

## Brief Report

# Structural re-design of the Animex Wildlife Bridge for the Hazel Dormouse (*Muscardinus avellanarius*): lessons learnt from two connectivity mitigation case studies in the UK

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**Abstract** – The Hazel Dormouse (*Muscardinus avellanarius*) is an arboreal mammal present in Europe and Asia minor. The population is declining in the United Kingdom (UK), partially due to habitat fragmentation caused by the development of linear infrastructure such as roads, railways and pipelines. In 2016, we designed and tested an arboreal bridge in Britain that was proven to be effective for Hazel Dormice. Subsequently, the bridge materials were upgraded to meet the technical standards of UK road agencies, so that it could be approved and implemented as mitigation on projects throughout the UK. In the UK, each bridge must be certified for technical approval by the relevant road authority and as the bridge is a unique structure, this can pose challenges on projects. The national safety standards of UK roads would not allow common methods used for arboreal bridges across the world to be applied, so we needed specialised engineering and design adaptations to be implemented. Two overarching installation designs were created: the standalone bridge and the retrofit bridge. Several bridges have now been installed across roads in the UK and we will be discussing the development and implementation process from two case studies: i) a 40-metre retrofit bridge to an underpass in St Athan, Wales and, ii) two 76+ metre bridges retrofit to an overbridge and underpass on the M1 motorway in Gayhurst, Buckinghamshire. The St Athan project was quickly approved and easily installed while the M1 project required several alterations to the design and installation methods to meet specific project requirements. This paper discusses what we have learned from these projects, how these projects have influenced the future designs of the Animex wildlife bridge and how this could be applied to future arboreal wildlife connectivity bridges across the world.

**Keywords** – connectivity, Hazel Dormouse, mitigation, road ecology, wildlife bridge.

## Introduction

The importance of arboreal connectivity can vary depending on the species, but is considered to be of importance for most arboreal animals (Soanes and van der Ree, 2015). While habitat connectivity appears to be less important for conservation of some species, such as the Red Squirrel (*Sciurus vulgaris*); other species

are significantly impacted by severance of habitat (Mortelliti *et al.*, 2011). For example, canopy connectivity is of great importance for the Ring-tail Possum (*Hemibelideus lemuroides*), with one study demonstrating that canopy clearings reduced the capacity of the species to return to their home range. Possums were also not recorded crossing at ground level, indicating a loss of canopy connectivity has a severe neg-

ative impact on the species (Wilson *et al.*, 2006). For Hazel Dormice, structural connectivity was identified in one study as the second most important factor, after the amount of habitat affecting species distribution (Mortelliti *et al.*, 2011).

There have been multiple studies on the impacts of habitat connectivity on particular species as well as the effectiveness of canopy bridges to provide connectivity. For example, Gregory *et al.* (2017) examined the use of thirteen natural canopy bridges for arboreal mammals in Peru, showing use of crossings for 25 different mammal species. Similarly, several rope bridges in rainforest habitat in Australia have proven effective for connecting habitat for the highly arboreal Lemurroid Ringtail Possum (*Hemibelideus lemuroides*) and other possum species (Goosem *et al.*, 2005). However, many of the studies that show proven use of bridges are focused in rainforest habitat and use natural or temporary artificial structures that do not have a long-term lifespan. In the UK, where standards for road structures are extremely high, these types of structures are not permitted by the Technical Approval Authority (TAA), and the habitats and species are different.

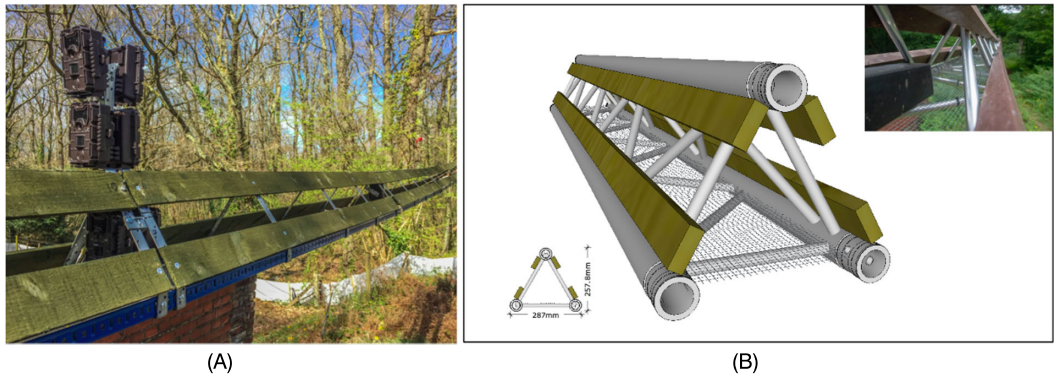
Over the 21st century, UK woodlands have become isolated in the landscape (Reid *et al.*, 2021). In 2020, for example, the total road length in Great Britain was estimated to be 247 500 miles (398 312 km), with 5000 miles (8046 km) of new roads constructed between 2000 and 2020, a 2.1% increase (Department of Transport, 2021). In addition, there has been a significant loss of hedgerows in the UK. According to the Forestry Commission census in the mid-1950s, the UK had 612 000 miles (985 000 km) of hedgerow and this has continued to decline with a recent estimate assessing that the UK currently has 281 000 miles (452 000 km) of hedges, with 74% in England and 17% in Wales (Forestry Commission, 2017).

The Hazel Dormouse (*Muscardinus avellanarius*) is a small, nocturnal rodent in the family Gliridae, native to Europe and northern Asia minor. They can hibernate when food becomes

scarce or unavailable, usually over the winter months, but when active they are a nocturnal and predominantly arboreal species. They occupy small home ranges of about 0.5 hectares and live at very low population densities compared to many other small mammals, with an average of 2.2 individuals per hectare in suitable habitat (Bright *et al.*, 2006). Optimal dormouse habitat consists of early successional woody vegetation that can provide a connected arboreal canopy for them to navigate, such as managed woodlands, supported by connecting scrub and hedgerows (Bright *et al.*, 2006).

Hazel Dormouse populations can be negatively impacted by inappropriate woodland management and by habitat isolation whereby hedges and linear shrubby corridors are inappropriately managed and become defunct or removed entirely (Bright, 1998). The removal or degradation of such landscape features can limit the ability of dormice to disperse to populate new areas. Stochastic events, such as a winter flooding resulting in the death of hibernating dormice, may lead to the extinction of a local dormouse population and habitat fragmentation may mean that the location will not be naturally repopulated by dormice. In recent years, there has been a 5.8% annual decline in the Hazel dormouse population across the UK likely attributed to habitat loss and degradation through inappropriate management, fragmentation and variable climate conditions (Bright *et al.*, 2006; Goodwin *et al.*, 2017). This has resulted in the Hazel dormouse being listed as a 'Species of Principal Importance for the conservation of biodiversity' under Section 41 of the Natural Environment and Rural Communities (NERC) Act 2006. Due to their legal protection, all development planning applications are required to consider dormice and their habitat and provide mitigation, where required, under a European Protected Species license.

Several arboreal bridges have been used to reconnect dormouse habitat in the UK, however there have been issues with previous designs. For example, a dormouse bridge erected in South Wales in 2010 comprised three mesh tube structures connected with wire hawsers that prevented continuity of the tube structure and only



**Figure 1.** (A) Photo of original trial bridge on the Isle of Wight in 2016. (B) Illustrative drawing of upgraded materials in 2016 and a photo of the prototype bridge replacing the trial bridge (inset).

had one entrance point at each end. This bridge collapsed following a storm in 2016, resulting in negative press stories. A housing development in Hampshire includes five dormouse bridges, which aim to maintain links through a severed hedgerow. Some of the bridges do not connect into the hedgerow and access is by a vertical tube at ground level, which makes them difficult for an arboreal species to find. Furthermore, there has been a lack of monitoring associated with these mitigation bridges after installation and no small scale bridges have shown use by Hazel dormice after installation. Only one bridge project in the UK has records of dormouse use, which is a large green overpass bridge constructed over the Lamberhurst bypass in Kent. The bridge has enough space to accommodate a single lane road and shrub planting on either side of the road. Multiple species have been recorded, including breeding dormice in 2011 (Songhurst *et al.*, 2012). While successful, this type of design is of a large scale and very expensive and would not be viable as an option for smaller projects.

Animex International, a private company focused on wildlife mitigation, and People's Trust for Endangered Species (PTES), a UK-based conservation charity, partnered in 2015 to design and test a bridge that would function to provide connectivity for dormice. The design was based on a Japanese design by Dr. Shusako Minato with the ecology and behaviour of dormice in mind, with multiple entry points and materials to climb on, as well as shelters

along the bridge (Minato *et al.*, 2012). A 30-metre length trial prototype bridge was constructed at a research site on the Isle of Wight, UK, suspended on cables between two woodland parcels over a railway and monitored using trail cameras (shown in fig. 1). Dormice were found on the bridge only nine hours after it was first installed and they showed a strong preference for using the bridge over the ground (White and Hughes, 2019). The bridge was monitored until 2019, with positive recordings of dormice still using the bridge.

Following the research trial, the aim was for the bridge design to be upgraded to be commercially sold and implemented on mitigation projects for dormice across the UK. In order for the bridge to be viable as a mitigation option, it had to be accepted by engineers and road authorities to meet the requirements for technical approval across roads.

This paper will discuss the approaches that have been undertaken to gain technical approval through upgraded materials and installation methods, and the lessons that have been learned through two case study projects: i) a 40-metre retrofit bridge to an underpass tunnel on a farm access road in Wales and, ii) two 76+-metre bridges connecting across an 8-lane motorway in Gayhurst, Buckinghamshire. These projects have informed the production of best practice guidance for the arboreal bridge and have influenced the design and implementation of the bridge on future mitigation projects in the UK (Animex International, 2021).

## Materials and methods

UK road regulations have very high safety standards. For the bridge to be installed on road projects, all materials must have an extensive lifetime, be low maintenance and all structures must be permanently fixed. This meant that the suspended cable installation used in the trial was not a possibility for a road project. Proposed highway structures are required to be assessed through a technical approval process, during which a structure is categorised as Category 0, 1, 2 or 3, depending on its level of risk (table 1). The dormouse bridge is a Category 0 or 1, with the level usually dependent on whether it goes directly over a road. Where the structure is a Category 1, an Approval in Principle (AIP) is required with the technical approval authority and encompasses a more stringent approval process.

Animex met with engineers and highways authorities in 2016–2017 to improve the longevity of the materials and installation methods to achieve road regulation compliance. First, the bridge modules were upgraded from those used in the initial trial to long-lasting materials (shown in fig. 1a, b). The base structure was replaced with an aluminium truss with an option for a triangular or square structure. In addition, the lumber siding was replaced with recycled plastic lumber and all fixings were changed to jubilee clips. All materials had an expected lifetime of at least 30 years.

In addition, two overarching installation methods were proposed by structural engineers, the standalone bridge and the retrofit bridge (shown in fig. 2). The standalone bridge was aimed to be self-supporting and consisted of permanent foundations at either end with base plates to build the structure from. The retrofit bridge could be installed directly to existing structures such as road bridges, underpass tunnels or culverts, fixed into the structure with rods secured with adhesive and channel braces to support the bridge.

While these improvements above met the technical requirements in theory, the true measure of success was to successfully obtain technical approval and installation on a real project. Two case studies will be discussed within this

paper, with the results measured by the ability for successful design approval and installation.

The first case study is a retrofit bridge located in St Athan, Wales (51.410975, −3.4596136). On this project there was an existing farm road used by the agriculture properties in the area. The area is predominantly arable land bounded by hedgerows, nearby the small town of Boverton. A new access road to the Bro Tathan Business Park was being constructed. This new road would cross the existing farm road, severing the hedgerows in this location (shown in fig. 3). For this reason, a dormouse bridge was proposed to reconnect the severed habitat. The dormouse bridge measured 40 metres in length, to be retrofit to the newly constructed road crossing along the roof of the underpass.

The second case study includes two separate bridges that reconnect habitat across the M1 motorway as part of a larger upgrade project. The motorway was being upgraded to a “smart motorway”, where a technologically advanced method is used to control traffic flow by automatically monitoring traffic rates. Part of this project involved widening the existing six-lane motorway into eight lanes, resulting in a loss of dormouse habitat along the banks. To mitigate for the loss of habitat, two dormouse bridges were proposed to reconnect the habitat either side of the motorway that had long been severed (shown in fig. 4). Both dormouse bridges were retrofit to existing structures, an access road underpass tunnel requiring a 76-metre dormouse bridge (52.104468, −0.77562490) and an access road overbridge requiring a 78-metre dormouse bridge (52.108623, −0.78438930). The location of the project was along the M1 motorway at Gayhurst, Newport Pagnell in Buckinghamshire, England. The habitats surrounding the motorway are a matrix of arable land and woodlands, with hedgerows and tree-lines bordering the agricultural properties.

## Results

### ST ATHAN, WALES UNDERPASS

The first commercial bridge to be installed was the St Athan, Wales underpass project. On this project, a dormouse bridge was specified to

**Table 1.** Criteria considered for determining a technical approval category, as defined in the Design Manual for Roads and Bridges CG300 Standards (Highways England, 2021).

Technical approval category	Criteria that are considered when determining a technical approval category (although the technical approval authority (TAA) may require a higher or lower category where deemed appropriate)
0	<p>Unless otherwise indicated by the TAA the following structures shall be category 0:</p> <ol style="list-style-type: none"> <li>1) single-span structures with span of less than 5 m;</li> <li>2) buried concrete boxes, buried rigid pipes and corrugated steel buried structures of less than 3 m clear span/diameter and having more than 1 m cover;</li> <li>3) multi-cell buried structures, where the cumulative span is less than 5 m, and having more than 1 m cover;</li> <li>4) earth retaining structures with an effective retained height of greater than 1.5 m but less than 2.5 m;</li> <li>5) minor structures listed within clause 3.3 (8) and not situated at a very exposed site as defined in CD 354;</li> <li>6) high masts 25 m or less in height and not situated at a very exposed site as defined in CD 354;</li> <li>7) noise barriers less than 7 m high and without overhangs;</li> <li>8) masonry arches with span of less than 6.5 m (for assessment only); and,</li> <li>9) portal and cantilever sign and/or signal gantries compliant with a generic AIP.</li> </ol>
1	<p>Unless otherwise indicated by the TAA the following structures shall be category 1:</p> <ol style="list-style-type: none"> <li>1) structures with a single simply supported or integral span of 5 m or greater but less than 20 m and having less than 25° skew;</li> <li>2) buried concrete boxes, buried rigid pipes and corrugated steel buried structures with a clear span/diameter of 8 m or less;</li> <li>3) earth retaining structures with an effective retained height of 2.5 m or greater but less than 7 m;</li> <li>4) minor structures outside the limits of those listed within clause 3.3 item (8) or situated at a very exposed site as defined in CD 354;</li> <li>5) high masts greater than 25 m in height or situated at a very exposed site as defined in CD 354;</li> <li>6) noise barriers 7 m or more in height or with overhangs; and,</li> <li>7) portal and cantilever sign and/or signal gantries with a span of less than 20 m.</li> </ol>
2	Structures, not included within the parameters of Categories 0, 1 or 3.
3	<p>Complex structures which require sophisticated analysis or have any one of the following features shall be category 3:</p> <ol style="list-style-type: none"> <li>1) high structural redundancy;</li> <li>2) unconventional, novel or esoteric design aspects;</li> <li>3) any span exceeding 50 m;</li> <li>4) skew exceeding 45 degrees;</li> <li>5) difficult foundation problems;</li> <li>6) movable bridges;</li> <li>7) movable inspection access gantries, gantry rail and gantry support systems;</li> <li>8) bridges with suspension systems;</li> <li>9) steel orthotropic decks;</li> <li>10) post-tensioned concrete structures;</li> <li>11) earth retaining structures with an effective retained height of 14 m or greater;</li> <li>12) rock anchorages and anchorages forming part of a structure;</li> <li>13) portal sign and/or signal gantries with a span greater than 50 m;</li> <li>14) structures with hidden or difficult to inspect critical elements; or,</li> <li>15) structures with cathodic protection systems installed in accordance with clause 6.5 of CD 370.</li> </ol>



**Figure 2.** Artistic drawing of standalone (top) and retrofit (bottom) installation methods.



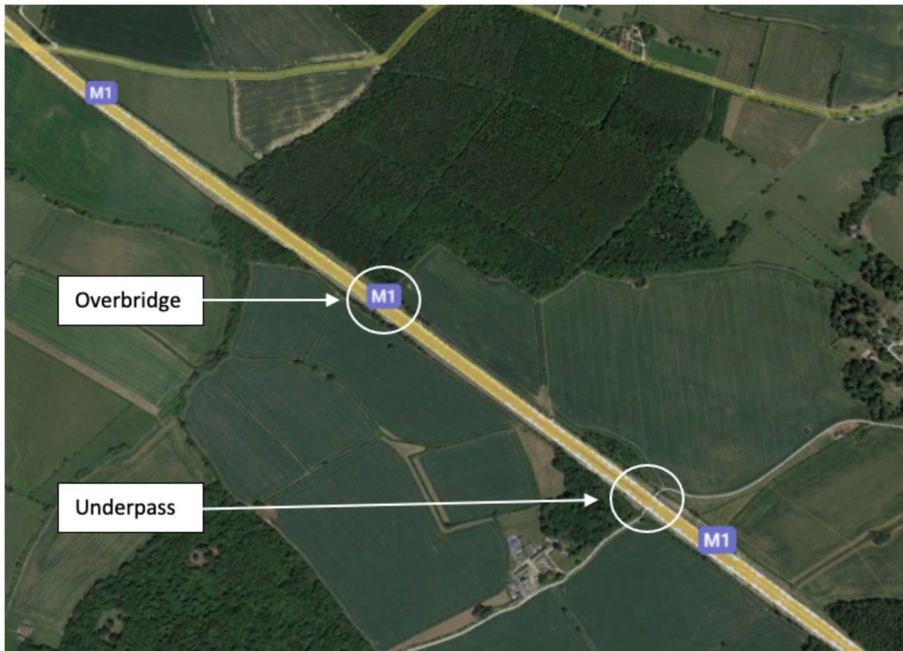
**Figure 3.** (A) Hedgerow connections prior to construction (August 2016). (B) Severance post-construction after completion of road and replanting (September 2021) (Google Earth, 2021).

be installed on a newly built farm access underpass structure. This project required bespoke engineering designs and an AIP to meet technical approval.

A square truss design was used for this bridge with straight lengths of two to four metres

fixed together with connectors. Fixings within the underpass were used a maximum of every five metres and comprised Hilti threaded rods secured with Hilti Hit HY-200 adhesive. The rods supported Halfen Channel, upon which the dormouse bridge structure was placed, while the





**Figure 4.** Locations of two proposed bridges within the wider landscape (satellite imagery from May 2020) (Google Earth, 2021).

ends of the bridge were supported by three supporting steel posts at each end, with a simple post encased in concrete foundation (shown in fig. 5).

At either end of the bridge, corners and sloped bridge sections were used to direct the bridge to the banks at the side of the road, which was to be revegetated. Each bridge section was connected, the mesh floor extended beyond the section to overlap with the next section and was secured on site.

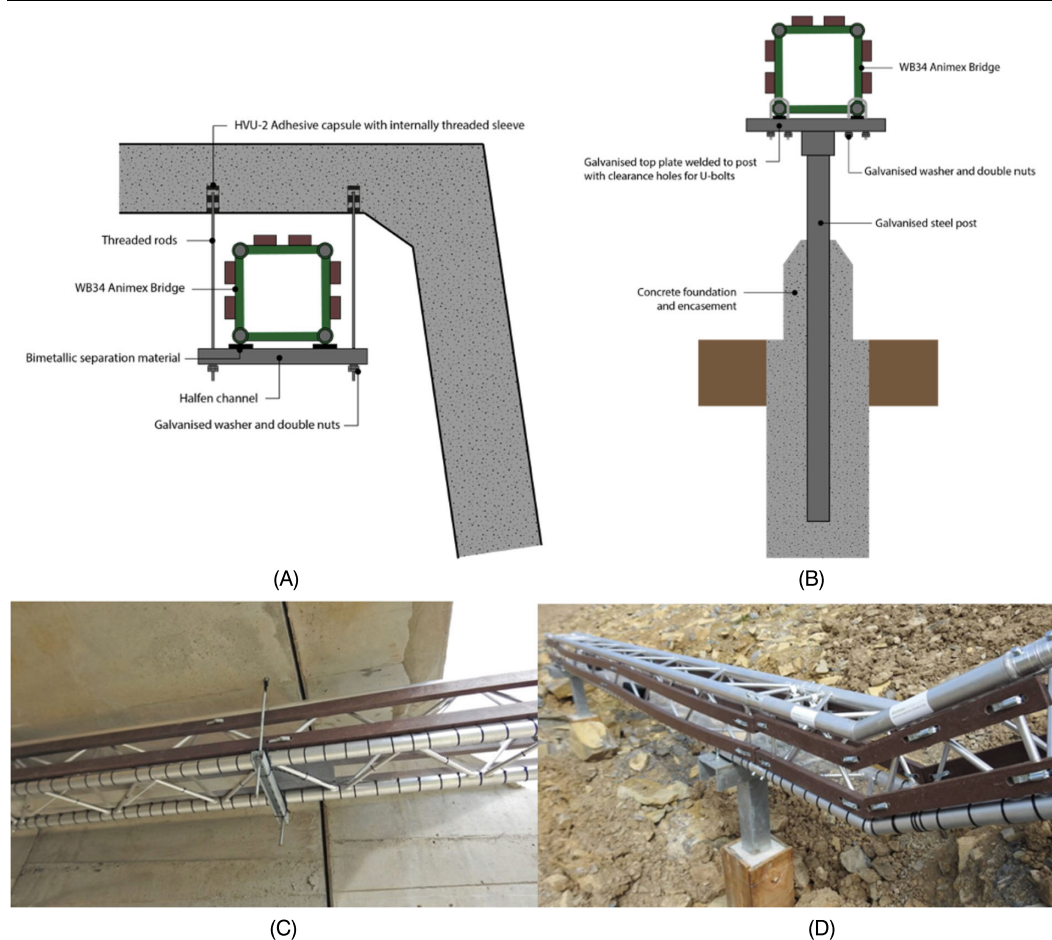
On this project, the design was the first of this type to be completed. It was accepted and achieved the technical approval without requiring significant redesign. The design was completed and approved in early 2019 and it was prepared for installation in summer 2019.

For installation, Animex supplied the bridge and supporting fixings with basic installation guidance. The client contracted two independent contractors to install the 40 m bridge in four days (including all fixings and foundations). Photos of the installed bridge can be seen in fig. 5. Despite this being the first bridge, it was quickly installed without issue. At the time

of installation, there was no vegetation present at the ends. This was revegetated in winter 2019-2020 with whips, as well as a dead hedge to provide interim connectivity. The bridge is planned to be monitored in future, as required by Natural Resources Wales, once the habitat is densely connected.

#### M1 BRIDGES, GAYHURST, BUCKINGHAMSHIRE

The second case study is the M1 motorway project in Gayhurst, Buckinghamshire comprising two separate dormouse bridges. One was constructed on an overbridge and the other on an underpass. This project began in February 2020 and presented a number of challenges in contrast to the St Athan project. First, this project was given a tight deadline originally with a 4-month turnaround from initiation including design, approval and installation, although this was delayed partially due to the COVID-19 pandemic causing delays at all stages of the process. To minimise time, the AIP category had to be kept to Category 0 to reduce requirements for



**Figure 5.** (A) Fixing specifications used to attach to the underpass roof on the St Athan, Wales bridge. (B) Fixing specification for end posts to support the bridge ends. (C) Image of installed bridge showing internal fixings. (D) Image of installed bridge showing end posts.

approval. Secondly, there were multiple stakeholders involved with this project, one being the landowner adjacent to the motorway who used both access roads for agricultural vehicles. This in itself posed a constraint, as both roads are very narrow and used by large tractors and farm equipment. Thirdly, both roads are public bridleways and therefore interference by the public and the associated safety risk had to be considered. Finally, the technical leads wanted all bridge sections to be disconnected and individually supported so they could be easily removed if maintenance was required; with a maximum length of two metres within the underpass to minimise risk when heavy lifting.

For these reasons, Animex had to redesign the bridge and its installation methods. Every bridge part had to be securely fastened with anti-vandal bolts so that there was no possibility of it being tampered with by the public. The fixings for the lumber sidings and the floor of the bridge had to be redesigned for the project. To secure the lumber, steel C-bolts with plates and spacers (to counteract the tension created by the shear nuts) were used, along with bimetallic separation material to prevent corrosion from the steel on aluminium. A system of rail and steel bolts were also used to secure the mesh floor tightly. Finally, the main structure was powder coated in green to provide further protection to the bridge surface.



In addition, we worked closely with the engineers on the project to come up with a new installation method. On the underpass, the existing structure had curved walls with limited clearance at the top. Therefore, the same roof fixing used previously on the St Athan project was not a possibility. Instead, cantilever brackets were used further down the wall where the space was wider to allow for adequate clearance (shown in fig. 6). An additional spacer was added to compensate for the curve in the wall. Each bridge section had to be individually supported with a maximum of two metres, therefore a fixing was used every metre.

On the overpass, clearance was also constrained by a narrow parapet. To keep the technical approval to Category 0, the bridge had to be installed inside the railing of the overpass and away from the access road. A new method of installation was created by elevating the bridge on posts along the entirety of the road, which can be seen in fig. 6.

Despite all the challenges and restrictions presented by this project, it was delivered and installed with an 8-month turnaround. The design was successfully approved by the engineers, project leads and Highways England, although multiple redesigns were required to meet the restrictive constraints for this project.

## **Discussion**

Overall, we have learned from these projects that there is not a “one-size fits-all” solution to the designs and installation methods for the wildlife bridge within the UK. The two case studies highlighted that there is a lot of variation in the restrictions placed by regional authorities and road types. A design that worked perfectly in one location will not necessarily be suitable in another.

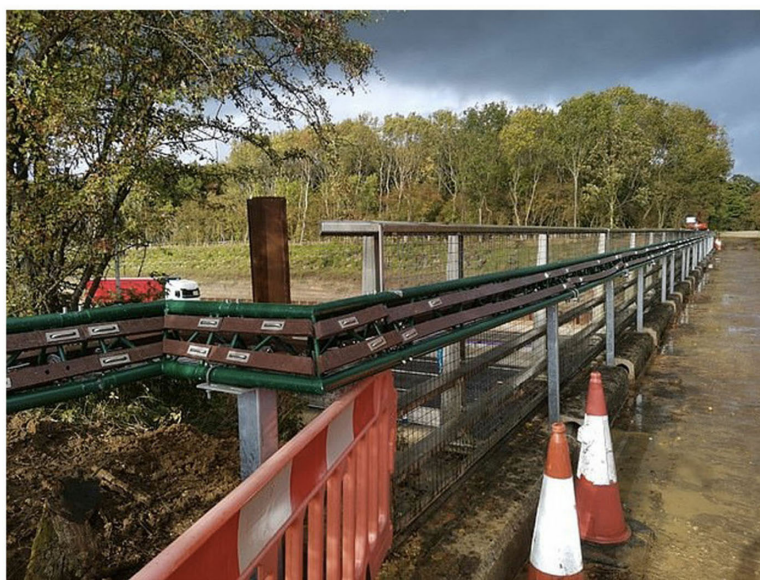
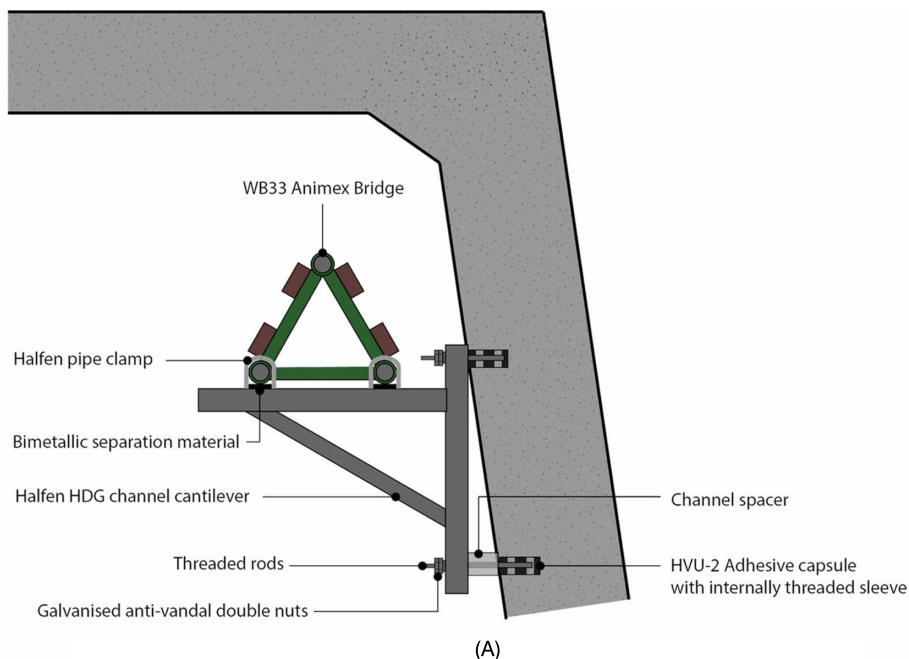
While both projects have been successfully approved and constructed, they identified some area of improvement for future projects. The M1 motorway project in particular has influenced the Animex standard bridge design. Based on the risk concerns, we have made security bolts for the lumber standard on all future projects. While the first project was approved without this, we are aiming to standardise the bridge

to the stricter requirements for future projects. With this in mind, we also decided to adapt the existing structure into a custom-built structure to minimise the number of individual parts to further reduce risk and allow for flexibility in the shape of the bridge.

From everything we’ve learned over the past few years, we also compiled the knowledge into a best practice guidance document (Animex International, 2021), to assist those looking to install bridges on future projects with information on the most suitable bridge types and design methods, technical approval, engineering, supply and installation and post-installation monitoring. While the advice within the guidance is specific to the dormouse bridge in the UK, some concepts can be used globally on arboreal bridge projects for a range of arboreal species.

The technical lessons learnt from these two case studies are also useful in applications of similar, small bridges in other countries with strict technical road requirements. The materials, methods for installation and principles of the design (e.g., multiple access points, predator protection) can be applied to many types of arboreal bridges. Within the UK, this design is also expected to be applied to other types of linear infrastructure and technical approval regulations. Currently, Animex is working with Network Rail with the aim to install the first arboreal dormouse crossing over a railway in the UK and the experience gained through these projects will be useful in achieving a high degree of safety to meet technical standards and reconnect Hazel dormice populations.

While these two case studies have moved forward our knowledge in regard to technical approval, it is also important that they are monitored to ensure continued use by the target species. All bridges have kept the same general design as the original trial study, but the materials, length of bridge and adjacent habitat types are different. Therefore, further monitoring study is recommended on the case study bridges to ensure continued use by Hazel dormice.



**Figure 6.** (A) Specifications for installation fixings to support the bridge on the wall of the underpass tunnel. (B) Photo of installed Animex wildlife bridge on the parapet of overbridge road.

## Conclusion

Canopy connectivity is important for a diverse range of species, with some species being more sensitive to fragmentation and loss of connectivity than others. Multiple studies have

shown the effectiveness of arboreal bridges at improving connectivity and how these can support vulnerable species such as the Hazel dormouse. While the effectiveness of an arboreal bridge can be determined by continuous moni-

toring of the target species, the technical design and ability to obtain technical approval is also important to consider. In a country where there are extremely high safety standards of road structures, natural bridges, rope bridges and temporary or medium-term lifespan artificial structures will not be permitted across roads. The design methods and lessons learnt from the two case studies of the Animex Wildlife Bridge for reconnecting Hazel dormouse habitat can be applied to other projects aiming to increase connectivity around the world where high standards may be required.

### Statement of ethics

This published article is not affiliated with a research institution and was not required to obtain ethics approval for the case studies included.

### Conflict of interest statement

Animex International is part of Ecosupport Ltd, a private limited company. The Animex wildlife bridge is sold as a proven mitigation solution on transportation infrastructure projects in the UK and Europe. Darrelle Moffat, Katherine Aburrow and Steve Béga are employed through Animex International/Ecosupport Ltd and Steve Béga is a director of Ecosupport Ltd.

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### Author contributions

All authors, Darrelle Moffat, Ian White, Katherine Aburrow and Steve Béga have contributed to the production of this paper, revision of the work, and its final approval.

### Data availability statement

There is no further data available associated with this manuscript, as datasets were not used in the production of this manuscript.

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