DESIGN ARTICLE

Crossing to Sustainability: A Role for Design in Overcoming Road Effects

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ABSTRACT

The Earth's network of roads is vast and is reaching new regions with each year that passes. The effects of roads as barriers to animal movement and as conduits for other threats to the conservation of natural systems are well documented. Wildlife crossings can successfully mitigate some of the negative effects of roads by making it possible for wildlife to traverse even major highways safely. However, despite decades of successful deployment, the use of crossings remains uncommon. Their continuing rarity has a variety of origins, but cost and public appreciation of their benefits remain the most important limiting factors. We hypothesize that design can address both challenges. Here we describe a crossing design that is unconventional by current standards. We employ massed wood in a bridge crossing using laminated modules. These modules make it straightforward to customize the structure to its site while also keeping costs low, both because the materials are relatively inexpensive and because the need for specialized labor has been minimized. Other benefits include the rapidity with which the structure can be raised and the reduced need to close roadways during construction. Collectively, these innovations are intended to make crossings much less expensive and more easily adapted to a particular application. The use of massed wood creates a structure that is strong enough to support landscaping on its surface, is both weather- and fire-resistant, and that sequesters many tons of carbon in a long lasting structure.

Keywords: bridge design, connectivity, massed wood, West Vail Pass, wildlife crossing, wildlife-vehicle collisions

Each year, the United States constructs more than 20,000 km of roads (Bureau of Transportation Statistics 2010). These new roads join an existing global network of more than 68 million km (Central Intelligence Agency 2012), collectively constituting the largest class of infrastructure on the planet (Forman and Alexander 1998). As they have proliferated over the past 2 centuries, modern roads have utterly transformed how humans live. The ability to rapidly and efficiently move people and goods has been associated positively with income, health, and well-being (Canning 1998). Simultaneously, the mobility roads afford has released human settlement patterns from their former constraints, fostering large increases in rates of vehicle travel (National Research Council 2005). In the U.S., the net effect is that a random point in the lower 48 states averages <1 km away from the nearest road (Riitters and Wickham 2003).

As the proximity to good roads has generated connectivity and its attendant benefits to humans, it has had the opposite influence on many other species (Trombulak and Frissell 2000). For wildlife, roads act more like fences, separating animals from resources they need, blocking their migration routes, and subdividing their populations. The effects of reduced connectivity on wildlife are now well documented (e.g., Gibbs 1998, Vos and Chardon 1998, Whittington et al. 2005, Frair et al. 2008, Dodd and Gagnon 2011). Even where plenty of good habitat remains, the disintegrating influences of roads can reduce the viability of wildlife populations (van der Grift et al. 2004). In part, this is because roads bring humans and wildlife into contact in the worst ways. In the U.S., as many as 26,000 people are injured each year in vehicle-wildlife collisions (Huijser at al. 2008). The annual economic cost of these collisions is estimated to exceed $8 million. Mortality of wildlife is staggering as well (Barthelmess and Brooks 2010).

To re-knit severed landscapes, reduce human and animal mortality, and foster the viability of wildlife species, we need to create networks of crossings to make landscapes permeable to animal movement. These networks can take advantage of a rapidly advancing frontier of understanding in the realm of animal movement (Downs and Horner 2012). We now know a great deal about the ways in which crossing structures can be created to foster their use by a wide range of species. We also better understand the ways in which such crossings will influence the animal populations they help to connect (van der Ree et al. 2009). In effect, crossing structures have become great tools for learning

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about restrictions on animal movement. If we know so much, why do crossings remain anecdotes across the world's landscapes? Part of the issue is awareness. Most people have neither seen nor heard of a wildlife crossing. It is difficult to ask society to support the creation of infrastructure in such a context. This is particularly evident when substantial investments would be required. A typical wildlife overpass can cost several million dollars. In an era where public works funding is under rapidly rising pressure, wildlife crossings can be a challenging sell.

We view both the awareness and cost issues as problems which can be addressed by design. Good design can bring positive attention to infrastructure. At the same time, smart design can contain costs. Many wildlife crossings have been built in ways not terribly distinct from highway overpasses, and yet their functions are very different. Here we describe a design (Figures 1 and 2) for a wildlife overpass that is unconventional by current standards but that we believe can help to change the conversation about the possibilities for crossings. Road networks are growing fast. If natural systems are to maintain or recover sustainability, crossing networks need to start growing faster as well.

Design: Initial Considerations

A successful wildlife crossing results from attention to 3 critical parameters: location, width, and the environment created by the structure (Clevenger and Huijser 2011). The location for the ARC design competition, West Vail Pass, Colorado, was selected from among 25 candidates (ARC 2010). The competition conveners considered a range of attributes, including the ecological importance of adjoining habitats, rate of wildlife-vehicle collisions, volume of traffic, public awareness of the site, charismatic nature of the site and its wildlife, and interest and willingness of the relevant Department of Transportation (DOT) representatives and adjoining landowners to work with ARC. The site is an excellent case study for the challenges of developing wildlife crossings more generally. Interstate 70, a heavily traveled highway west of Denver, is surrounded by Federally managed high elevation forest, which is home to a wide range of wildlife, including elk (*Cervus canadensis*), lynx (*Lynx canadensis*), black bear (*Ursus americanus*), and mule deer (*Odocoileus hemionus*). Local environmental organizations and federal and state officials had documented a high frequency of wildlife losses from collisions, including a lynx released as part of a relocation program. In addition, camera trapping along the highway margins revealed a concentration of movement activity in the midst of a 6.4-km stretch of roadway without crossings available and at a point where natural features in the surrounding landscape concentrated wildlife use.

After the site has been selected, there is no single design parameter of greater importance than the width of the bridge (Clevenger and Huijser 2011). Many animals shy away from narrow environments. Wider bridges also provide the scope for heterogeneity in vegetation. For the present example, we have chosen a design parameter of 100 m in width. Based on experience with the same wildlife species in other locations (Clevenger and Waltho 2005), we expect this width will promote high rates of use.

Careful choice of substrate and vegetation also promote the use of crossing structures by wildlife. Our bridge design allows for heterogeneity of soil depths to support a variety of vegetation types (Figure 3). By using local, native soil and planting a bridge with familiar species arranged to provide both open and more covered movement opportunities, the range of species that will use a crossing can be maximized. It is critical that the wildlife crossing structures be flexible to accommodate the unforeseen circumstances of wildlife patterns in the future understories, depending on soil depth, moisture, and climate change. In high elevation forests in Colorado, rich diversity and a dense cover of herbaceous and shrub species can be found in the understory of moist groves, while drier sites provide a grassy understory of thurber fescue (*Festuca thurberi*), slender wheatgrass (*Elymus trachycaulus*), and blue wild rye (*Elymus glaucus*) (Colorado Natural Areas Program 1998). Our proposal extends these locally present plant communities onto the bridge while strategically considering the more severe bridge climate, including challenging conditions of water availability, temperature, winds, shallow soil, harsh winter climate, and proximity to highway.

Design: Form-Finding Process

Our design utilizes the surrounding landscape to create a new shape inspired by nature. We employ a low-tech system of layering wood planes to create an easily modifiable shape. The main design intent of the crossing is creation of a structure derived from the abstraction of the topographical layers in the landscape above (Figure 3). The smooth organic curves of the topography in the natural environment of the crossing's surface are reconstituted below (Figure 4) in the rigid stratification of the structural layers in the built environment for vehicular traffic. The expression of this mirrored topography looks as if it had been carved from a single block of wood, optimizing the material to its maximum before reaching its final shape. The result is a design that incorporates a flexible system that is able to respond to the dynamic requirements of the ecosystems it serves to protect while creating boundaries that visually and spatially isolate it from the analogous artificial human domain below. There are no complicated details, just glue-laminated wood beams with partial reinforcement of long screws. This low-tech approach used in conjunction with wood, the availability of which is strongly correlated with the distribution of medium and large vertebrates for which crossings are most often created. In fact, where local wood resources are available, templates could be shipped to a site shop where modules could be manufactured (Gerald Epp, personal communication). Along with the savings in shipping tons of materials, massed wood bridges will lock large volumes of carbon in the structure itself. Gerald Epp (StructureCraft & Fast + Epp) maintains that one of the beauties of the scheme is that the depth of wood structure will be proportional to the span, creating a visually natural structure in the natural environment. There is no reason, if the appropriate care is taken in the design, why 12 lanes of highway could not be spanned.

Undoubtedly, we are interested in the aesthetics of the bridge, and wood for wildlife crossings in open or forested country seems a desirable aesthetic choice. Aesthetics is not a separate agenda from that of sustainability. Things that are beautiful make those who admire the beauty of a design rally to maintain and protect the design so it builds lasting value.

Design Material: Beetle-Killed Timber

Our wildlife crossing proposal envisions a future of crossings that embraces a cradle to cradle, regenerative approach to our built environment. The possibility of utilizing mountain pine beetle (*Dendroctonus ponderosae*) -killed lodgepole pine (*Pinus contorta*) in our Colorado model produces a positive environmental solution to an environmentally catastrophic event. The devastation of hundreds of thousands of hectares of pine forest throughout North America creates an unexpected availability of timber for construction. When harvested within a few years of being attacked, the wood can be used in a number of applications. There are several existing wood bridges in the northeast, but it needs to be researched keeping in mind that it will take some time to overcome the ignorance and bias about the fire performance of wood. For ARC, we envision the trees harvested cost-effectively from beetle kill areas owned by project stakeholders, such as the Forest Service, DOT, and others. The product is readily and locally available. Think LOCAL: this essentially free material will employ a local labor force and build local economy and community. Think GLOBAL: harvesting beetle-killed trees for lumber ensures that the carbon value in the wood remains intact and is not released into the atmosphere as a result of the impending forest fires.

The Design Process

An interdisciplinary design team was formed to generate a uniquely innovative, flexible, cost effective bridge system. This team composition is itself an important part of the design. The team includes landscape architects, ecologists, architects, engineers, cost consultants, and construction experts who worked closely on every aspect of the design process. Each party added value to the design, challenging each other until the final design was conceived.

In advance of a major capital investment like a wildlife crossing, it will pay to invest first in developing an understanding of movement patterns by focal wildlife species. Some initial information can be gleaned from collision data. However, there is no substitute for the use of wildlife cameras in documenting animal movement patterns. Such data can aid crossing designers in locating a bridge in a position that best reflects the movement tendencies of animals.

Each element of the prefabricated modular structural system fits in the standard dimensions of a semi-truck trailer for easy transportation to the site. Installation of the modular system will be fast, without the need to close the freeway or disrupt traffic for extended periods. We expect construction time at this site to be from the beginning of prefabrication to final installation will take a period of 2–3 months (Figure 5).

The surface of the bridge and its surroundings will read as a single living landscape. The flexibility of the bridge structure will allow each bridge to have plantings in various configurations that will fit the specific conditions and demands of the animals at each site. Ideally, the bridge surface will accommodate animals which prefer to move through environments with open sight lines as well as those who prefer denser cover. A vegetation arrangement incorporating 'traffic lanes' for both types of animals is one solution when an ample bridge width is employed.

The bridge will also act as a data collection system, helping to further the understanding of the movements and habits of the animals crossing the structure. With the help of a modest number of cameras covering the approaches and deck surface, the ways that animals use and react to the bridge will be thoroughly documented. The timing, duration of use, and movement paths can be cataloged and analyzed. In this way a new bridge can be used to inform the design of future bridges or to retrofit current bridges in ways that will increase their effectiveness and promote their use by target species.

These steps reflect a philosophy in which each bridge is produced based on a strong understanding of its local context as well as a strategic vision of how the bridge fits within a network of such structures designed to work as a system. As each structure is built, information resulting from its creation and use is fed forward to continually optimize the system of crossings. In broad terms, this approach mirrors that used by transportation officials to create road networks. Their approaches offer a sound model for creating movement systems for wildlife.

Discussion

The first wildlife crossings are now several decades old. The collective experience associated with the continual development of wildlife crossings has produced a set of practices which have proven effective in an enormous range of contexts (Clevenger and Huijser 2011). At this point, wildlife crossings as agents of landscape permeability are a known, successful commodity. However, they are far from common. To catalyze their wider use and increase their benefits to humans and wildlife, 2 issues must be addressed: awareness and cost. Design will be critical on both fronts. Most wildlife overpasses look like an ordinary piece of highway infrastructure. Many have signs advertising their true nature, but most travelers pass them by without thinking about them let alone recognizing what they are or what they do. Designs that announce their purpose through the use of unusual materials and that reflect the aspirations associated with crossings can change the conversation about their use. At the same time, new designs can promote cost savings.

Our design is based on the use of wood. This is, perhaps, a remarkable choice for a highway crossing structure, but on the merits it makes sense. Our design announces its purpose by reminding people of the connection between the built and natural environments. No one will need a sign to tell them that the crossing is not an ordinary piece of highway infrastructure. Of equal importance, it will save money in materials, manufacture, and installation. At each of these steps, wood provides advantages relative to other materials (Hauke Jungjohann, personal communication). The cost of wood is similar to that of traditional constructions methods, but maintenance costs will be much less so, and over the years it will become much cheaper. The main saving will be in CO_2 emissions as glue-laminated timber uses less energy for construction, maintenance and disposal and the CO_2 is retained in the wood structure. The scheme uses low-cost lumber of ordinary dimensions in a knit-together composite to achieve efficiency and economy. Most of the bridge is pre-fabricated in a shop. The pieces, sized to the maximum allowable transportation size, can be assembled at the crossing location adjacent to the roadway. These assembled modules (arches) remain light enough to be handled by a modest-sized crane. This system of construction minimizes interference with traffic and reduces construction time. Additionally, no scaffolding is needed. One of the most attractive features of our design approach is its adaptability. The shape of the modules used to create the bridge may be easily customized to suit the contours of a particular site. There are no forms that dictate the structure's shape, as with cast concrete. Wood is widely distributed and, in fact, its local availability is strongly associated with the distribution many of the wildlife species crossings are intended to serve. The bridge deck itself need not be a simple shape. Rises and falls in the deck can match the topography found at either landing point and offer heterogeneity of habitats that is matched to the surroundings. This flexibility can also be used to vary soil depth to allow for heterogeneity in plantings. There are no limits as to soil depth. In service, wood is highly durable. Dry, wet, cold, or hot locations will not pose difficulties for a massed wood structure. In Europe, the flexibility of wood as a bridge material along with its aesthetic qualities promote its increased use (e.g., Meierhofer 1996, Mettem 2011). Massed wood also has excellent fire resistance, which has been demonstrated by extensive fire testing, and will perform much better than unprotected steel. No additional fire protection is needed.

The aspect of our design that provides its signal advantages in promoting awareness and controlling cost is the same characteristic that poses its major challenge. Wooden bridges are not the norm in the world of highway infrastructure. Highway management agencies will need to develop familiarity with a new approach before it will be adopted. Beyond that, agencies responsible for building and maintaining crossing structures need to be convinced that there are benefits that exceed those emerging from the use of traditional structures. We believe that trial use of our approach will convince transportation agencies that new designs and materials can improve upon the status quo. Part of the reason crossings are rare is because the agencies that are charged with creating them are expending prized resources on what amounts to an invisible amenity. When a new lane is added to a highway, travelers recognize and understand the change immediately. When a wildlife crossing is added, do they notice? Do they understand its need and function? Structures that advertise their purpose, particularly when they save resources, can help agencies meet their goals while simultaneously constructing a more sustainable future. The success of crossing structures in contexts such as Banff National Park in Canada (Clevenger and Waltho 2005) offer models for the ways in which a strategic program to reconnect severed landscapes can also enjoy widespread public support.

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