XR in Sustainability:
A Holistic Approach to Testing Transportation Design Proposals

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Abstract

This study examines how current transportation infrastructure can be redesigned to reduce ecological decline and the effects of climate change, using extended reality tools. The latest findings suggest that transportation is the largest contributor to United States greenhouse gas emissions, with over two thirds of these emissions derived from passenger vehicles. A comprehensive case study suggests that there are extensive solutions in development to solve this problem, yet very few holistic metrics to determine the viability of such solutions. A key reason for this is the lack of emphasis placed on quantifying social sustainability, as most analyses focus on economic and environmental sustainability. There is an opportunity for industrial designers to employ extended reality technology as a medium to test the social, environmental, and economic viability of sustainable transportation solutions before they are built.

Key Words: User Testing, AR & VR, Systems Design, Environmental Preservation, Rural Transportation, Social Psychology.

Executive Summary

This research investigates the potential of using extended reality tools to redesign current transportation infrastructure and minimize ecological decline and the impacts of climate change. Recent research has revealed that transportation is the primary contributor to greenhouse gas emissions in the United States, with passenger vehicles accounting for more than two-thirds of these emissions. Although numerous solutions are in development, few comprehensive metrics exist to evaluate their effectiveness. This lack of metrics is largely due to the failure to incorporate social sustainability into most analyses, which primarily focus on environmental and economic sustainability. Industrial designers can leverage extended reality technology to test the social, environmental, and economic feasibility of sustainable transportation solutions before implementing them, presenting a significant opportunity. A detailed case study demonstrates the wide range of solutions that exist to address this issue.

The study was conducted in three stages, each examining a different aspect of sustainable transportation methods to combat ecological decline. The initial stage, which was primarily secondary research, aimed to comprehend the connection between nature and design in transportation design to enhance environmental conservation. As a result of this phase, a new research question emerged.

The subsequent stage, phase two, sought to answer this question by exploring the potential of extended reality technology to evaluate the feasibility of sustainable transportation design propositions. Primary research was gathered in two subphases: conversational interviews with industry professionals and directed interviews with individuals recommended by those in the first subphase.

The third and final phase centered on analyzing the sources suggested by interviewees during the primary research phase, gathering secondary research to complement the information collected in the first two phases, and linking the two topics examined in each corresponding section. As a next step, this study has the potential to investigate the factors that motivate people to use public transportation instead of relying on personal vehicles. However, for the time being, it has addressed the central inquiry of measuring the social, economic, and environmental impacts of sustainable transportation solutions through extended reality technology.

During phase 1, various frameworks for promoting ecological design were identified, with specific guidelines and metrics discussed for evaluating economic and environmental aspects of proposals in the early design stages. In phase 2, interviewees emphasized the importance of using virtual or mixed reality for creating immersive experiences in research settings and incorporating storytelling to elicit social feedback during user testing. Ethical considerations regarding the use of such technologies to elicit responses from potential participants were also discussed.

In phase 3, it was discovered that some businesses are already integrating these concepts into their design processes, but many areas have yet to apply this technology. Moving forward, potential areas of application for this research include comparing rural and urban transportation systems, designing public transportation in suburban areas, adopting biomimicry principles to create better systems, exploring XR beyond headsets, and enabling users to view urban environments from the perspective of animals.

Overall, the technologies discussed in this study have the potential to assist designers and design researchers in developing transportation infrastructure that supports environmental preservation and improves sustainability for all.

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Acknowledgements

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Introduction

Our transportation infrastructure in the United States has had an undeniably negative impact on our environment, as we have seen in the escalation of climate change due to carbon emissions. According to the *United States Environmental Protection Agency (EPA),* nearly 30% of domestic carbon emissions are derived from transportation, 72% of which come from road vehicles, such as cars, lorries, buses and other road vehicles. Two factors contribute to the escalation of this problem: the average American commute is 10 miles, and 45% of Americans do not have access to public transportation (EPA). As a result, the infrastructure in our country has been designed almost entirely for passenger vehicles, with little consideration for the natural landscape that surrounds it. In places like Wilmington, NC, 3 times as much land is dedicated to parking lots compared to green space (Praats, 2019). There are many ways to address these problems, and researchers around the country are working hard to improve the state of our transportation infrastructure to reduce ecological decline.

One of the main roles of an Industrial Designer is to perform user testing, which ensures products, services, and systems will be well received by consumers, before they enter the market. As we work to create more sustainable transportation methods in America, how do we test the viability of our solutions before they are built? How do we ensure that solutions have been designed to be truly sustainable from a social, economic and environmental lens? While there are many experts focusing on testing proposals from economic and environmental perspectives, it is extremely difficult to quantify social impact in the early design phase, which is one of the main components of defining sustainability. My research explores how we can use extended reality technology as a tool to test the social, economic and environmentals benefits of sustainable transportation design proposals before they are actually built.

Methods and Methodology

The following research was conducted in three phases. Each phase explored a new subset of the general subject, creating more sustainable transportation methods to reduce ecological decline. Phase one was dedicated to understanding the intersection between nature and design to improve environmental preservation as it relates to transportation design. Research collected from this phase was mainly secondary. Sources range from academic journals to podcasts from industry professionals. From the research in this phase, a new research question emerged.

Phase two explores this next question, “how can extended reality technology be used to test the validity of sustainable transportation design proposals?” The purpose of phase two was to collect primary research in response to the research question. The approach to gathering this data was divided into two subphases. Subphase one consisted of conversational interviews with industry professionals, where the research question was pitched, and a dialogue ensued in which more information emerged about the subject. Subphase two consisted of guided interviews. Interviewees in subphase two were introduced to the researcher from interviewees in subphase one. The research question was again pitched to these candidates, who were asked specific questions about their work, knowledge in the subject, and perspective on the future of their field.

Phase three was dedicated to the examination of sources suggested by interviewees in the primary research phase. This phase was focused on gathering secondary research to supplement the information gained in phases one and two, and connecting the two subjects explored in each respective section.

Summary of Findings Phase 1

Phase 1 began with the intention of exploring the intersection between nature and design to improve transportation infrastructure. Sources were gathered based on their affinity to subjects such as urban planning, experimental agriculture, and using technology to enhance environmental preservation. The following analysis details the relevant information collected from each source and the ideas that emerged from reviewing the literature.

The Metabolism of Cities

The first place to look when thinking about improving the intersection between nature and design is in our cities. Cities are spaces that are largely dominated by human traffic, and in most neighborhoods, natural ecosystems have been devastated by the creation of infrastructure. In the podcast *How to Biodesign Episode 13: Metabolism of the City,* hosts Emma Van Der Leest and Menno Schilthuizen interview Dr Nadina Galle, an ecological engineer and Ir. Pierre Oskam, a landscape architect, researcher and teacher. In their discussion, they aim to investigate creative ways to stimulate nature in cities using innovative forms of technology (BlueCityGroup, 2021). A couple specific questions explored to support this topic include: “how can we bring nature back when there is so little soil left for nature to thrive? What do bioneers encounter when contributing to the living metabolism of our cities?" (BlueCityGroup, 2021).

Starting with the first question, nature needs soil to thrive, but in order for that soil to be healthy, it also needs biodiversity. While "biodiversity is a term used to describe the enormous variety of life on Earth," it can also be used more specifically "to refer to all of the species in one region or ecosystem" (nationalgeographic.org). Holistically "biodiversity refers to every living thing, including plants, bacteria, animals, and humans" (nationalgeographic.org). In cities where humans dominate the landscape, there exists a lack of biodiversity, because certain species populations grow out of control when major predators are eliminated by humanity's presence.

Think for example, New York City, where the rat population has skyrocketed out of control, and is wreaking havoc on the safety, cleanliness, and ecology of the city.

According to Dr. Nadina Galle, "the best way to stimulate biodiversity is to leave nature alone." Based on this quote, the solution seems simple: allocate spaces in cities where nature is allowed to thrive unrestrained by the daily activities of humans. However, as available space in cities shrinks due to our growing population, how might we decide which spaces are allocated to improving biodiversity? And how can this decision contribute to the overall metabolism of the city? In response to these ideas, Dr. Galle presents the concept of using technology, essentially combining two agendas to simultaneously create green cities and smart cities. Through this combination, a new concept emerges, one that she refers to as the Internet of Nature. A concept which focuses on mapping, monitoring and managing ecological growth through technology. The internet of nature as it applies to this research, is explored further below, but it raises an interesting question about how the gap between nature and design can be bridged.

Another point heavily stressed by researchers in this podcast, is the importance of dead wood in stimulating biodiversity and improving the health of urban soil. Dead trees typically garner a negative reaction, but actually serve as an important proponent of promoting a healthy ecosystem (Galle). In cities, dead trees raise safety concerns, and are typically removed to prevent them from falling on pedestrians, vehicles or roads (BlueCityGroup). However this removal leads to an interruption in the circle of life in city ecosystems, and adds to the decay in soil quality. This is an avenue of opportunity for researchers exploring the promotion of healthy biodiversity in ecosystems, and researchers in this podcast propose various ways to approach this problem using design.

One approach discussed by Dr. Galle is attaching LiDAR scanners to cars to gather data on trees bordering transportation infrastructure. Many studies conducted by conservationists stress the importance of mapping and classifying dead trees in reforestation efforts. *Silvi-Net - A* *dual-CNN Approach for Combined Classification of Tree Species and Standing Dead Trees From Remote Sensing Data,* discusses how aerial LiDAR scanners may be used to help researchers understand the health of the ecosystem. If we were able to use existing vehicles in heavily trafficked areas, rather than deploy specialized ones, average citizens may be able to contribute to the gathering of such data.

Soil quality may be monitored using a similar approach. Dr. Galle discusses precision agriculture, "a management strategy that gathers, processes and analyzes temporal, spatial and individual data and combines it with other information to support management decisions according to estimated variability for improved resource use efficiency, productivity, quality, profitability and sustainability of agricultural production" (Stafford, Deboer). In agriculture, farmers are able to use precision agriculture to increase output while reducing resource input.

Soil sensors are one example of the type of technology used in this practice. Dr. Galle explains how the same soil sensor approach may be incorporated into cities, allowing researchers to monitor areas in the city most in need of improvement. These improvements may be carried out by anyone, professionals, city planners, citizen scientists, or even children in classrooms – the possibilities are endless.

These proposed solutions rely on emerging technologies to monitor ecosystems. Which brings us back to the concept of the Internet of Nature and how we can apply the principles of our technology connected world to further our understanding of our ecosystems.

The Internet of Nature

In her work *The Internet of Nature: How Taking Nature Online Can Shape Urban Ecosystems*, Dr. Galle explains how the IoN serves to enhance urban environmental management, not replicate the natural world with technology. Further, "the true solution for nature deprived humans lies in the establishment of deep, meaningful interaction with wild nature," and the IoN can be designed as a tool to foster that relationship (Beatley, 2011). The concept arises as a modification of the concept of the Internet of Things (IoT), a term coined by computer scientist Kevin Ashton in 1999 when he proposed that Proctor and Gamble put

radio-frequency identification (RFID) chips on products to track them through a supply chain (visionofhumanity.org). The internet of things describes the creation of a network of data which connects physical objects through the use of sensors, tracking devices, cameras and more. "Cities have been deploying IoT technology for more than a decade – to streamline everything from water meter readings to traffic flow," so the shift to using the same concept for improving ecosystems in cities has the potential to be seamless (visionofhumanity.org).

“The age of metropolis is contributing not directly and indirectly to the widespread destruction and subsequent loss of natural landscapes and habitat while the rapid rise in digital technologies is allowing citizens to connect to each other and their surroundings at a breathing pace” (Galle, Nitoslawski, Pilla). The pace at which we are evolving with technology has affected the ways in which the living organisms in our ecosystems are evolving as well. Urban animals evolve based on exposure to urban stresses and opportunities. We see this in the way “weeds growing out of cracks in pavement produce heavy compact seeds,” and “pigeons develop detox plumage to protect lower air quality” (Galle, Nitoslawski, Pilla). As this occurs in our ecosystems, it becomes difficult for researchers to gather data in accordance with the rate of change. Hence, the IoN, a system which has the potential to embed “digital infrastructure into the urban fabric to collect and supply information for managing assets and resources more efficiently” (Galle, Nitoslawski, Pilla).
Potential applications of this concept include monitoring and management, ecosystem functioning and resilience, and linking social with ecological systems. In Figure 1, she outlines 18 ways the concept may be executed.

The *Internet of Nature*: Examples and applications for urban forestry and green infrastructure management.
1) LiDAR for monitoring canopy quantity and forest structure. 2) Remote sensing and satellite imagery for monitoring canopy cover. 3) Smart building and green-grey infrastructure integration for energy savings and building performance. 4) Development and land-use planning decisions based on ecosystem services trade-offs and information acquired from complementary data sources. 5) Plants as biosensors for ecosystem resilience. 6) Aerial seeding for urban reforestation. 7) Virtual collection of plant pathology information for pest detection and diagnostics. 8) Sensor networks for monitoring stormwater, urban heat islands and air pollution uptake. 9) Street-view imagery and AI for green cover quality and management. 10) Biodiversity enhancement through volunteered geographic information. 11) VR and AR for green space perceptions. 12) Sensor networks for monitoring the effectiveness of stormwater management strategies and soil quality. 13) Social media platforms for public values elicitation about green space design. 14) Wearable technologies for health management in response to green space exposure. 15) Blockchain and cryptocurrency for greening initiatives. 16) Robotics for green infrastructure maintenance. 17) All ecosystem intelligence stored in the ‘cloud’. 18) Real-time communication between IoN network and city.

Figure 1: Galle, 2019. “The Internet of Nature: Examples and applications for urban forestry and green infrastructure management"

Terrestrial LiDAR

The term Terrestrial LiDAR (light detection and ranging) can also be described as Terrestrial Laser Scanning (TLS) or topographic LiDAR in practical applications (Oguchi & Wasklewicz, 2011). In the process, the scanner “acquires XYZ coordinates of numerous points on land by emitting laser pulses toward these points and measuring the distance from the device to the target” (Vosselman and Maas, 2010). The points are then used to generate a 3D point cloud, which can be converted into a grid DEM to create topographic maps and spatial analyses of land masses and their ecosystems (Oguchi & Wasklewicz, 2011). There are three categories of scanners: short, medium and long range scanners. Short scanners can capture points up to several hundred meters away, while long scanners can capture points up to several kilometers away. CloudCompare, the software used to combine the ASCII point cloud generated by the LiDAR scanner, is free and open source, making it an accessible tool for designers and developers to employ in various applications.

Terrestrial LiDAR is already being used to produce topographic data rapidly with accuracy and precision. This data is then "combined with data describing process mechanics to detect environmental change" (Oguchi & Wasklewicz, 2011). In this specific use case, the 3D point cloud produced using TLS was able to capture "canopy surface with a spatial resolution below 2 mm and was well suited to describe subtle changes in the canopy during the growing season" (Oguchi & Wasklewicz, 2011). Meaning, the software produced a model accurate enough to track the canopy growth down to the millimeter, see Figure 2. The possibilities for this software are extensive, but it is not without its shortcomings. One of the main issues is that it is not yet able to differentiate between species, meaning it is "not possible to quantify relative abundances based on TLS data" (Oguchi & Wasklewicz, 2011). In order to do so, this data would need to be combined with machine learning or on the ground data to generate species specific data.

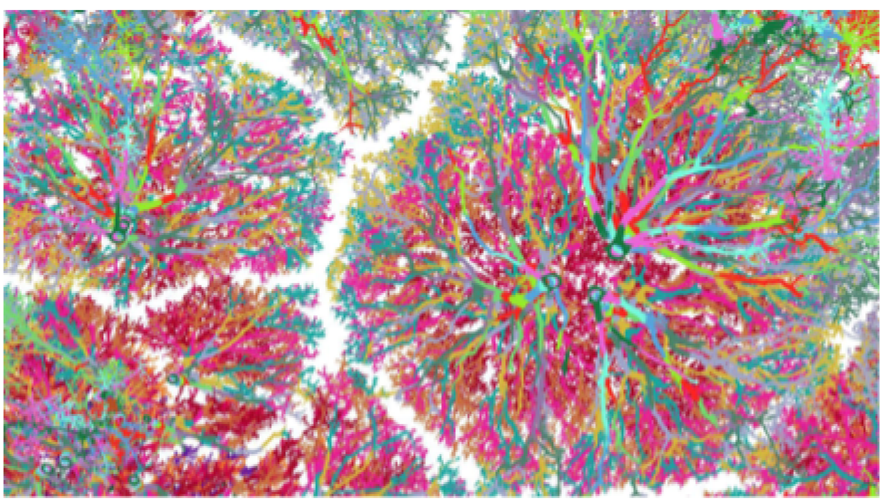


Figure 2: Wytham Woods, UK (see Calders *et al.*, 2018).
Terrestrial laser scanning (TLS)-derived tree architecture captured from beneath a deciduous broadleaf woodland canopy. Colours represent separate branch segments derived from the TLS data. 'Crown shyness' is clearly visible.

One such platform it could be combined with is *Diversitree*, an open source software developed in coordination with Dr. Galle, at MIT. "D*iversitree* is an interactive web-based visualization tool, research paper and open-source project repository exploring the diversity of species, genera and family in street tree inventories within — and across — eight cities internationally" (Galle, 2020-21). It explores the 10/20/30 rule, "which suggests an urban forest should be no more than 10% of one species, 20% of one genus, and 30% of one family" (Galle, 2020-21). Using the software, researchers are able to determine the diversity of the street tree network through a snapshot view displaying how dominant any single species, genus or family is within a city. If terrestrial liDAR scans were combined with *Diversitree* data, it may solve the issue of denoting biodiversity as it relates to canopy growth. One important point made by Dr. Galle in her overview of Diversitree is as follows:

> "Of course, *how* species adapt to local conditions is more important than diversity in and of itself. Street tree diversity should always seek to fulfill a range of community forest objectives, rather than adherence to numerical standards alone. Those numerical standards, however, *can* show us places where street tree diversity has room to grow" (2020-21).

This highlights an important point in the conversation surrounding using technology to improve and protect the state of our environment. These practices are simply tools to help researchers gather information about that state of ecosystems. The data gathered still needs to undergo holistic analysis before true conclusions can be deduced about how to proceed in working with them.

It is important to note that 3d models of organic life forms, such as trees, are difficult to generate unless assisted by some sort of scanning technology or general algorithm. Terrestrial LiDAR may offer a way for realistic 3D models of trees to be generated for various purposes. Possibilities include educational environments, virtually simulated spaces, or animated films.

Ecocathedrals

Returning to the quote by Dr. Galle, "the best way to stimulate biodiversity is to leave nature alone," perhaps it is not necessary to monitor nature at all, but simply to give it the space it needs to thrive. In the same podcast, Ir. Pierre Oskam, mentions eco-cathedrals, a concept developed by Louis Le Roy in 1966 in the Netherlands (Wouda). The term combines eco (nature) and cathedral (culture), to describe spaces that have been designed for nature to evolve naturally. The term does not refer to cathedrals in a religious sense, but in the way that these spaces will take centuries to finish (Wouda). The idea is: spaces can be created in cities using discarded building materials as a framework for nature to take over and reclaim said materials. These are meant to be collaborative spaces where citizens from around the city may participate in gardening, building, and maintenance. In Figure 3, a man is shown stacking concrete blocks, which will act as a structure for plants to grow. Wouda expounds on the concept and the benefits it may bring to a city, stating:

> “Le Roy knew that a city somehow needs a relationship with nature to survive. By excluding territory from usual urban planning, and allowing creative, natural processes to emerge in time, we can be reminded again that it is pointless and dangerous to keep cutting back on time and just focus on the speed of development.”

This poignant quote highlights the potential that eco cathedrals possess in terms of improving our cities. They are not meant to be a quick fix for solving climate change, but are meant to help us connect in a deep and meaningful way with the natural landscape of our cities.

Again, the solution seems simple: allocate spaces in cities where nature is allowed to thrive unrestrained by infrastructure and development. However, determining which spaces should be dedicated to improving biodiversity still remains a question, which is where additional technologies may be necessary. This also brings up the importance of urban planning, and determining ways to allocate natural resources like soil, water, and sunlight, in these spaces, to allow nature to thrive.

Figure 3: Wouda, Peter. "Images of Eco Cathedrals"

Experimental Forestry

In 1973, Japan planted an experimental forest of sugi (Japanese cedar) trees in Japan’s Miyazaki prefecture (EcoWatch, 2018). “The experiment was carried out by planting trees in 10 degree radial increments forming 10 concentric circles of varying diameters,” which allowed researchers to demonstrate how planting distance affects tree growth (Johnny, 2018). If you look closely at figure 4, you’ll notice that the trees on the outer circle are larger than those in the inner circle. This height difference was measured to be 5.3 meters, according to *Japan’s Ministry of Agriculture, Forestry and Fisheries*. This is a direct result of the planted pattern, “more space equals less competition for resources such as water and sunlight, so it’s easier for these outer trees to grow bigger and stronger while those on the inside fight it out amongst themselves,” and reveals that using these concepts, we may have the

power to shape how forests grow (EcoWatch, 2018).

Imagine if we were able to apply this concept to urban environments or in spaces where trees border transportation infrastructure. Think about roads that have become nearly undrivable due to roots growing through the asphalt, causing potholes, bumps, and cracks.

Infrastructure maintenance is expensive and inconvenient for everyone. Perhaps there is a way to reduce the amount of maintenance needed in our roads by accounting for the way nature grows in design. Some of the technologies discussed in the sections above, such as terrestrial LiDAR or the Internet of Nature may be employed to help researchers better understand how experimental forestry may be executed in accordance with infrastructure.

Impact of Infrastructure

Before one can truly understand how to improve transportation infrastructure through the lens of ecological design, it is important to note the impact that various modes of transportation have on the environment. Figure 5 below

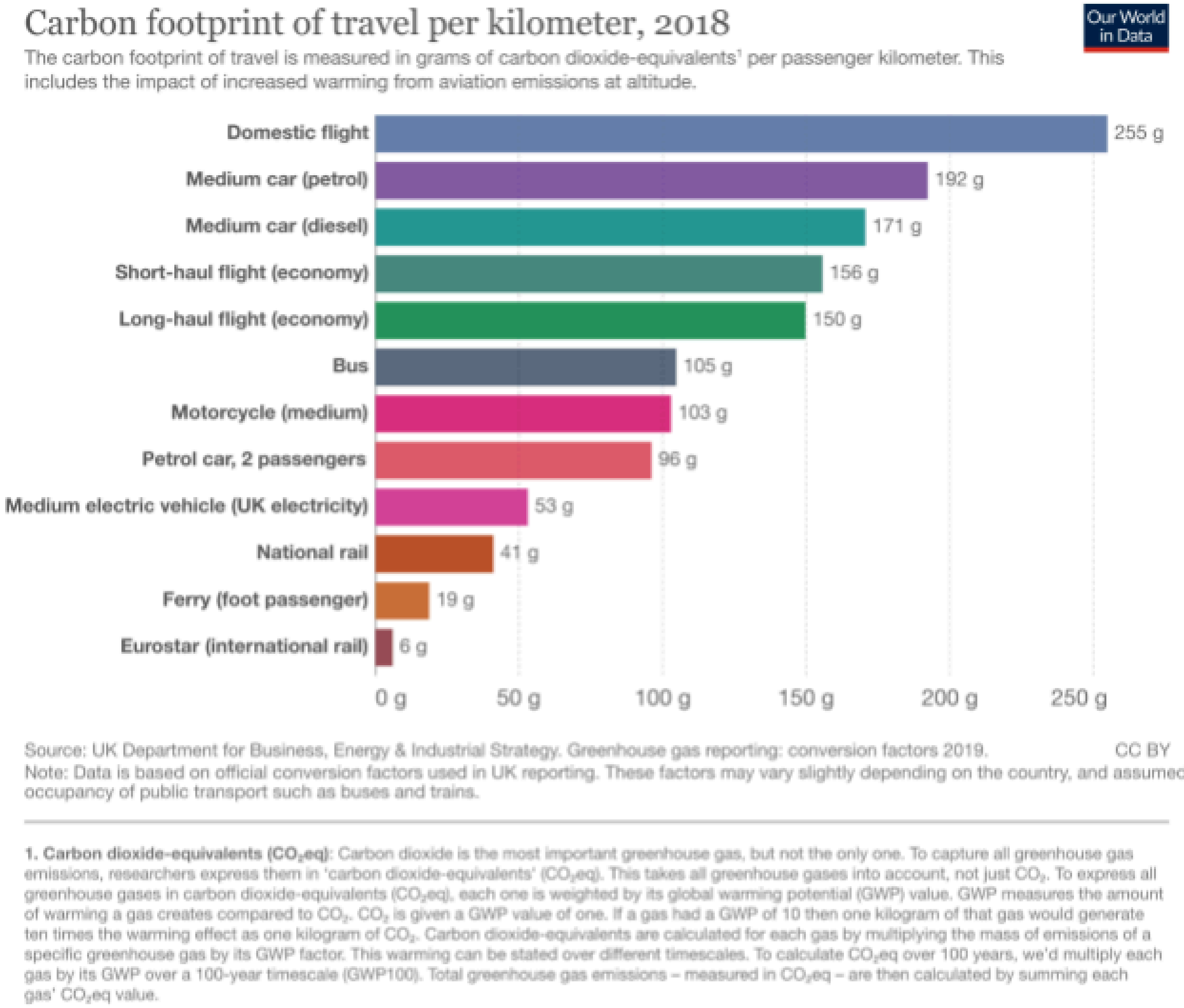
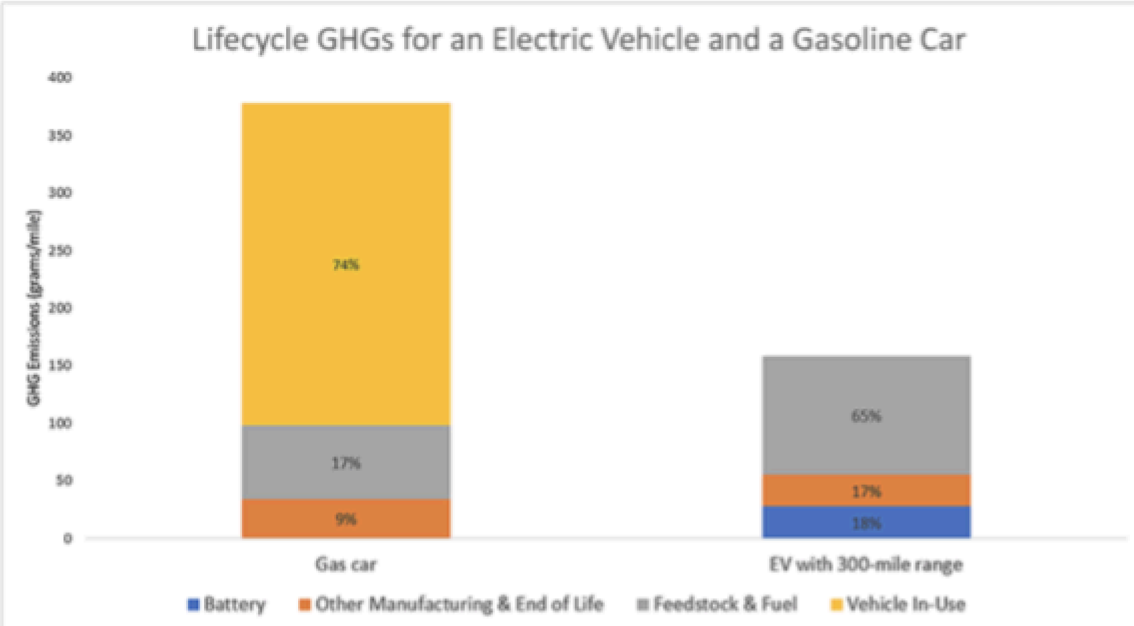


Figure 5: Our world in Data, 2019, "Carbon footprint of travel per kilometer 2018"

compares the carbon footprint of travel methods measured in grams of carbon dioxide-equivalents per passenger kilometer, including the impact of increased warming from aviation emissions at altitude (Ritchie, 2020). It reveals that although electric vehicles and light rail produce considerably less emissions than petrol or diesel vehicles, they still have an impact.



Estimates shown[6] from GREET 2 2021 are intended to be illustrative only. Estimates represent model year 2020. Emissions will vary based on assumptions about the specific vehicles being compared, EV battery size and chemistry, vehicle lifetimes, and the electricity grid used to recharge the EV, among other factors.

Above, the blue bar represents emissions associated with the battery. The orange bars encompass the rest of the vehicle manufacturing (e.g., extracting materials, manufacturing and assembling other parts, and vehicle assembly) and end-of-life (recycling or disposal). The gray bars represent upstream emissions associated with producing gasoline or electricity (U.S. mix), and the yellow bar shows tailpipe emissions during vehicle operations.

Figure 6: GREET, 2021 "Lifecycle GHGs for an Electric Vehicle and a Gasoline Car"

Even more notable is figure 6, which compares the lifecycle greenhouse gas emissions produced by electric vehicles versus gasoline cars (GREET, 2021). It highlights the importance of using electric vehicles to reduce lifetime fuel emissions, but also shows how the carbon used to generate fuel for electric vehicles actually exceeds that of gasoline vehicles, see the gray bar. These figures demonstrate the importance of incorporating renewable energy sources when creating infrastructure for electric vehicles. Without which, we are simply perpetuating the problem of burning fossil fuels in the transportation sector, which, according to the *US Department of Energy,* accounts for "approximately 30% of total U.S. energy needs and 70% of U.S petroleum consumption." Another thing to keep in mind is that the figure on the left is sourced from the UK. This is a standard graph used around the world to measure greenhouse gas emissions, but it highlights how important access to light rail is in reducing net carbon emissions, something that the United States is severely lacking.

Wind Turbines in Action

Figure 7: Erickson, 2022 "FREE Center Turbine"

Wind turbines are an important example of renewable energy. One specific site to reference in crafting sustainable infrastructure is the *Fenner Renewable Energy Education (FREE) Center.* In Fenner, NY, a rural community about 30 minutes outside of Syracuse, the FREE Center resides upon a hilltop, surrounded by acres and acres of lush farmland. The center is dedicated to educating the public on renewable energy methods. It is free and open for anyone to visit, at any time of day, "about 5,000 people visit the FREE Center annually, including school, scout, civic, and church groups; college students; and government and industry representatives" (CNYCF, 2020). When visitors arrive at the center, they are able to see "renewable energy in action and learn how the 20 turbines create energy that powers about 10,000 homes" (CNYCF, 2020). They can also sign their name in the guestbook, which provides a catalog of how frequently the site is visited. The farm began operating in 2001, and has since added a solar farm nearby, the educational center in 2006, and a classroom in 2014 (CNYCF, 2020). The center highlights the importance of education in making efforts towards a more sustainable future.

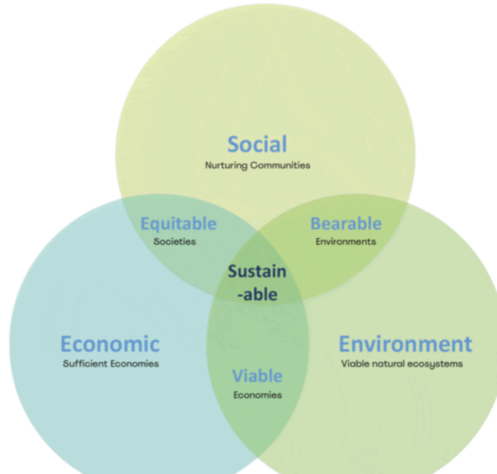
At the FREE Center, there is a seamless relationship between design, technology, and nature. The livestock on the surrounding farms exist in harmony with the wind turbines, which power the homes of the farmers who in turn care for the livestock. Hypothetically, if these communities relied solely on electric vehicles, they would be entirely free from petroleum dependence. Even better, in producing food for themselves and surrounding communities, they would be creating a net positive impact on the environment, from a sustainability perspective.

Defining Sustainability

Figure 8: Erickson, 2022 "FREE Center Diagrams"

The FREE Center offers extensive information on renewable energy, but also provides an explanation behind the word sustainability. Sustainability is a term that is thrown around frequently by companies aiming to maximize their profits, while reducing corporate or consumer guilt; it has also permeated the subjects discussed in this paper. So what does it mean exactly? According to the images in figure 8, sourced from the FREE Center, "a resource is sustainable if it can be consumed today without compromising future generations." This definition is compounded by two clauses, "all sustainable resources must be renewable" and "not all renewable resources are sustainable if treated poorly" (figure 8). As seen on the continuum, wind, solar, and waste biofuels, are examples of more sustainable resources, compared to natural gas, nuclear energy, coal, and oil (figure 8). These resources are considered non-renewable because they take a long time to replenish, they can only be found in specific places or exist in limited quantities.

Most relevant to this research is the sustainability venn diagram pictured on the bottom left corner, and expanded in figure below. This diagram shows how a practice or policy can only be considered truly sustainable if it is beneficial socially, economically, and environmentally. When developing a more sustainable future for transportation, ensuring that solutions fall on the center of this diagram will be crucial. The rest of the research performed in this phase was dedicated to finding examples of design proposals that met this criteria.



Ecological Design in a Campus Transportation Network

Continuing with the concept of the importance of education, the first example explored was a case study of Izmir Katip Çelebi University Çiğli Campus, in Turkey, titled *Rethinking the Campus Transportation Network in the Scope of Ecological Design Principles.* The study was conducted in two phases. First, researchers analyzed the current situation of the campus transportation network (Onac et al., 2021). Next, they made recommendations "for a sustainable transportation system within the campus, taking into account the ecological design criteria" (Onac et al., 2021). They emphasize the importance of their research with a quote from UNEP, *the United Nations Environment Programme* (2013), "it is not possible to have a sustainable world in a place where universities support unsustainable conditions, and it is possible to say that universities could act as a catalyst to create a sustainable world." Universities serve as important agents of change in sustainable transportation methods because they exist as small urban environments containing highly adaptable and innovative users.

UNEP is responsible for creating one of the most important guidelines for creating sustainable practices in universities, which is known as the "Greening University Toolkit" (Onac et al., 2021). This study employs this toolkit as an analytical tool, but also relies on many others such as the "*Global Universities Partnership on Environment for Sustainability"* (GUPES), the "*Environmental Education and Training Unit"* (EETU), "*Green League*," "*Environmental and Social Responsibility Index*," *"Sustainability Tracking and Assessment System"* (STARS), and the "*Green Metric*" (Onac et al., 2021). The "*Green Metric",* see figure 10, stands out as a tool because it is the first global metering system. The study was meant to take the criteria developed by these organizations and develop specific recommendations for the Izmir Katip Çelebi University Çiğli Campus. Their approach is helpful to understand because it provides a framework for how one might test the sustainability of future transportation designs.

Table 2 Green Metric Sustainable Transportation Criteria (GreenMetric 2013)

From: Rethinking the campus transportation network in the scope of ecological design principles: case study of Izmir Katip Çelebi University Çiğli Campus

	Criteria	%
Transportation	Per capita vehicle	%18
	Services	
	Zero emission vehicle policy in the campus	
	Zero emission vehicles per capita	
	Ratio of parking spaces to total campus area	
	Transportation program designed to limit or reduce parking Spaces in the campus for the last 3 years	

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Figure 10: Onac, 2021, "Sustainable Transportation Criteria

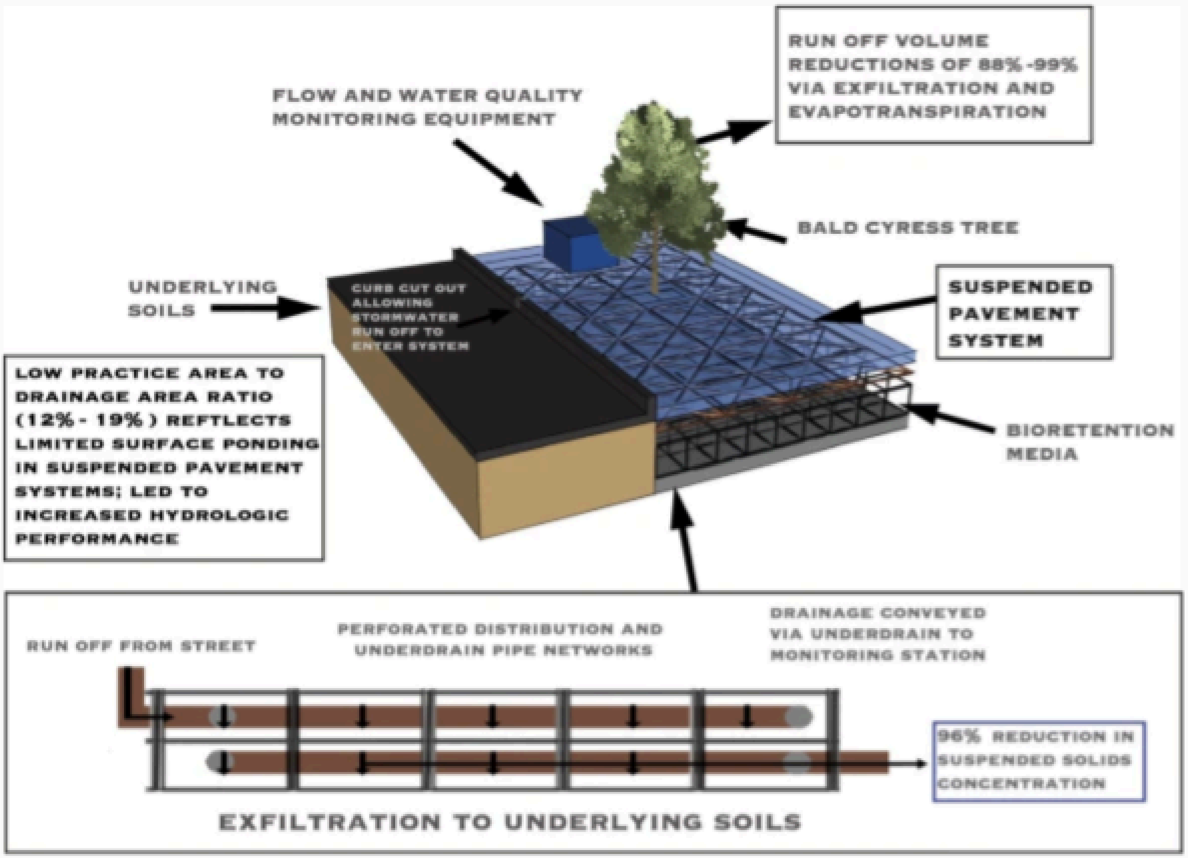
Some recommendations consistent amongst these frameworks and through the analysis performed by the researchers in this study include the addition of the following practices to ensure sustainable transportation on university campuses:

- Car sharing system
- Parking spaces
- Promoting public transport
- Internet system for transportation information
- Promoting bicycle transportation
- Promoting pedestrian transportation

However these concepts are very general, and do not necessarily account for ecological design, which was the main focus of the study. According to Yeang and Woo (2010), ecological design "is to develop the design by being aware that everything in the ecosystem on Earth is chained and that intervention within that chain affects the ecosystem, both locally and globally." This approach ensures that human made environment or design systems are compatible and compliant with the natural environment. This principle is seen in how the researchers were able to determine small correlations between design and user behavior. One example is the correlation between parking availability and chosen transportation method. When there is more bike parking, more people are likely to bike to campus, while free car parking leads to less people using bikes (Onac et al., 2021).

Additionally, sustainability is the main element of ecological design. The idea is to create a balance between what is received and what is given to the environment. A common way this can be accomplished on campuses is with the addition of bio-comfort. Examples of bio-comfort include tree shade, to rest or walk under, grass to lie on, or the addition of shrubbery for privacy. In urban spaces, bio-comfort may need to be designed for, as human traffic and infrastructure may compromise soil viability, access to light etc. as discussed above in the work of Dr. Nadina J Galle. “Impermeable and permeable large ground surfaces should be planted and if not possible, reflective materials should be used for covering to reduce the absorption of heat and heat island effect” (Onac et al., 2021). The figure below details a way that a suspended pavement design may encourage a healthy ecosystem by allowing water run off to permeate soil. This suspended pavement design has the potential to be applied on a larger scale, to promote ecological growth in urban environments.

Fig. 3



Suspended pavement system, green infrastructure (Tirpak et al. 2019)

Figure 11: Tirpak et al., 2019 “Suspended pavement system, green infrastructure”

Lastly, Onac and his fellow researchers developed a schematic for a sustainable transportation network based on the ecological design principles accounted for in the first phase of their study. The figure below outlines their recommendations to the university campus.

Sustainable campus transportation network based on ecological design principles

Figure 12: Onac, 2020. "Diagram of sustainable campus transportation network based on ecological design principles"

The most notable recommendations relevant to the subject of transportation design include:

- Guidelines for what makes a good bike route
- Multifunctional suspended pavement systems
- The importance of drainage along road networks in improving water quality
- Adding charging stations that utilize solar energy to charge electric vehicles

One key feature missing from this study is a guideline of recommendations regarding public transportation. Rather than aiming to reduce car traffic through bus systems, the ecological design performed in this study aims to promote bio-comfort, biking and pedestrian roads. This may be a factor of the climate at the university. In many places, such as Syracuse, NY. It is extremely difficult to be outside for extended periods of time year round. The results of this study highlight a key feature of transportation design, that there is no one size fits all, and the design must vary on a case by case basis.

Cradle-to-Gate Sustainability Measures in Pavement Design

One topic explored extensively in the study performed at the Izmir Katip Çelebi University Çiğli Campus, was the implementation of suspended pavement designs. A study that nicely compliments this concept was performed in 2018 by Sujata Subedi and associates, which explores a *Decision-Making Tool for Incorporating Cradle-to-Gate Sustainability Measures into Pavement Design.*

Pavements strain the environment and the economy because they consume large amounts of energy, materials and a significant portion of maintenance funds (Subedi, 2018). Life cycle analysis (LCA) is difficult to perform in pavement design because it requires substantial time and resources. "There is a growing recognition that highway construction and maintenance have major environmental impacts…the ecosystem could be affected through possible vegetation removal, erosion and sedimentation, soil compaction, and noise, as well as aesthetic disturbance, contamination, and toxicity," revealing a need to improve the status of pavement design systems through ecological design (Subedi, 2018). Especially "because transportation activities are expected to continue to grow, it is imperative that sustainable technologies be introduced in order to reduce the impacts on the environment and social life, while optimizing the cost of maintaining the transportation network" (Subedi, 2018).

In this study, they developed a framework that allows developers to identify cost effective and environmentally preferred pavement solutions. It includes three main criteria:

1. EPD analysis, quantifies impact of raw materials extraction to manufacturing
2. A transportation analysis, transporting mixes from plant location to construction site
3. Economic analysis, assigning monetary value.

The developed software can be "used by the designers to select cost effective solutions, by the manufacturers to benchmark and by the consumers in selecting which product offers the best combination" (Subedi, 2018). The output is referred to as LCCA, and includes MEPDG, a mechanistic-empirical pavement design guide, and AASHTO, an industry standard pavement design method.

In order to test this framework, they conducted a study in which they built road designs with different thicknesses and compressive strengths. They defined different impact categories such as vehicle types and fuel type, assigned weights and then analyzed them over time to produce the results. The figure below visualizes some of their first results produced from the

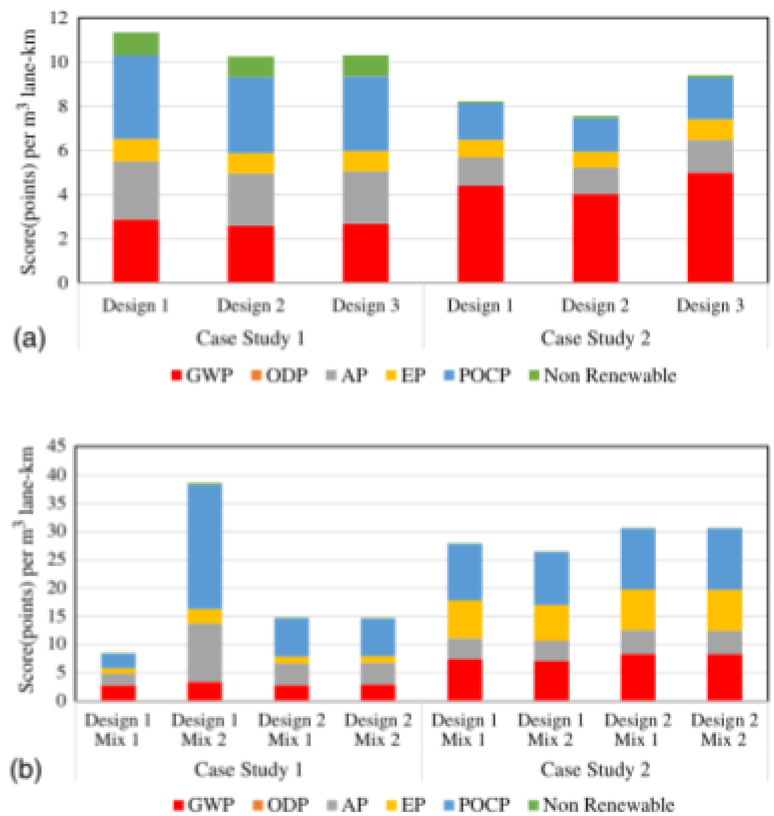


Figure 13: Subedi et al., 2018, "Environmental performance for (a) benchmark analysis; and (b) product comparison"

decision making tool.

LCA-Based Tooling for Sustainable Transportation Design

Another example of a framework constructed to improve the efficiency of LCA was created in a study performed by William Haanstra from the Department of Design Production & Management, University of Twente, titled *Design for Sustainable Public Transportation: LCA-Based Tooling for Guiding Early Design Priorities* (2020). The purpose of the study was to develop a "computer-assisted streamlined Life Cycle Assessment tool…to evaluate the environmental efficacy of various design decisions during the early stages of train modernization" (Haanstra et al., 2020). This research was performed as part of the effort to move Europe to 100% renewable transportation systems to reduce the effects of climate change. Although trains have a low footprint, there are still opportunities to evaluate and improve their sustainability.

The streamlined LCA tool is based on four main principles:

1. Sacrificing the declarative function of LCA
2. The use of Input-Output-based Life Cycle Inventory
3. The inclusion of shadow costs
4. The limitation of the included environmental impact categories

Essentially, this tool sacrifices accuracy for efficiency, which allows designers to make informed decisions about their designs in early phases, but does not replace the full LCA that would be required when carrying out the final solution. Think of it as a quick sketch compared to a full painting, one is higher in fidelity, but the former gets the idea across faster. The figures below depict the software and the principles that went into its creation.

Figure 14: Erickson, 2022, "Compilation of figures from LCA-Based Tooling Study"

While the framework may have been built for trains in the Netherlands, the concept and research could be applied to development of a similar tool to help urban developers and automotive designers, in the United States, quantify the sustainability of their project proposals before they are put into action.

Phase 2

While phase 1 was dedicated to exploring how transportation infrastructure could be designed more sustainably to improve our relationship with the natural environment, the research collected reveals a crucial feature missing from existing design tools. The sustainability venn diagram highlights the importance of improving social, economic and environmental conditions when designing systems. While many of the tools noted above have extensively analyzed ways to examine economic and environmental impacts of transportation systems during the early design phase, there is very little research on how these proposals may impact us socially, in our communities.

In industrial, user interface, and systems design, one of the most important steps of the design process is user testing. User testing allows designers to gather feedback on their products, before they are sent to production. This step saves costs for everyone involved, as it proves the product's viability and ensures it will be well received by consumers. The United States desperately needs to improve the sustainability of its transportation systems and infrastructure, in order to meet goals set by the United Nations in the carbon emission reductions. Yet, as we begin to develop proposals concerning infrastructure improvements, how can we ensure that our solutions are viable for our communities, and will be adopted en masse by users?

Combining the key concepts pulled from the research in phase 1 led to the emergence of a new question to be explored, "how can extended reality technology be used to test the social, environmental, and economic viability of sustainable transportation solutions before they are built?" The question was examined through qualitative research, conducted in two parts, to gather information from design professionals who are experts in fields related to the topic.

Conversational Interviews

Exploring extended reality as a medium for user testing is a relatively new concept and very few academic sources exist on the topic. Most of the researchers exploring this topic are still undergoing publication processes or work for large corporations. The work done by the latter group is owned by organizations striving to gain a competitive advantage, and access is therefore restricted to the public. In order to navigate this landscape, the best course of action to acquire new information was to speak with individuals who have extensive experience with extended reality technology and learn ways they have applied it in their work. The first part of conducting said research consisted of conducting conversational interviews with individuals in the immediate university circle. These interviews were intentionally unstructured as they were meant to be a general exploration of the subject, rather than a means to assess specific information.

Interviewee 1

Profile: Interviewee 1 is a tenured professor of industrial and interaction design at a widely recognized private institution. He earned his undergraduate diploma in product design in Berlin, Germany, and his masters in Cincinnati, supported by a competitive stipend from the German government. He offers combined European and American design values, and possesses a unique mission to foster collaborative, interdisciplinary design processes between industry leaders and academia. He has worked as associate director/senior design research at the Live Well Collaborative, founded by Proctor & Gamble and UC, producing work for Hill-Rom and P&G. He is currently focused on researching factors that influence creative, as well as design technology. He was chosen for this study because of his interest in promoting the use of virtual reality and augmented reality in classrooms studying industrial design.

Key Takeaways:

- What are the challenges in regards to sustainable mobility?
- How might an XR simulation manifest? In a 3rd person view or a first person perspective. What are my most sustainable ways to go from point A to Point B?
- “It looks like you are touching on city planning. I think you should look at examples in cities around the world, where urban planners have attempted to improve the status quo. It would be helpful to create a taxonomy of different types of mobility systems, to create an overview of all the systems available in that space, which shows all the different possibilities of how mobility is afforded to different people” (13:20). It goes from a children's bicycle, to uber, to subways, to motorbikes, walking, skateboards, etc.
- “Before there was uber and lyft, nobody could really tell you if these were a great idea or not” (14:30). “The first sharable items to me were bike sharing systems.” They were the first species in the market of sustainable sharing transportation. The idea that you could rent a bike and leave it anywhere changed the pathway from A to B and made it A to A.

- "The challenge for your thesis is going to be to narrow into an area rather quickly. When you show someone something in a headset that they have never seen, it can be very difficult to get feedback, because it is an abstraction of what you are aiming to convey" (16:10).
- Introduced the work of Interviewee 5, and described how VR is being used in transportation manufacturing to train forklift drivers. This data could be used to develop and test future iterations of forklift models.
- What is the industrial designer's role in bringing XR simulations to life?
- Your responsibility as a designer is to promote your ideas about the way the world should be (23:41).
- Even if European public transit systems are much more advanced compared to systems in the US, there are still problems that need to be solved, meaning these systems are constantly changing to improve the experience for users. How could your work support this organic evolution? (25:20).

Interviewee 2

Profile: Interviewee 2 is an associate professor of Computer Art and Animation at a widely recognized private institution. He earned his undergraduate degree in Industrial and Interaction Design, and his Masters of Fine Art in Computer Art. He is also a co-founder of (sphere) optics company, and a technomancy specialist at RAM industrial design. He is active in his community as a proponent of sustainability as an avid biker, camper, and 3 time winner of the Meals on Wheels Alley Cat Race in Syracuse, New York. He has filed numerous patents related to extended reality technology, including: *an omnidirectional catadioptric lens with odd aspheric contour or multi-lens* (2016), *multi-view point/location omni-directional recording and viewing* (2017), *Advertising system for virtual reality environments* (2017), and *wireless immersive experience capture and viewing (*2017). He was chosen for this study because of his extensive experience with extended reality technology and his affinity for producing inventions or cutting edge systems related to the subject.

Interviewee 3

Profile: Interviewee 3 is an instructor of Industrial Design at an accredited private institution. He earned both his BFA and MFA degrees in industrial design from separate institutions.He is the

founder and principal designer of Ram Industrial Design, inc, a consultancy specializing in consumer products, user interactions and experiences. Throughout his career he has developed products and solutions for a wide range of clients including: Alcoa, Bose, Carrier, Chobani, Energizer, Honeywell, KitchenAid, Kodak, Maxi-Cosi, MINI, NASA, Procter & Gamble, RIDGID, Safety 1st, Swiss Army, and Welch Allyn. He is named in over 50 patents, and has been an instructor of Industrial Design for over 10 years. He has guest lectured on design and technology at several colleges and universities including Hobart and William Smith's Colleges, Penn State, Rochester Institute of Technology, Syracuse University, Yale, SUNY College of Environmental Science and Forestry (ESF), and the University of Oregon. He is also the
co-founder of (sphere) optics, a company specializing in precision optics for augmented and virtual reality applications, through the development of the world's first and only 360 degree spherical image capture solution. He was chosen for this study because of his experience in developing and applying new technologies for design applications, as well as his knowledge of extended reality in the transportation sector.

Key takeaways from Interviewees 1 and 2:

- They have developed this camera called the Sphere, which allows users to take full 360 images and video. The applications are endless, but most relevant is the way this footage could be used as background in VR applications.
- Using this technology, humans could get used to watch full panoramic video (7:48)
- "3D modeling in VR is kind of hard, I think, to get that fidelity that you'd need or you know, it sounds cool.. But I would much rather built it in can and import it in." (Interviewee 2, 12:21)
- How could we interact with CAD data in a way that allows us to analyze how people would actually feel about it?
- Amber Bartosh is using VR in Architecture to test how users interact with spaces. "She has the pipeline set up," which is the hardest part (14:07).
- At the end of this project, "something that I think could be really interesting if you want to do the range of real life to AR to VR would be to set up kind of like a dummy cabin or a dummy seating compartment or … some type of modular space where when you're wearing the headset, you can kind of skin it in various ways but still have some physical, tangible aspect of it." (Interviewee 1, 21:34)

- Taking that experience and using eye tracking, hand tracking, sensors etc. to capture quantitatively how people feel about the experience they are confronted with, would be a really interesting way to get feedback on designs. (25:14).

Guided Interviews

Guided interviews were conducted after the conversational interviews in order to gather more consistent feedback and information on the topic of implementing extended reality in a research environment. These interviews began with a summation of the research in phase 1, and an explanation of how this research led to the main research question, “how can extended reality technology be used to test the social, environmental, and economic viability of sustainable transportation solutions before they are built?” The figures below depict the slides in the presentation that was given to each interviewee.

Figure 15: Erickson, 2022, “Slides of my Thesis Pitch”

Following the concept presentation, interviewees were asked a series of questions to get a clear idea of their knowledge of the subject, and how it may relate to the research question.
The questions are as follows:

- What type of XR technology are you most familiar with?
- How do you use XR technology in your work?

- What differences do you see in using XR for research purposes vs pure entertainment?
- What are the biggest challenges you face when working with AR/VR software?
- What type of hardware and software do you rely on the most?
- Do you ever face any ethical concerns when using XR?
- For VR specifically, what do you notice about how users interact with their physical surroundings when they are focused on the virtual experience?
- What opportunity excites you most about XR?
- Do you have any experience with the field of transportation design?
- From your perspective, what do you hope for the future of sustainability in transportation?
- Do you have any sources or recommendations of people I should speak to in order to continue my research?

Although these interviews were guided, conversational follow up questions were interwoven throughout the interview to get as much information as possible from the interviewees.

Interviewee 4

Profile: Interviewee 4 is the David J. Levidow Endowed Professor at one of the top communications schools in the country. She has conducted internationally recognized research in the area of media psychology, studying the ways in which people process and respond to persuasive messages in mass media, social media, and extended reality environments. She examines ways that social and psychological factors affect responses to news media content. Her work has been published in over 12 notable journals related to research in communication and has won top paper awards at the annual conferences of the *International Communication Association*, the *National Communication Association* and the *Association for Education in Jounalism and Mass Communication* (AEJMC). She held the Newhouse Endowed Chair of Public Communications for 3 years, served as interim director of the media studies master's degree program, and is the former chair of the Communication and Social Cognition Division of the National Communication Association. She currently holds a grant with the Department of Homeland security to explore how extended reality technologies may influence the behaviors of users and the potential they may face concerning indoctrination into harmful organizations. She was chosen for this study because she is one of the leaders in researching the psychological effects of extended reality, and has been an advocate for conducting research using the technology for many years.

Key takeaways:

- "VR has the capacity to be the ultimate empathy machine" can XR be a medium to test how users might feel about potential design elements? One way to accomplish this is to test how people feel while they are driving different vehicles in XR environments. (5:12)
- In a study on how users respond to riding an exercise vehicle while looking at a screen, vs how they responded while doing it in VR, they found that when in the immersive world, users actually exerted more muscle effort than when using the bike normally. This shows that there could be ways to test people's physical/biological reactions along with their self reported thoughts later, by using cameras and sensors during the experiment. (6:10)
- In terms of creating XR simulations for researching the sustainability of transportation, VR may be most beneficial because of the immersive nature of the software, and the sensors that are already built into headsets. (7:10)
- For simulations, think flight simulators, which measure facial expressions, and sensors on physical objects/features in space. (7:20)
- One important aspect of using VR in research is the importance of story. Existing entertainment narratives can be used to test people’s reactions. (12:21)
- VR as an empathy machine: her current research with homeland security explores how people’s attitudes towards various cultures change when exposed to individuals in VR, such as Syrian Refugees.
- Most commonly used software: Unreal Engine (13:50)
- Biggest Challenge when working with headsets: VR sickness (15:50)
- When XR was first being introduced, it was difficult to convince people that it was an important area of study. Now that it has entered into mainstream culture, public interest has allowed a lot more research to be done. (18:12)
- Another challenge when working with this technology is that “we are trying to fly the plane while designing it, no sooner do we get things along and then someone comes along and finds a new way to put the wings on." 3 months in the tech world means 4 or 5 new things have come out already. The question is “how do you build something that will continue to be usable as time goes on?” (21:34)

- From a sustainability perspective, this is concerning, as much of her old VR tech, is just sitting boxes, unused. (25:50)
- Last point, people get lonely in headsets, these programs work better if people are able to do things and interact with each other. (28:20)

Interviewee 5

Profile: Interviewee 5 is an industrial design manager at the Raymond Corporation, which is a part of the Toyota material handling group. He is the head of design for North America and responsibility advocacy for the Raymond brand. He works on forklift technology in Toyota brand warehouses, focusing on material handling products, all forklifts, primarily electric, and the related technologies or accessories that are used with those, such as telematics units and batteries. He promotes the manufacturing of batteries in green, allowing product lines to continue to expand, overseeing production and coordination from a global perspective with colleagues in Japan, Italy, and Sweden. He earned his degree from the University of Bridgeport, and has worked in the transportation sector for 23 years. His contributions to the field of industrial design are immeasurable, as he has been the chair of the central new york IDSA chapter for 16 years. He was chosen for this study because of his work using virtual reality simulations to train forklift drivers in manufacturing warehouses, and his extensive knowledge of how transportation manufacturing has evolved over the years.

Key Takeaways:

- For forklift training, VR has allowed Toyota to train employees in precarious situations they may not be ready for. It provides an opportunity for suggestions or visual aids during training, which can't be done in an actual setting. It also gives researchers an opportunity to see exactly what users are seeing in a virtual environment. You know where their head is, their eyes, so if they are supposed to come to an intersection and look at a mirror, you can tell if they have or have not looked in the mirror. (4:30)
- There are endless ways to customize this software, such as adding audio prompts, or selecting whether something is translucent. The main way it works is by creating lessons, which are an effective way to carry out forklift training, while reducing accidents. (5:00)
- It was one of the first softwares of its kind in the manufacturing industry.

- 5 years ago, this program required five different units, which all accounted for different things like eye and hand tracking. Since then, the technology has evolved tremendously, allowing one computer and one headset to carry out most of the work. (5:52)
- The nature of it is very realistic, "people get a much more beneficial response because it's one to one and you're actually looking in the actual directions that you should be looking, et cetera, so it feels real." (6:25)
- "We very often would build plywood bucks to test human factors, aspects of products. So in VR, we create VR bucks so that even though you're in a virtual environment, you can actually step onto a real truck, grab the handle, and it looks where you're looking at. Your hand in the VR environment matches what you feel and you grab." (7:38)
- There are some considerations that complicate the experience, one is angle of view. (9:39)
- "We find a high success of somebody that learns in VR and moves to the real world," (11:28)
- "it's tremendously powerful when we use it for our product development, to have the real world and to superimpose AR mixed reality environments." (19:11)
- The ethics of facial tracking are complicated, but in a research setting, they are further compounded by the ethics of user testing.
- When creating simulations for user testing, your software of choice will be most affected by the question of how immersive you want the experience to be. Most immersive and most realistic is VR. (28:43)
- Sustainable transportation is systems level design (32:22)
- When thinking about how transportation can be improved, he began to speak about how mobility is much more accessible in Europe than in the United States. Even further, pointing out how there is a lot of access to public transportation in urban areas, but in small rural towns, "there is no infrastructure to get me anywhere. I have to have a car." (32:22).
- "I wish there was a co op share timeshare in the Village. How often do I need a pickup truck? Not too often, but I would love to be able to be in the Village and say, you know what, I need a pickup truck this weekend." (33:50)
- Think about "What needs and wants people have for future mobility and what would meet those needs and then overlay it to what are the more sustainable options?" (35:52)
- Use examples from biology to influence systems design "are there any parallels in nature of mobility? How do migrations occur?" (41:44)

- If “a picture tells a thousand words, a video tells a thousand pictures. VR may be a way that you just create this whole world,” and are then able to test it (47:44).
- Lastly, “we're on the bleeding edge of VR being a fast prototyping tool, right now, you need unity experts, so its not a very fast process,” how could one make the figma of VR prototyping? (50:50).

Phase 3

Phase 3 of this research process was dedicated to the analysis of sources suggested by interviewees in Phase 2. This phase was conducted to supplement and corroborate some of the points made by the interviewees, and answer some of the questions that were raised in the discussion.

Extended Reality Tools

The first topic explored was the availability of extended reality tools. Extended reality (XR) is an umbrella term for all the immersive technologies - augmented reality, virtual reality, and mixed reality (Marr, 2018).

In augmented reality, virtual information and objects are overlaid on our surroundings via devices like AR glasses, screens, tablets, and smartphones to enhance the real world (Marr, 2018). The most well known examples of augmented reality are Pokemon Go and snapchat filters, which both operate using simple facial and planar tracking available on nearly any smartphone. As AR has progressed, programs have incorporated LiDAR tracking to make effects more realistic and accurate. In terms of development, augmented reality has become extremely accessible for public development, with platforms such as tik tok, snapchat, and meta, making their AR development free and open source.

In virtual reality, VR, users are fully immersed in a simulated digital world. There are many ways to facilitate this interaction, but the top two examples of hardware on the market are the Oculus headsets and HP’s Omnicept. Oculus headsets have gained popularity due to the dramatic push made by Mark Zuckerberg in creating the metaverse. However, as far as software development, HP’s Omnicept is much more adept. The graphics system is able to run Unreal Engine more efficiently and the sensors on the headset would make it more applicable for complex user testing. Further, Meta’s backend software for all platforms, facebook, instagram, and oculus, is updated so quickly that it makes it difficult for developers to keep up.

Mixed reality, MR, sometimes referred to as hybrid reality, is more difficult to define, and is not as frequently discussed in mainstream media as AR or VR. In this medium, digital and real-world objects co-exist and can interact with one another in real time (Marr, 2018). One example is Microsoft's HoloLens, which "allows you to place digital objects into the room you are standing in and give you the ability to spin it around or interact with the digital object in any way possible" (Marr, 2018). These types of headsets require a lot more processing power than VR or AR, but are more collaborative to work with. Another avenue that could be explored in relation to MR is projection mapping, which projects images onto 3-Dimensional objects, to create optical illusions (Marr, 2018). This may be an avenue to consider in creating experiences that are tangible for more than one viewer at a time, rather than in headset or on devices, which are more individualized experiences.

Virtual Reality as a Tool for Automotive Designers

Many of the interviewees in phase 2 discussed the importance of the immersion facilitated by VR technology, and the potential that the platform has to facilitate user testing. VR is already being used across the design industry as an ideation tool, think Gravity Sketch. One example of a VR platform that has been developed as a quick prototyping tool for designers in the transportation industry, is Garage by Teague. Teague "started using virtual reality at the beginning of the decade while tackling cabin design and development in commercial aviation" (teague.com). Through VR, they were able to validate their design concepts in a fraction of the time and at a lower cost (teague.com). In 2019, they were commissioned by Teague to develop the world's first fleet of hybrid electric off-road powersport vehicles in collaboration with a team nearly 6,000 miles away. Disappointed by the available market options of VR prototyping tools, they developed their own, which is now known as Garage.

This software is free and open source and has allowed them to "increase the speed of iteration, enable design at scale, and improve distant collaboration" (teague.com). One example of a mode of sustainable transportation developed by teague using this software, is their design of a Virgin Hyperloop supersonic passenger experience. This hyperloop experience was designed to respond to the call for the need of the next generation of energy-efficient mass transit vehicles.

Teague has performed many speculative design studies over the years, and their core values as a company represent a lot of the concepts present in this paper. However, it seems their garage tool still has room to incorporate even more concepts as a tool for analyzing sustainability.

Toyota Woven City

Interviewee 5 was very focused on the concept of creating a system for rural communities that would allow citizens to have access to rideshare, or some form of public, sustainable transportation. Car companies are already aiming to capitalize on this concept by creating their own “cities.” One example referenced by the Interviewee is Toyota Woven City, “a test course for mobility,” which is being constructed “in Susono City at the site of the former Toyota Motor East Japan, Higashi-Fuji plant. Woven City is how Toyota will integrate automobile manufacturing "Monozukuri" (craftsmanship) with the latest technologies” (woven-city-global).

The site is 175 acres, and will initially house 360 residents, but plans are to grow the ‘city’ to 2000 residents. These residents will be employees of Toyota and partner companies, some are independent developers, and others are ordinary residents, from children to senior citizens. The findings developed from the experiments in the woven city, which are planned to begin 2024 or 2025, will be used to create mobility solutions for communities across the world.

Although woven city preaches honorable intentions, one cannot help but wonder if these types of ‘experiments’ are simply another ploy by the automobile industry to remain relevant as their products continue to decrease in popularity due to the effect they have on climate change.

Benefits of Public Transportation over Passenger Vehicles

Which leaves us with one final topic to discuss before moving on to summarizing the findings in this paper: the benefits of public transportation over passenger vehicles. “Every segment of American society—-individuals, families, communities, and businesses—benefits from public transportation” because it provides economic opportunities, it is safer than automobile travel, it saves money, it reduces gasoline consumption, and enhances opportunities (American Public Transportation Association). In referencing the sustainability diagram public transportation is in the dead center. However, the amount of Americans that rely on public transportation is only 2 percent compared to western European countries, where the number ranges from 10-20 percent. So the final question is, how do we motivate Americans to use public transportation, and how can we ensure that our design solutions to this problem are truly sustainable?

Conclusion

Moving forward, this research has the potential to continue by further exploring motivations users may have in taking public transportation over relying on passenger vehicles.

However, for now, it satisfies the main question of how social, economic, and environmental impacts of sustainable transportation solutions may be measured using extended reality technology as a medium for design researchers. In phase 1 of the research, multiple frameworks for promoting ecological design emerged, with specific guidelines and metrics discussed for analyzing economic and environmental features of proposals in the early design phase. In phase 2 of the research, interviewees suggested the importance of using virtual or mixed reality, over augmented, when creating immersive experiences in research settings.

Interviewees also stressed the importance of story in garnering social feedback in user testing, and the ethics of using such technologies to evoke responses from potential subjects. In phase 3, a brief analysis reveals that some companies are already beginning to adopt these concepts into their design process, but the technology has yet to be applied to many areas. Some areas where this research could be applied as this work moves forward into the design phase include: comparing rural and urban transportation systems, designing public transportation in suburban areas, placing users in the perspective of animals in urban environments, using principles of nature (biomimicry) to design better systems, and exploring XR beyond headsets. Overall, the technologies presented throughout this paper have the capacity to help designers and design researchers implement transportation infrastructure that can support environmental preservation and improve sustainability for all.

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