Reconsidering the role of the built environment in human–wildlife interactions

Christopher Serenari

Texas State University – Biology, San Marcos, TX, USA

Correspondence
Christopher Serenari
Email: c_s754@txstate.edu

Handling Editor: Ambika Aiyadurai

Abstract
1. In facing our greatest challenges, researchers have questioned where the 'wild things' will reside in the future, and large carnivores have been a primary focal area.

2. The built environment plays a critical role in the propagation of countless species including carnivores; however, contemporary conceptualizations of human–nature relations do not satisfactorily attend to where the built environment should be placed within existing human–nature relation frameworks or how it impacts our ability to find space for carnivores.

3. This paper fills this information gap by investigating the role of the built environment in social–ecological systems (SES), specifically wildlife and carnivore conservation.

4. The paper unfolds in four stages: The first reviews empirical efforts to capture the relationship between human–natural–wildlife systems and the built environment. Second, using insights from the built environment literature, I argue that moving away from a common pool resource focus, decoupling wildlife and natural systems, investigating all infrastructure types and their interactions across systems, and considering the notion of hybrid systems offer pathways forward. Third, an explanation of the built environment's linkages to human and carnivore systems is undertaken to illustrate how the built environment facilitates the material and symbolic interactions through a blending of properties from human, wildlife and natural systems. Lastly, the argument is made that attending to the role of the built environment in human–wildlife relations can stimulate new research that reveals unhelpful habitual behaviour, feedbacks and barriers, and may also help explain unintended or unexplained consequences impacting human–carnivore relations not fully considered under existing frameworks.

Keywords
built environment, carnivore, human–wildlife interaction, infrastructure, social–ecological system
1 | INTRODUCTION

Researchers have wondered where ‘wild things’ will reside in the future (Bruskotter & Wilson, 2014). Humans are super-predators and the major driver of the ongoing Holocene extinction (Darimont et al., 2018; Shaver, 2018). Our activities have resulted in incalculable negative impacts to biodiversity. This trend will continue without drastic global reforms about how we interact with Earth’s natural systems and non-human inhabitants.

A portion of the planet-in-crisis literature has focused on human-large carnivore (carnivores) dynamics. Carnivores are critical components of healthy ecosystems (Estes et al., 2011; Packer et al., 2013). Larger bodied carnivores regulate disease risk, suppress less desirable wildlife and promote seed dispersal (Ripple et al., 2016). Humans benefit from carnivores in the form of subsistence, economic, aesthetic and cultural value (Naughton-Trevés & Sanderson, 1995). For instance, carnivores positively impact human health and well-being through disease mitigation, contribute indirect influences to agricultural production and provide organic waste regulation services (O’Bryan et al., 2018). Hence, on an increasingly crowded planet with dwindling resources needed for survival, humans will need to choose to spare land for carnivores, share space with them, doom them to extinction or perhaps find technological fixes to our grand challenges concerning the so-called predator paradox (Shivik, 2014).

As historic ranges contract and spatial extent of human and carnivore niches overlap, the built environment has and will continue to contribute a great deal to solving the paradox (e.g. Coonan et al., 2010; Wielebnowski, 1998). Conceptualizations of the built environment generally comprise hard infrastructure as well as technological systems. Human-built systems designed for human activity often refer to buildings, parks, roads, electrical grids and other structures as well as a tight network of public and private infrastructures (Anderies, 2014). The built environment is often defined in contrast to the ‘unbuilt’ environment, such as a forest (Moffatt & Kohler, 2008). A built–unbuilt dichotomy concerned primarily with the material domain is problematic, however, because it does not make explicit the diverse infrastructures that ostensibly exist in a social–ecological systems (SES). The array of material and non-material infrastructures comprise and influence interactions between humans and carnivores. I outline below that infrastructures give meaning to human-constructed spaces and link human, natural and wildlife systems. Though the built environment plays a critical role in carnivore conservation through acts such as veterinary care, rehabilitation, rescue or reintroduction, and is anticipated to play an even greater role in the future, researchers have dissimilarly conceptualized or integrated the role of the built environment in SES. Inadvertently, important carnivore and other wildlife management system dynamics that inform coexistence schemes may be overlooked.

To address this need, I argue that carnivore conservation research requires greater consideration for the role of the built environment. A major aim of this paper was to link dialogues concerning human-constructed spaces and loss of biodiversity, specifically carnivores. The hopes are twofold, in that a closer examination of the built environment’s role in carnivore conservation will better integrate it into complex SESs in the future and assist in theory development. To achieve this aim, I first review contemporary empirical efforts to capture the relationship between human–natural systems and the built environment. Second, I propose and describe four ways in which research can clearly capture the role of the built environment in carnivore conservation. Third, I apply contemporary concepts from the reviewed built environment literature to human–carnivore relations to further illuminate the role of the built environment in SES. The paper closes with thoughts on pathways forward to inform dialogue and theoretical development.

2 | CONTEMPORARY APPROACHES TO INCORPORATE THE BUILT ENVIRONMENT IN SES

Over the last 40 years, scientists have generated interest in explaining problems related to the creation and maintenance of infrastructure and distribution of metabolisms (balanced flows of energy and materials between human and natural systems). Early research by Clark et al. (1979) helped focus scholarly attention on the importance of infrastructure in SES.

Since, four leading approaches to investigate and express the role of the built environment and SES have come to the fore. First, urban biodiversity studies have explored broad connections between systems, investigating the frontiers of green urban planning and sustainable cities and situating a growing number of inquiries within the built environment nature nexus. The implications of this research often inform urban biodiversity (e.g. Aronson et al., 2017) or climate resilience planning (e.g. Wilby, 2007). Foci include ways to increase biodiversity within cities through practices such as wildlife gardening (Gaston et al., 2007; Mumaw & Bekessy, 2017) and modifying the built environment to better incorporate the presence of wildlife, mainly birds (e.g. Menacho-Odio, 2018; Snep et al., 2016). Researchers of the ecosystem services–urban planning nexus as well as ecosystem studies have proposed the concept of hybrid systems to capture these interactions. For urbanscape researchers, hybrid systems yield services resulting from the blending of elements from human and natural systems. Taking an anthropocentric view, hybrid systems provide ‘intentional’ (planned) and ‘hybrid’ (synergistic) services to humans (e.g. provisioning, protection, regulation; Grimm et al., 2015). In the conservation sciences, hybrid systems embody a state in which an ecosystem resides, somewhere between ‘historical’ and ‘novel’, such as ‘pre-degradation’ and ‘current’ (Grimm et al., 2015; Hobbs et al., 2009). As presented here, a hybrid system would theoretically have its own unique and dynamic role in adaptive processes over time, blending properties from human, natural and wildlife systems.

Another approach involves situating the built environment within the human system in a coupled system: ‘The built environment is constructed by humans, and thus it is considered a part of the human subsystem’ (Liu et al., 2016, 20). Situating the built
environment in the SES of Bengal tigers Panthera tigris tigris, Carter et al. (2014) conveyed an interest in what built environment researchers describe as hard infrastructure, attending to the presence and spatial distribution of roads, buildings and settlements (Natural System > Landcover), as well as the services that hard infrastructure such as hospitals and tourism infrastructure provide humans (Human System > Community). Yet, both humans and tigers are impacted by the built environment and, as described below, its myriad infrastructures. For instance, tigers benefit from veterinary practices and facilities, rehabilitation in captivity or translocation by road 11 hours from Chitwan National Park to Bardia National Park (Lamichhane et al. 2017; Worldwide Fund for Nature (WWF), 2011). Moreover, material and symbolic elements of the built environment give rise to forms of telecoupling and operationalize them. These processes and interactions between systems and their components are catalysed or moderated by an array of infrastructures that imbue system dynamics (i.e. mass and energy flows) with meaning and shapes, and transforms the existence of human and non-human organisms.

Drawing from Fischer-Kowalski and Weisz (1999), Moffatt and Kohler (2008) conceptualized a third approach where the built environment is a SES. They established that the relation between the built environment and the ecosystem has evolved since the 16th century, an integration of the histories of nature and human culture. The built environment is viewed as a cultural artefact (i.e. conveys information about human culture) dependent upon historical context, and situated within the region of intersection originating from the union of material (nature) and societal (culture) domains. Two-way causal relationships emerge (later echoed by Hassler & Kohler, 2014). The system is dynamic in its form and function as well as a product of complex feedbacks with the ecosphere. Cultural context, environmental histories, and spatial and temporal information are particularly influential in placing the built environment as well as humans and domestic animals in the region of intersection. These factors set the boundaries by which mass and energy flows between built and natural systems can be modelled. Culture buffers innate human desires to control and care for all aspects of life-sustaining systems. Unlike domesticated animals and plants, wild animals kept in human-built spaces for the benefit of humans and wildlife conservation may be artefacts of the built environment within this socially constructed representation of the nature–society dichotomy. This approach also considers symbiotic relationships between systems and their levels. It may help explain humans having a balanced flow at the local level (e.g. a rehabilitation centre brings a sick animal in and sends a healthy animal out), but an imbalanced relationship between systems at the macro level is due, in part, to historical perspectives (e.g. culture of fear) that inspire the separation of humans and carnivores and hinder coexistence schemes (Chapron et al., 2014).

A final approach encourages thinking in terms of infrastructure, shifting the unit of analysis from SES to special characteristics of infrastructure and accounts for its potential to mediate relations between human and natural systems. The coupled infrastructure system (CIS) concept extends Ostrom’s (2009) general SES and Anderies et al.’s (2004) Robustness of SES frameworks and describes a SES as a special case of CIS. Anderies et al. (2016) asserted that the core or foundational components of social, ecological, natural and built systems in which humans interact with one another and their environment (both built and natural) are ‘classes of functional infrastructures’ and that separate logics assigned to human and natural systems are ‘artificial’ and linkages between them can be misinterpreted (p. 502). They clarified that there are five main types of infrastructure that constitute CISs:

1. hard infrastructure which is human-made structures such as roads, irrigation systems and nuclear power stations (cf. Frischmann, 2005, ‘traditional infrastructure’);
2. soft infrastructure which are collections of human-made ‘instructions’ for using other types of infrastructure such as institutional arrangements and decision-making processes (cf. Frischmann, 2005, ‘intellectual infrastructure’);
3. natural infrastructure which is hard infrastructure that is not human-made but is critical for society, such as wetlands for absorbing and filtering water (cf. Frischmann, 2005, ‘environmental infrastructure’);
4. human infrastructure which refers to knowledge (often referred to as ‘knowledge capital’ in economics, cf. Frischmann, 2005, ‘intellectual infrastructure’);
5. social infrastructure which refers to the relationships we have with others. (p. 502).

Analysing infrastructure in this way moves beyond the previously mentioned and potentially problematic hard–soft dichotomy as well as individual logics implicit of SES, and also explicitly attends to the role of the built environment in SES. The CIS approach has been applied to post-hurricane (Comes & van de Walle, 2014), energy (Kong et al., 2019), water (Tellman et al., 2018; Yu et al., 2014) and climate change (Clark et al., 2019) contexts.

When taken together, SES and CIS frameworks assist researchers to advance investigations into the role of the built environment in human–wildlife relations. In the next section, I draw from these literatures and suggest four propositions that further the intellectual project proposed.

### 3 | CLARIFYING THE ROLE OF THE BUILT ENVIRONMENT IN HUMAN–WILDLIFE RELATIONS

One proposition is to extend approaches that analyse the relations between human, natural and wildlife (carnivore) systems beyond common pool resources (Paavola, 2007). Whether employing popular frameworks that attend to infrastructure, such as SES, Robustness of SES or CIS frameworks, researchers’ primary focus has been managing and conserving common pool resources. These approaches have clearly defined principles, concepts and definitions with which to conduct systematic analysis. However, the study of wildlife presents challenges to applying these approaches. For instance,
thorough wildlife hunting (Smith et al., 2019) and tourism (Moore & Rodger, 2010) are reasoned to be common pool resources, it is not yet established that, unlike fish stocks, terrestrial wildlife such as carnivore populations should be catalogued in similar manner. Furthermore, wildlife is viewed as a resource for humans (Naughton-Treves & Sanderson, 1995), but the contested ownership of wildlife, particularly privately owned, non-game and threatened or endangered species, can pose challenges for situating wildlife–built environment interactions within SES and CIS frameworks. It seems practical that future research on the role of the built environment in SES will need to account for these dynamics.

A second suggestion is to decouple wildlife and natural systems, following Liu et al. (2016). Often the case in SES studies, wildlife systems are enfolded within the natural system. But, there are at least two reasons why this parting is necessary to attend to the role of the built environment. The first is a spatial matter. Previous SES research commonly places wild animals within wild nature and not in the same spaces that humans occupy. This is often not the case in certain contexts, and the built environment helps facilitate the co-occupation of humans and wildlife, blurring the lines between systems. A second reason is that researchers often neglect to mention captive wild animals, which are unique to our understandings of SES as well as the role of infrastructure in SES. A wild animal has not been domesticated to live with humans (Akhtar, 2012) and, therefore, greater consideration for and intellectual space given to free-ranging and captive, yet still wild, animals should be given to analyses.

Drawing from CIS and Moffat and Kohler’s cultural approach (2008), a third proposition is to parse and investigate the suite of infrastructures from their systems (a) because it is counterproductive to perceive divisions between systems that do not actually exist and (b) to clearly see connections between infrastructures and their cultural meanings or significance. Researchers must account for the degrees to which certain infrastructures inspire, mediate or are developed by human activity occurring over time and within natural or wildlife systems. For instance, an overemphasis on the material neglects how hard infrastructure is woven into other aspects of the human experience. Finnish architect Pallasmaa (2000) reasoned that, ‘A building is not an end in itself. A building conditions and transforms the human experience of reality; it frames, structures, articulates, links, separates and unites, enables and prohibits’ (8).

Furthermore, how humans design the various infrastructures is important for reinventing unsustainable human relationships with natural and wildlife systems and attending to the politics of wildlife conservation. To quote Escobar (2018), the material foundations of ‘‘hardwires’ particular kinds of politics into bodies, spaces, or objects’’ (18).

A fourth and final suggestion inspired by urban and ecosystem studies is that researchers should consider the idea that a theoretical hybrid system may exist, created through the joining of human, natural and wildlife system properties (SES perspective) or infrastructures (CIS). These systems would display novel properties and services to humans and nature.

![FIGURE 1](image-url)

**FIGURE 1** A gradient of blending among human, natural and wildlife systems

Taking these suggestions in aggregate, I provide examples of how the built environment blurs the lines between distinct human, natural and carnivore systems, rendering the need for clearer articulations of infrastructure’s role in SES. When systems intersect (Figure 1), characteristics (e.g. infrastructures) of one system may theoretically persist while those of another system can change dramatically or slightly. In the middle of the gradient, systems overlap, but their properties merge and perhaps creates a novel, undertheorized hybrid system of shared and emerging properties.

At the far left of the spectrum, we find conventional zoos and aquariums. Each are distinct built environments embedded within the human system, often constructed within urbanscapes. To exist, they draw energies from wildlife and natural systems but the properties of the system resulting from these interactions mainly reflect the human system (i.e. soft, human and social infrastructures). They generally consist of well-defined enclosures or ‘exhibits’ in which species are kept, but these settings mainly exist for human benefit. They serve as centres for human recreation, education and work. They connect people with ‘nature’ (Bruni et al., 2008) and are spaces used to educate visitors about species and ongoing wildlife conservation efforts (Perdue et al., 2012). Zoos and aquariums may be owned by private individuals, legal entities, museums, research institutions or educational institutions, among others. Local, regional and federal governments most commonly create the rules these entities must follow to possess, display, care for, propagate, collect, transport, trade or sell wildlife, though some countries such as Lebanon or Turkey do not have such legal requirements. Often, however, owners require a valid permit and corresponding rules regarding the safety and health conditions for wildlife and penalties for violations. Sites may or may not be accredited by institutions such as the Association of Zoos and Aquariums (AZA) or the Eurasian Regional Association of Zoological Parks and Aquaria (EURAZA). Instead of using simply hard elements (e.g. iron bars), managers may convert, modify and incorporate naturalistic elements into their enclosure designs to make the wild inhabitants comfortable (Grazian, 2012; Maple & Finlay, 1987). Interactions between humans and wildlife are strictly regulated and human welfare is often prioritized above that of the animal. An animal’s space ‘should be respected’ by people, but animals may be euthanized in the event of a mauling or attack on a human (e.g. killing of Harambe the western lowland gorilla [*Gorilla gorilla gorilla*]).

We must also fully consider how zoos and aquariums take part of the broader planned and coordinated conservation of threatened and endangered carnivores occurring at broad scales (Chapron et al., 2014). The global zoo and aquarium network is comprised of private, public and non-governmental entities. Hard infrastructure
is critical in these instances because various human-built elements connect the three systems to support captive breeding programs. These spaces offer resources where energy and material flows are extracted from both wild and natural systems with the hopes of returning it in a larger quantity than it was extracted (e.g. supplementing the wild population, developing a self-sustaining captive population, Earnhardt, 2010; Fraser, 2008; Laidlaw, 2001; Ralls & Ballou, 2013). Roads, runways, bridges and other hard infrastructure is required to access and transport animals into and out of human and natural systems. ‘Elaborate enclosure technologies’ such as electric cables or glass panels are often required to contain animals (and keep others out; Grazian, 2012, p. 551) while human-built dens provide shelter and safe spaces. Buildings with functioning electrical, water and sewer infrastructure are required to carry out the logistics of captive breeding and veterinary care. Hard infrastructure is also necessary to store species’ sperm in vats of liquid nitrogen (i.e. the so-called frozen zoo), keep track of breeding efforts and provide veterinary care. The red wolf Canis rufus captive breeding program is deeply reliant on energy and material flows from the human system (Wielebnowski, 1998), but the system in which it operates reflect mainly human system properties and infrastructures. There are approximately 200 red wolves in captive breeding facilities across the United States. Their existence is supported by 26 of 44 approved zoos and wildlife centres throughout the country that manage the captive red wolf population as a genetic reservoir and to supplement the wild population.

Much like zoos and aquariums, some wildlife conservation activities occurring within human-constructed spaces move us a step away from zoos and aquariums and closer to the middle of the gradient. System properties still reflect the needs of humans and are designed for high levels of human activity, but natural and wildlife system properties begin to emerge more clearly. Since 1955, large investments have been made in captive breeding of giant pandas Ailuropoda melanoleuca in China (Reid & Gong, 1999). The Gengda Wolong Panda Center located within the Wolong Nature Reserve supports this effort. The compound hosts a range of human activity. It comprises a 465-m² research laboratory, an equally sized panda hospital, and indoor and outdoor reintroduction training areas. Various buildings serve human activities such as logistics and management, food processing, material storage building and staff facilities. The compound houses visitors and volunteers. Fifty-nine landscape enclosures incorporating natural infrastructure include indoor and outdoor areas with human-built wooden structures to climb, sit and play. A 188-ha bamboo forest helps feed the pandas. The mammals are eventually driven between reserves for (re)introduction into China’s wilds (Holland, 2016).

Sanctuaries, reserves and some ‘farms’ are one step further right from spaces comparable to the panda centre and ever-closer to centre of the blending gradient. Blending results in human system properties still dominating, but they are progressively diminished compared to the above-mentioned examples. Energy and material flows coming into the human system from wildlife and natural systems may or may not be returned, which results in system properties reflecting the properties of all three systems more equally. This location on the gradient is characterized by the Red Wolf Education and Health Care Facility (i.e. The Red Wolf Center) in Columbia, North Carolina. The 111-m² pre-fabricated building is situated near Pocosin Lakes Wildlife Refuge within the existing red wolf recovery area and now run by the North Carolina Wildlife Federation and volunteers. It doubles as an education and wild wolf health care facility. The education side of the facility provides an opportunity for visitors, mainly tourists, to view exhibits and educational material about red wolves. Operating like a small-scale zoo, visitors can also view a small number (often a pair) of older, non-reproductive wolves that make a double-fenced forest enclosure their permanent home. The other side of the building is used for organizing and administering veterinary care services where wild wolves are brought into the human system, treated for mange, gunshots and other maladies, and deceased or unidentified canids may undergo genetic testing or other processing. Healthy wolves are released back into the wilds. The complex is also used for reintroduction efforts (P. Benjamin, pers. comm., 10/23/19).

Middle ground on the gradient may be best represented by wildlife game ranches and spaces facilitating animal husbandry operations. In this location, properties of human and non-human systems exist relatively equally and the built environment helps establish and regulate interactions though it cannot always control them. Wildlife ranching establishments in South Africa are legally permitted to own wildlife as long as it is adequately fenced or enclosed. The wildlife ranching industry in South Africa protects nearly four times the number of wildlife as the public park system (Bothma et al., 2009). There are four economic pillars to South African wildlife ranching in which this and other reserves may participate with the aid of the built environment: breeding of species to replenish ranch populations; breeding to support trade or sale of parts, products or whole animals; photographic tourism; and hunting (Van der Merwe & Saayman, 2005). One example, to which the author is familiar, is the Tshukudu Game Lodge, a ‘Big 5 game reserve’ that borders Kruger National Park. Wildlife are owned by the reserve but generally free to pursue their biological inclinations. Tourists are provided opportunities to engage the wildlife and natural systems through carefully designed aspects of the human system that facilitates game drives, bush walks and comfortable, safe accommodations. Yet, walking at dark is not recommended. Animal husbandry operations around the world often characterize this middle ground as well. In Europe and the American West, though not full-proof, livestock owners use the built environment, such as enclosures, to protect their livestock from wolves (e.g. Karlsson & Sjöström, 2011). In Africa, villagers use natural infrastructure to build fences made of brush, stone or wood to safeguard humans and livestock from predators (e.g. Ogada et al., 2003).

Progressing towards the right side of center on the blending gradient are spaces where the built environment still facilitates a balanced mix of human and natural properties, but properties of natural and wildlife systems are more pronounced. Wildlife in these spaces live in large enclosures that equate to much larger territories within a natural habitat. In these spaces, wildlife is given a chance to share...
space with a greater number of their own kind, and individuals can more fully express normative behaviour such as stalking wild prey, socializing or foraging. However, human presence is not eliminated. Spaces representative of this position on the gradient are wildlife versions of retirement homes where older, orphaned, injured, abandoned or disabled animals can live out their days. Elephant Lake in the Bago region of Myanmar is one example of such a human-built space. Over 1,000 former working elephants remain unemployed due to a decline in timber markets. Owners often have to choose between killing, selling or abandoning their elephants. Spaces offering a more balanced mix of human and natural properties comprises a fourth alternative for elephants. FOUR PAWS, a non-governmental organization, started construction on such a space on 1 May 2018. A collaboration between public, private and non-governmental entities, over 17,000 hectares of forest will be home to nearly 300 former logging elephants over the next 10 years. Another example is the Libearty Brown Bear Sanctuary in Zarnesti, Romania, the largest brown bear Ursus arctos reserve in the world. It is home to abused and abandoned bears and wolves. The effort to create this ‘not a zoo’ (Millions of Friends, 2010) was monumental. Heavy equipment moved 1,500 m³ of soil, while 3,000 wood posts, 150 loads of gravel and 15 km of electric wires were used to create the semi-natural habitats. Cement trucks and hundreds of man-hours were needed to complete the facility. Over 100 bears live in a 30-ha forested enclosure situated on approximately 69 total hectares. They contain large fresh water pools, hibernation dens and natural vegetation. In addition to human feedings, bears feed on the vegetation, nuts and berries available in the forest and intra-population dynamics are allowed to play out (e.g. posturing over food). Yet, similar to the panda reserve, human activity is critical to support the prolonged existence of the many bears there. A large central sanctuary building contains staff areas, storage and preparation areas for food for the bears, a veterinary clinic and a number of quarantine dens for new or sick bears, visitor staging areas, and a food processing area to distribute over a ton of fruit and vegetables a day around the sanctuary enclosures. Revenue from hosting visitors, who are able to view the bears’ supplemental feedings, defrays costs of facility upkeep and bear care. Similar but smaller scale examples of natural spaces that serve wildlife conservation include some public game lands in North Carolina where orphaned or injured black bears Ursus americanus are treated and cared for by humans (Figure 2). The difference between this space and the aforementioned red wolf centre or bear sanctuary is that bears may spend days to months in rudimentary fenced enclosures surrounded by native habitat. They are placed far from and are not exposed to human activity outside intermittent instances of care. They are eventually transported back to the natural spaces from which they came.

Moving to the far-right end of the gradient, the full extent of natural and wildlife system properties dominate. Though the built environment extends into natural and wildlife systems and is important for facilitating interactions between the three systems, its role is substantially diminished. These areas comprise several elemental aspects of the built environment constructed to promote the presence and activities of humans (i.e. soft, human and social infrastructures), but not unacceptably disrupt wildlife or natural systems. National parks can be examples of such systems. Parks contain social and physical elements of the built environment, such as sense of place or park architecture, that blur the lines between and give meaning to systems (Louter, 2009; Moffatt & Kohler, 2008). Roads, trails, restrooms, gift shops, golf courses, fences and lodging help integrate other human infrastructures into the other two systems. Unlike the other areas of the gradient, a space’s position to the far-right end of the spectrum encompasses a system that permits passage and usage by humans, but the occupation of those areas by humans is often temporary or seasonal. Moreover, direct human support for wildlife conservation is minimal. In these often rural systems, the expectations of how system dynamics are structured and function and the outcomes of interactions may be guided by natural law, higher power or socially derived source (e.g. ethic). Often humans designate these landscapes and spaces within them as rightful domains of wildlife, prescribing how human will interact with wildlife. For instance, a Bengal tiger P. t. tigris may chase a jeep carrying tourists in a sanctuary in Ranthambhore National Park or a sow grizzly bear U. arctos ssp. may maul a hiker on a trail in defence of cubs in Yellowstone National Park and these behaviours are commonly deemed legitimate and human retaliation unreasoned. Acts that promote human encroachment on wildlife such as feeding or harassing them are
often discouraged or prohibited. Elements of the built environment may be used by wildlife when humans are less or not present such as drainage pipes, trash repositories or swimming pools. There are non-park examples as well. Logging roads bring humans into natural systems to engage in work and recreation, but they tend to serve carnivores as well. In Sweden, forest corporations create gravel roads to harvest timber, creating preferred routes for Eurasian wolves Canis lupus lupus to access moose that avoid these roads (Eriksen et al., 2009) while fire breaks (sandy tertiary roads) in on a military base in North Carolina may influence coyote Canis latrans resource selection (Stevenson et al., 2019).

Aspects of the built environment can be altered resulting in a space moving to a new position on the gradient. For instance, enclosure failure can result in wildlife more fully coming into contact with the human system or humans intervening within or occupying natural or wildlife systems. Livestock depredation serves as a specific example where carnivores depredate domestic animals, while humans try to solve the problem through management of carnivores (i.e. wildlife system alteration). Additionally, gaps or deficiencies in the human system can result in captive wildlife returning to a natural system, introducing new wildlife into or altering existing wildlife and natural systems. For example, surplus zoo animals can be abandoned, killed or sold to hunting ranches (Wallace, 1991). Weaknesses in hard infrastructure can have the same result. Texas is home to more free-ranging (able to move from one property to another) exotics than perhaps anywhere else in the world (Traweeek & Welch, 1992). Accidental release (e.g. storm damage, neglect) of captive, exotic cervids such as Sika Cervus nippon, axis Axis axis and nilgai Boselaphus tragocamelus place them back into carnivore-deficient natural systems, often to the detriment of native whitetailed deer Odocoileus virginianus (Young, 2016) and with political implications.

4 | DISCUSSION

There is general agreement that as species’ populations continue to decline there will be increasing reliance on the built environment to propagate them (Wielebnowski, 1998). These spaces are sites of human activity, natural processes and human-manipulated natural processes. Humans use the built environment to establish intricate connections to wildlife or balance societal needs and ecological functions. Perhaps humans’ romanticized view of the wild as places in nature independent of human influence or the relative novelty of the built environment construct (Moffatt & Kohler, 2008) resulted in relative inattention to the built environment thus far.

There is no correct way to situate the built environment within SES, but one benefit of attending to the built environment is that it helps tell the story of a system (Allen & Giampetro, 2006). Though human–wildlife interaction researchers have spent much time considering where we should put the wild things, yet, the story of how humans have constructed places to interact with wildlife and, specifically, carnivores has, thus far, largely been untold. While the built environment redistributes species, energy and materials (i.e. various infrastructures), the story of how the built environment influences interactions between humans, wildlife and natural systems will inform attempts to integrate humans into urban and rural ecologies. Furthermore, the idea to write this paper was prompted by reflections on red wolf recovery and how it seemed similar to putting together an ‘ill-fitting system jigsaw puzzle’ of variables and dynamics; recovery did not seem to be adequately addressed by existing, dualistic human–natural system frameworks because they did not systematically describe the role of the built environment in historical and future recovery outcomes. The ideas presented here may provide explanations for researchers who have been wrestling with similar considerations.

Another benefit is knowing there is a cost associated with overlooking the role of the built environment. Exploration of the built environment can inform our understandings of reactive conservation’s limits. Proactive species conservation is certainly ideal, but conservation generally occurs when species populations are already in a critical state, when recovery requires substantial resources to accomplish (Drechsler et al., 2011). The implications for species of greatest concern are clear as the built environment sustains many of them, and that dependency is likely to grow. Conservation-reliant species also come to mind because over 80% of species listed under the Endangered Species Act in the United States can be labelled as such (Scott et al., 2010), and the threats that they face can only be managed by humans and not eliminated (Goble et al., 2012). Many carnivore species will be impacted by this trend. In the end, regardless of whether researchers find utility in a tripartite human, natural and wildlife system (Liu et al., 2016), five-infrastructure (Anderey et al., 2016), or other approach, each are underpinned by properties that shape what can be achieved through management action (Mee et al., 2015). These actions serve as a window into the soul of our own relationships with, in this case, carnivores. If the built environment is designed for reactive conservation supported by stretched budgets and a partiality towards walling-off carnivores, then we cannot expect, as Chapron et al. (2014) suggested, to share space with most of them. Humans will continue to pursue a triage or hospice approach (Peterson et al., 2020) to carnivore conservation or need to pursue bold measures to save them and ourselves (e.g. Half-Earth, Wilson, 2016).

The plight of red wolf recovery puts the proposed approach into relief. Careful accounting of the built environment and its properties and applying elements of the CIS framework for heuristic purposes reveals system memory (e.g. cyclic human and wolf behaviour), feedbacks and locked-in behaviour or choke points that have contributed to the slow motion, three-decade catastrophe that is red wolf recovery. For example, and without diving into the depths of a full-fledged case study analysis, which is a critical role of future research, or starting at the cradle of recovery in 1967, natural infrastructure (e.g. predator-prey dynamics, percosin hydrology) rendered refuges less desirable to wolves than humanly altered private lands. Institutions (e.g. ESA, local land...
ethic, anti-wolf resolutions, Serenari et al., 2018), and built (e.g., roads, technology, buildings), social (e.g. social networks, poor relations between governing agencies, Serenari et al., 2018) and human infrastructures (e.g. illegitimate governance, political discourse, Serenari & Lute, 2020; Serenari & Taub, 2019) interacted to create, modify and destroy infrastructure and distributions of metabolisms between human, natural and wildlife systems. A focus on the built environment highlights, for example, an undervaluing of the spirit and utility of captive breeding programs occurring in zoos and elsewhere, misjudging the social unpalatability of an essential but multi-infrastructure-consuming conservation reliance approach in the rural landscape of northeast North Carolina, as well as a dogmatic emphasis on wilderness ideals to perpetuate red wolves on private lands. Dynamics are embedded within and bisect critical spaces residing along the proposed gradient of blending (e.g. zoo/breeding facility, rehabilitation and viewing complex, agricultural fields, refuges), as well as within spaces where humans and wolves never come into contact (e.g. legislative buildings, public meetings). The properties of the built environment are brought into relief by the nexus of actors (e.g. lawmakers, landowners, biologists) and their practices (e.g. translocation of wolves, courtroom proceedings, captive breeding efforts) and natural and wildlife systems that promote, encourage and discourage the co-occupation of North Carolina by residents and red wolves. Hence, viewing the built environment as a blending of system elements, flows and properties over time and across space may have helped foresee its influence on a hardened, omnipresent and destructive politics of red wolf recovery and its negative impact on human and non-human lifeworlds. This foresight may have, for instance, prevented the production of damaging harmful discourse about the artificiality of wolf recovery (Serenari & Lute, 2020), cultivated an appreciation for the conservation reliance designation as a policy instrument (Serenari, forthcoming), prevented a range of legitimacy deficits (Serenari & Taub, 2019) or encouraged development of a prepared and resilient recovery program that could better withstand negative trends and threats over time.

Inquiries of the transformations to carnivore governance regimes are necessary to more fully attend to the role the built environment in SES. Governance is responsible for ways the built environment is produced, managed and evaluated to achieve positive growth and development in societies (Du Plessis & Brandon, 2015). Insights offered here may be considered a first step in adaptive learning that is essential to design sustainable wildlife and carnivore governance that effectively dissolves boundaries between systems that do not actually exist and produce healthful futures for humans and carnivores. Proactive rather than reactive ideas and strategies can be led by governance arrangements that more fully consider all three systems or the five infrastructures and adhere to innovative design principles (Anderies et al., 2016; Steelman, 2016) to find ways to blend the properties of all systems into new, sustainable relations between humans and carnivores. Theoretically, a shift in design thinking, from categorizing the built environment as artefacts of human systems or itself a SES to, instead, a hybrid system having its own unique and dynamic role in adaptive processes over time (Cole et al., 2013), may be helpful to researchers to ensure the story or role of the built environment in a SES (a) is considered, mapped, measured and assessed, (b) makes clear novel properties and services that identify spaces and ways to enhance interactions between human, natural and wildlife systems and (c) has a dedicated framework that is not exclusive to common pool resources and accounts for space and time.

5 | CONCLUSION

There is a strong need to establish how the built environment may change the way researchers model human, wildlife and natural systems. The study of the role of the built environment in SES can play an essential role in pioneering new ideas to guide decision-making and wildlife management practices across contextual, spatial and temporal scales. For instance, the gradient of blending proposed here is really an expression of how humans ultimately make sense of nature through social and physical infrastructures—mediating cultural production of human–nature relations on a continuum from curated to raw nature. Theoretical revisions or their impacts will not be immediate, but governance that draws from these revisions would be able to prescribe a more suitable mixture of subsystem properties that yield new and, hopefully, sustainable relations with carnivores and other species with which we share the planet.

ACKNOWLEDGEMENTS

The author thanks the editorial staff, two anonymous reviewers, and Drs M. N. Peterson and E. Rubino for providing insights that greatly developed this manuscript.

CONFLICT OF INTEREST

The author has no conflict of interest to declare.

DATA AVAILABILITY STATEMENT

This article does not contain any data.

ORCID

Christopher Serenari https://orcid.org/0000-0001-9554-7479

REFERENCES

Akhtar, A. (2012). Animals and public health. Palgrave Macmillan.
Allen, T. F. H., & Giampetro, M. (2006). Narratives and transdisciplines for a post-industrial world. Systems Research and Behavioral Science, 23, 595–615. https://doi.org/10.1002/sres.792
Anderies, J. M. (2014). Embedding built environments in social–ecological systems: Resilience-based design principles. Building Research & Information, 42, 130–142. https://doi.org/10.1080/09613218.2013.857455
Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society, 9(1). https://doi.org/10.5751/ES-00610-090118

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society, 9(1). https://doi.org/10.5751/ES-00610-090118

Anderies, J. M., Janssen, M. A., & Ostrom, E. (2004). A framework to analyze the robustness of social-ecological systems from an institutional perspective. Ecology and Society, 9(1). https://doi.org/10.5751/ES-00610-090118
http://wwf.panda.org/wwf_news/?200511/Nepals-first-collared-tiger-poisoned
Young, G. C. (2016). Free-ranging exotics. [online] Retrieved from https://scout.com/outdoors/hunting/Article/Free-Range-Exotics-101457669/
Yu, D. J., Qubbaj, M. R., Muneepeerakul, R., & Anderies, J. M. (2014). The effect of infrastructure on social-ecological system dynamics: Provision thresholds and asymmetric access. CSID Working Paper Series #CSID-2014-007. The Center for the Study of Institutional Diversity, Arizona State University.

**SUPPORTING INFORMATION**
Additional supporting information may be found online in the Supporting Information section.

**How to cite this article:** Serenari C. Reconsidering the role of the built environment in human–wildlife interactions. *People Nat*. 2021;3:104–114. [https://doi.org/10.1002/pan3.10163](https://doi.org/10.1002/pan3.10163)