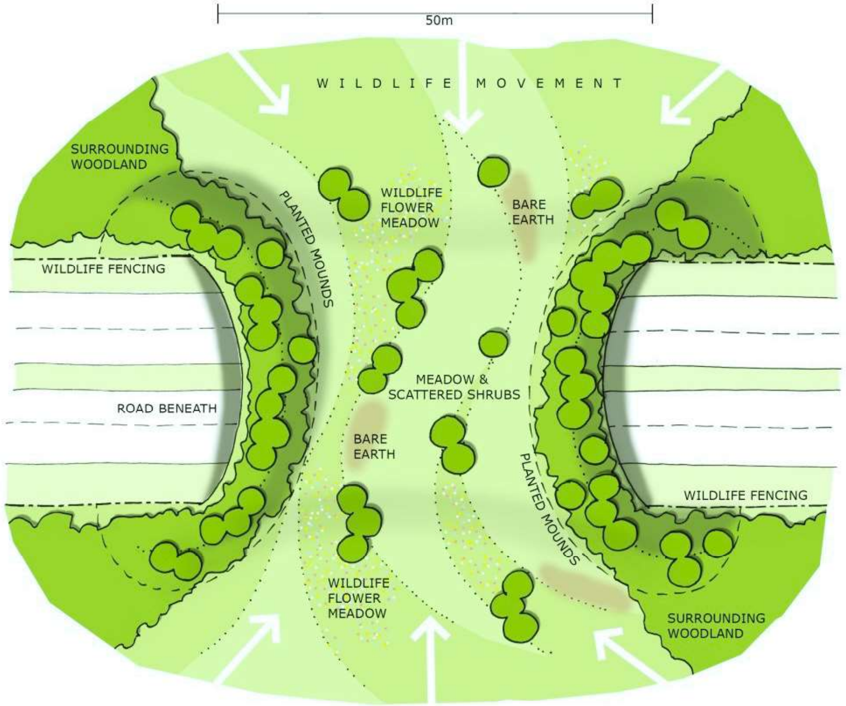

Figure 2: Example sketch of a Wildlife Bridge

Further information can be found in the following documents:
A.Clevenger and M.Huijser (2011) Wildlife Crossing Structures Handbook (http://www.cflhd.gov/programs/techDevelopment/wildlife/documents/01_Wildlife_Crossing_Structures_Handbook.pdf)
Iuell et al. (2003) Wildlife and Traffic: A European Handbook for Identifying Conflicts and Designing Solutions. (http://www.iene.info/wp-content/uploads/COST341_Handbook.pdf)

Mixed Use Bridge

These are designed where access is the principle aim and where any species use is seen as an additional benefit rather than a core aim. To determine the width, the minimum width of the natural zone should be calculated, based on the project aims in terms of target species. The required width for the recreational zone should then be added to this to give the total width. It is recommended that the recreational zone is placed on the outer edge to maximise the area of wildlife zone (e.g. so human disturbance is limited to one side of the wildlife zone). Alternatively where the main drivers are access, with wider biodiversity goals, it may be appropriate to position the recreational zone in the centre of the bridge, for example as has been done on the Scotney Bridge (see case studies below).

Width – 15-20m (e.g. recreational zone: 10m, wildlife zone: 15m)

Soil – Where possible avoid importing from outside the area. Aim for depths between 1.5m to 2m (may need to be shallower in the centre). Soil must be deep enough to allow water retention. A variation in soil depths can be used to create a mosaic of vegetation, including maintaining areas of bare ground, and creating a varied topography.

Habitat creation – As for the other bridges the aim is to create a habitat mosaic. Shrubs and/ or a hedgerow should be used to create a degree of separation between the wildlife corridor and the pedestrian zone, if the wildlife using the bridge is likely to be sensitive to disturbance.

Fencing/ screening – Screening required between wildlife and recreational zone with a recommended minimum height of 1m. Ideally screening should be natural and permeable to wildlife, but provides a visual screen. Boulders may also be used either side of the bridge to prevent vehicle access.

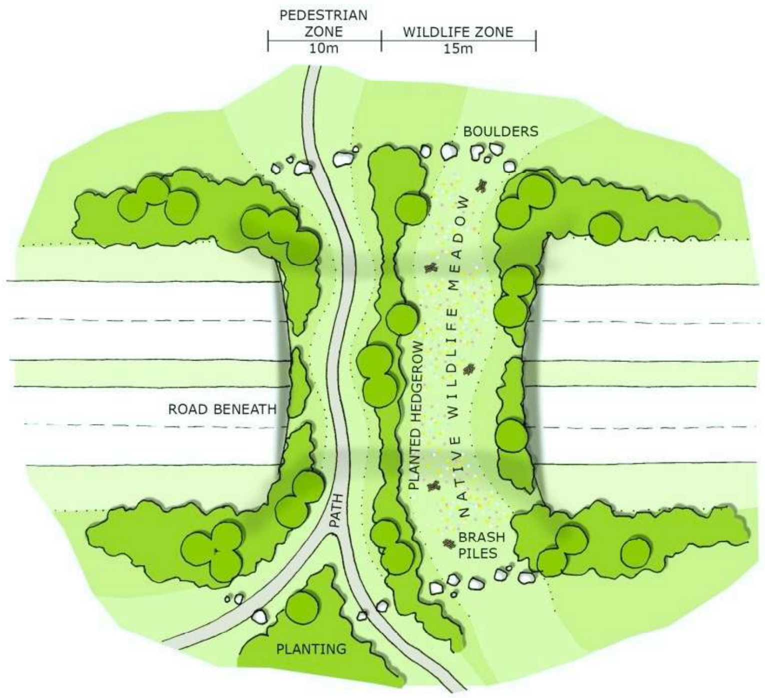

Figure 3: Example sketch of a Mixed Use Bridge

Modified Grey Bridge

A lower cost option to provide a limited level of mitigation is to adapt a grey bridge (either proposed or existing). This is not an alternative to the other green bridge options as it is unlikely to provide the same level of function, but it will improve the general permeability of the infrastructure. This type of option may be suitable for forestry and farm tracks across infrastructure or in an urban setting where it may be possible to modify redundant infrastructure, for example disused railway and road bridges which may be used as wildlife corridors or linear parks. It is not recommended for tarmacked roads or roads with heavy usage.

A bridge can be modified to provide a green strip on one side, or either side of the road or track. The minimum width of this strip is 1m (although ideally this should be wider to maximise the benefits), with a soil layer of 0.3m or greater. The strip can be seeded with a natural seed mix or left to colonise naturally. Whilst the strip becomes established, fencing between the strip and the road should be considered to prevent trampling and compaction. Depending on the width of the strip consideration should be given to providing other habitat features such as dead wood, tree stumps and rocks, which may have value for invertebrates and amphibians.

This type of bridge structure is less likely to provide any landscape value, but may have wider biodiversity benefits, such as providing plants for pollinating species. Modifying an existing structure may be more in keeping with the wider landscape surroundings than providing a new one, depending on the design of the original structure.

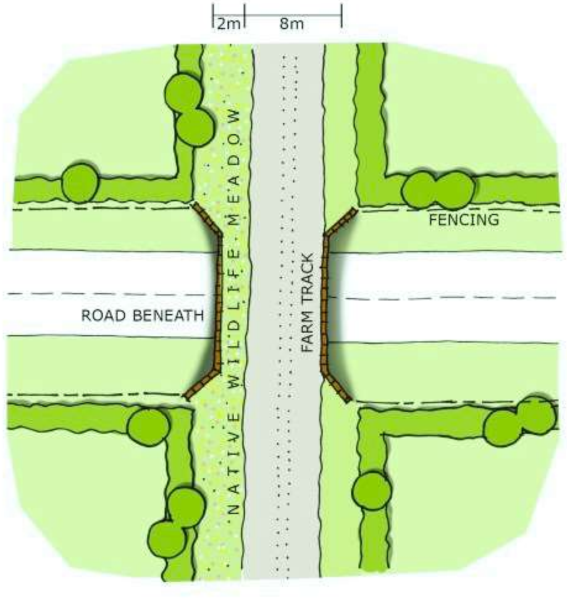

Figure 4: Example sketch of a Modified Grey Bridge

Case Studies

A21 Scotney Castle

Key facts:

First Green Bridge in UK – Example of a Mixed Use Bridge designed for historic landscape purposes

Part of a Highways Agency improvement scheme for a new dual carriageway by-pass around Lamberhurst village. The original proposals would have severed the historic West Drive which was laid out in 1842 and still used as the main entrance to Scotney Castle. Located within the High Weald AONB.

To mitigate a “landbridge” was built which enabled the West Drive to be reinstated on its original line with landscape and habitat connectivity.

There have been wider ecological benefits with evidence of dormice using the bridge.

It formed part of the £22 million overall costs of the scheme (including Public Inquiry), but the cost of landbridge has not been calculated separately.

Design Aspects

Hourglass shape

92m in length (48m in the centre and 18m and 25m either side)

29m in width at centre (55m at widest point on east side and 43m on west side)

Soil depth between 0.6m and 1.5m

Drive across bridge is 3.5m wide

Planting to create a continuous thicket between 3 and 10m in width and old tree stumps and banks of moss used to create habitats

Arrangement to collect rainwater and to deliver into soil layers and a ribbed central reservoir

Photographs

Top photo: Model of proposed bridge, Middle photo: Bridge during construction phase,

Bottom photo: Bridge following construction

Photos courtesy of LUC

A21 Scotney Bridge (Provided courtesy of Fira Landscape)

Banff Wildlife Crossings, Canada

Key facts

Example of a Wildlife Bridge

Constructed 1996.

Annual monitoring provides detailed information of bridge use.

Other crossings are also present (culverts and underpasses) along the Trans Canadian Highway.

The bridges are closed to the public.

Built to mitigate wildlife mortality and fragmentation

Long-term monitoring has found that there is an adaptation period and learning curve for large mammals using the wildlife crossing structures, and that ungulates adapt more quickly than carnivores.

Studies into different monitoring methods on the bridge found that remote cameras are the most cost-effective means of conducting crossing structure monitoring.

The wildlife bridges are part of a suite of mitigation measures for an 82 km section of the Trans-Canada Highway in Banff National Park which has been upgraded from two lanes to a four lane divided highway in 1981. The mitigation was installed over time and was completed in January 2014. There are now 38 wildlife underpasses and six overpasses.

Design Aspects

50m wide

Open span bridge structure

Crosses four lane highway

Ecoduct Wambach, Netherlands

Key facts

Example of a Natural Bridge.

Constructed 2011-12.

First green bridge designed with climate change resilience as an objective.

Design considered climate change resilience to match the water management on the green bridge with Intergovernmental Panel on Climate Change based climate scenarios of the Royal Dutch Meteorological Institute.

Concrete ridges are glued to the deck of the green bridge which form basins to retain water available for drought periods. Polystyrene bases of embankments retain water through raised edges covered with foil. To avoid excess water during rainfall peaks, an oversized drainage system has been designed to channel water to two ponds. The drainage system may also be used in a reversed fashion, to supplement the green bridge with water.

Design Aspects

The adjacent pastureland is to be planted with woods to connect into surrounding woodland to create a green corridor at a landscape scale.

The bridge is 36m wide and 58m long.

Photographs

Top image: Digital design plan of bridge, Bottom photo: Bridge during construction phase

Photos courtesy of Victor Loehr, Rijkswaterstaat

Groene Woud, Netherlands

Key facts

Example of a Wildlife Bridge

Constructed 2003.

Design aimed to create optimal humid conditions for amphibians.

Located within the National Landscape Groene Would, the bridge connects wetland areas which are bisected by a motorway.

The bridge is closed to the public.

Design Aspects

50m wide and 65m long, crosses the motorway at 7m above ground level.

The access ramps leading in are 110m and 85m and at a gradient ratio of 1:14 and 1:10 respectively.

0.5m of topsoil on the bridge and 1m on the access ramps.

The topsoil has been taken from the area immediately surrounding the bridge, and is placed in its original sequence to maintain layers.

Controllable groundwater level on the top of the bridge, across the length of the structure and the access ramps, with a wetland zone created by a chain of small ponds. Water is pumped up to the top of the bridge and slowly released through the cascade of small pools towards bigger pools at the bottom on the access ramp.

Six amphibian species recorded on the bridge, common toad, common frog, smooth newt, great created newt, marsh frog and edible frog.

Photographs

Top photograph: Side on view of bridge (Provided courtesy of ALTERRA / E.A. van der Grift)

Bottom photograph: View on top of bridge (Provided courtesy of ALTERRA / E.A. van der Grift)

Aerial view of Groene Woud (Provided courtesy of Rijkswaterstaat)

Post-construction recommendations

Monitoring

A monitoring plan should be developed which will help to assess the effectiveness of the green bridge. The nature of the plan will be determined from the original aims of the green bridge and the monitoring should look to establish if the aims have been met. The level of survey undertaken will be dependent on those aims.

For example for a bridge which has been developed for species use, it may be appropriate to install camera traps on the bridge as these have found to be a successful method of monitoring green bridges. Where habitat creation has been undertaken, then botanical surveys should be undertaken.

Specific monitoring approaches may be needed for some species such as bats. Monitoring should follow species-specific established protocols where these are available. The methodology for pre, during and post construction survey should be consistent to allow data to be compared and used to assess the effectiveness of the structure.

It is important that long term monitoring is undertaken as species use may increase following a period of familiarisation. With this in mind, a typical monitoring programme may survey the bridge annually for years 1-3, then year 5 and year 10 following construction.

Any misuse of the bridge identified during monitoring should be reported and if required recommendations fed into the maintenance plan or used to amend the design to allow the structure to deliver its original objectives.

The findings of this monitoring should be reviewed in relation to project aims and should be reported to Natural England to help with further planning and design of green bridges.

Management and Maintenance

A detailed management and maintenance plan should be developed; this should tie into the monitoring, making changes where necessary if issues are picked up during the monitoring. The plan should detail the management for the first three years after construction. After that the management should be adapted based on the findings of monitoring and should be incorporated into the managing agency’s long term maintenance programme.

The responsibility for ongoing maintenance should be agreed from the project outset. This is especially important when the organisation has not been involved in the planning process. It is important that they are aware of the purpose of the bridge along with the maintenance plan and associated maintenance costs. Community engagement in the design of the bridge can lead to a Friends Group being formed which can help to maintain the green bridge as a high quality greenspace.

Maintenance should include inspection of the bridge drainage to ensure it remains functional.

The management of the bridge should be tailored to the habitats created on the structure. For example it may be appropriate for an annual hay cut where meadows have been sown, with scrub and hedgerow management every 3-5 years and tree coppicing every 5-10 years depending on the species used.

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