

Embodied Virtual Reality: The Impacts on Human-Nature Connection During Engineering Design

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Abstract

The engineering design process can underutilize nature-based solutions during infrastructure development. Instances of nature within the built environment are reflections of the human-nature connection, which may alter how designers ideate solutions to a given design task, especially through virtual reality (VR) as an embodied perspective taking platform. Embodied VR helps designers “see” as an end-user sees, inclusive of the natural environment through the uptake of an avatar, such as a bird or fish. Embodied VR emits empathy toward the avatar, e.g., to see as a bird in VR, one tends to feel and think as a bird. Furthermore, embodied VR also impacts altruistic behavior toward the environment, specifically through proenvironmental behaviors. However, limited research discovers the impact of embodied VR on the human-nature connection and if embodied VR has any impact on how designers ideate, specifically surrounding nature-based solutions as a form of a proenvironmental behavior during the design process. This research first presents a formal measurement of embodied VR’s impact on the human-nature connection and maps this impact toward design-related proenvironmental behaviors through design ideas, i. e., tracking changes in nature-based design choices.

The design study consisted of three groups of engineering undergraduate students which were given a case study and plan review: a VR group embodying a bird (n=35), a self-lens VR group (n=34), and a control group (n=33). The case study was about a federal mandate to minimize combined sewer overflow in a neighborhood within Cincinnati, OH. Following the plan review, VR groups were given a VR walkthrough or flythrough of the case study area of interest as a selected

avatar (embodied:bird, self-lens:oneself). Participants were tested for their connectedness to nature and a mock-design charrette was held to measure engineering design ideas. Verbal protocol analysis was followed, instructing participants to think aloud. Design ideation sessions were recorded and manually transcribed.

The results of the study indicated that embodiment impacts the human-nature connection based on participants' perceived connection to nature. Only the bird group witnessed an increase in connectedness to nature, whereas the self-lens and control groups did not report any change. This change in connectedness to nature was also confirmed by engineering design ideas. The bird group was more likely to ideate green-thinking designs to solve the stormwater issue and benefit both nature and socioeconomic conditions, whereas the control group mostly discussed gray designs as the catalyst for minimizing combined sewer overflows. The self-lens group also mentioned green design ideas as well as socioeconomic change, but mostly placed the beneficiary of the design toward people rather than nature in the bird group. The mode of analysis for these findings was driven by thematic content analysis, an exploration of design space as a function of semantic distance, and large language models (LLMs) to synthesize design ideas and themes. An LLM's performance lent accuracy to the design ideas in comparison to thematic content analysis, but struggled to cross-compare groups to provide generalizable findings. This research is intended to benefit the engineering design process with a) the benefit of perspective-taking on design ideas based on lenses of embodied VR and b) various methods to supplement thematic content analysis for coding design ideas.

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General Audience Abstract

The use of nature in the constructed world, such as rain gardens and natural streams for moving stormwater, is underused during the design process. Virtual reality (VR) programs, like embodiment, have the potential to increase the incorporation of nature and nature-based elements during design. Embodiment is the process of taking on the vantage point of another being or avatar, such as a bird, fish, insect, or other being, in order to see and move as the avatar does. Embodied VR increases the likelihood that the VR participant will act favorably to the subject, specifically when the natural environment is involved. For example, embodying another individual cutting down trees in a virtual forest increased the likelihood that individuals would act favorably to the environment, such as through recycling or conserving energy (Ahn & Bailenson, 2012). Ultimately, this research measures the level of connection participants feel with the environment after an embodied VR experience and motions to discover if this change in connection to nature impacts how participants might design a solution to a problem.

This design experiment is based on a case study, which all participants were provided alongside supplemental plan documents of the case. The case study used is about stormwater issues and overflows from infrastructure in a neighborhood in Cincinnati, OH, where key decision-makers were mandated by the federal government to minimize the overflows. The bird group (a bird avatar) performed a fly-through in the area of interest in VR, whereas the self-lens group (first-person, embodying oneself) walked through the same area. The control group received no VR intervention. Following the intervention, participants were asked to re-design the neighborhood

and orate their recorded solution. Then, participants were required to score a questionnaire measuring their connectedness to nature. The results show that when people experience the space as a bird in virtual reality, they felt more connected to nature and also included more ideas related to nature in their design. More specifically, ideas involving green infrastructure (using nature-based elements, e.g., rain gardens and streams) and socioeconomic benefits were brought up by the bird group.

This research presents embodiment as a tool that can change how engineers design. As stormwater policy has called for more use of green infrastructure (notably, through the Environmental Protection Agency), embodiment may be used during the design process to meet this call from governmental programs. Furthermore, this research impacts how embodiment's effects on design can be interpreted, specifically through quantitative methods through natural language processing and the use of large language models to analyze data and report back on design-related findings. This research is intended to benefit the design process with a) using different avatars in embodiment to impact design ideas and b) a comparison of thematic content analysis and large language models in summarizing design ideas and themes.

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Dedication

This work is dedicated to the oft-forgotten stakeholders in engineering and land development – the end-user and nature. May the future of infrastructure development see through your eyes to build more resilient communities.

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CHAPTER 1: INTRODUCTION

The use of nature is traditionally underutilized within the built environment despite the benefits of the human-nature connection. In everyday life, modes of interaction with natural landscapes through the built environment improve overall satisfaction with life, stress recovery, and boost mental and physical health (Chang et al., 2020; Chavaly & Naachimuthu, 2020). Nature within the built environment also restores environmental health that urbanity degrades, with benefits such as the reduction in urban heat-island, improved water and air quality, and increased biodiversity (Randolph, 2003; Beatley, 2016; Kellert, 1995, 2018). The incorporation of nature within the built environment has been referred to as biophilic design (Kellert, 2018), which has been met through green infrastructure (also referred to as 'nature-based solutions'). Despite the benefits of incorporating nature-based solutions to the human-nature connection, these solutions are typically underutilized for manmade infrastructure made from concrete and steel (Rosenbloom, 2018), such as gutter and drainage systems. To impact the use of nature within the built environment, the engineering design process must strengthen the human-nature connection (Kellert, 2012; Yang et al., 2013).

To strengthen the human-nature connection, the engineering design process must form empathy toward nature as a stakeholder in the design process. Often, nature is undervalued and is placed as a passive stakeholder within the design process, which calls for interventions to uphold its value, specifically toward increasing empathy (Mok et al., 2021; Schultz, 2000). Perspective-taking toward natural systems and beings is one method of increasing empathy toward nature (Schultz, 2000). Specifically, perspective-taking can lead to more altruistic behavior toward the end-user by including more favorable design components that benefit the end-user (Oswald, 1996; Batson et al., 1997). In context, perspective-taking can lead to altruistic behavior toward nature as a stakeholder within the design process. For example, taking the perspective of a logger felling trees in a virtual environment led to an increase in proenvironmental behaviors by spurring

empathy toward the environment, such as conserving household energy and water (Ahn & Bailenson, 2012). In other words, perspective-taking is a form of empathy (Köppen & Meinel, 2015) and can increase nature-based thinking through proenvironmental behaviors.

Taking the perspective of the end-user is a form of empathy, which can be made more robust through virtual reality (VR) and impact the human-nature connection. Traditional modes of perspective taking include stakeholder engagement activities within the design process, such as through charettes, door-to-door canvassing, and focus groups (Widén et al., 2014). However, these modes of engagement typically prevent a firm understanding of the problem and solution space between the designer and end-user (Gheisari & Wen, 2020). More immersive perspective-taking platforms could help a designer see as the end-user sees, such as through VR. VR enables direct perspective-taking of any end-user, which increases the robustness of end-user feedback toward a design and can lead to altruistic behavior toward the natural environment (Herrera et al., 2018; Schultz, 2000)

VR can spur empathy toward a perspective. Referred to as the “ultimate empathy machine” (Herrera et al., 2018), immersive VR can affect altruistic real-world behavior toward the virtually impacted subject (Loon et al., 2018). For example, a curb in racial bias was witnessed by taking on the perspective of an individual of a different race facing workplace microaggressions in VR (Chen et al., 2021). The uptake of an avatar, such as one of a different skin tone, is referred to as *embodiment*. In connection with nature-based solutions, embodiment can change one’s perspective to an avatar, such as a bird or fish, to consider their viewpoint from a design challenge (Markowitz et al., 2018).

Embodied VR is comprised of two lenses which this dissertation explores: self and other. The self-lens places a VR participant as an extension or version of their current self. For example, negative stereotyping of elderly individuals can be reduced by embodying young VR participants as older avatars of themselves (Yee & Bailenson, 2006). The other-lens (OL) allows the VR participant to

embody another being or person. For example, beyond the previous explanation of embodying racial conditions, empathy for individuals with mental disorders increased by embodying an avatar with a mental disorder (Żuromski et al., 2018).

This dissertation compares the self and other lenses, which has limited exploration in previous literature. Markowitz et al. (2018) reflect one example of comparing the self vs. other lens within VR for climate change education, but no significant difference was discovered between the groups on sense of imminence with nature. However, with a dearth of comparable research, this dissertation aims to add to Markowitz et al. (2018) to compare different lenses within VR. Specifically within the field of architecture, engineering, and construction, this research applies an embodied intervention during the design process to gauge its impacts toward decisions made by designers.

Nature within engineering design

The imperative to build and live around nature has been attributed to the biophilic hypothesis. Kellert (1995, 2018) describes the inherent need for humans to coexist with nature as part of an evolutionary requirement. The human-nature connection is vital to public health and can be affected by infrastructure (Parker & Simpson, 2020), however, natural systems can often be underutilized and overridden by manmade systems and facilities. In urban planning, manmade systems and facilities have become vital and largely improve the quality of life, but have muted the restorative effects of that natural surroundings provide (Randolph, 2003). The balance of manmade vs. nature-based solutions is at the behest of engineering design within urban planning.

Stormwater infrastructure presents one area of engineering design which contests manmade vs. natural systems. Rosenbloom (2018) discusses how the past century's planning for infrastructure systems have led to systemic failures due to gray stormwater infrastructure: manmade structures comprised of concrete and steel, such as underground pumps and pipes. Advocates of the

human-nature connection have called for green stormwater infrastructure to replace or subvert its gray counterpart – e.g., the use of nature to convey stormwater through rain gardens, bioswales, and streams – to bridge the gap in infrastructure resilience along side various co-benefits to public health (Randolph, 2003; Van Oijstaeijen et al., 2020).

Embodied VR presents a tool that can enhance the engineering design process through the human-nature connection. Spangenberg et al. (2022) hypothesized a greater relationship to nature through embodying a tree in VR, but found no increase in the connection to nature between the embodied group and the non-embodied group following the intervention. However, Spangenberg et al. (2022) did not utilize the engineering design process as a vehicle for promoting empathy, which this dissertation invokes in the following three chapters by centering the experiment around a design case study. Thus, this research seeks to discover any change in human-nature connection as a result of embodied VR (Chapter 2).

Embodied VR can impact empathy toward nature within the engineering design process. Scurati et al. (2021) discovered that the perspective-taking ability of VR can impact preference toward environmentally-friendly designs for the end-user, but how does this relate to the designer? This research aims to identify if embodied VR changes engineering design ideas to be more or less inclusive of nature within the engineering design process. Thematic Content Analysis (TCA) is the traditional approach to analyze this type of qualitative dataset (Smith, 2015) and was used to find generalizable findings between the three groups in this research (Chapter 3).

This research fills a gap in ways to evaluate design ideas after an embodied VR intervention and compares the outcomes to traditional evaluation through thematic content analysis (Chapter 4). Gero and Milovanovic (2020) characterize the design space as all the design ideas that are generated during a design session. The authors use natural language processing (NLP) to calculate semantic distance within the corpora of each designer, which can then be visualized through a linkograph that connects design ideas (Kan & Gero, 2018). Furthermore, emergent

methods including the use of large language models through OpenAI's ChatGPT were used to compare a synthesis of design ideas to the coded thematic themes (Gamielien et al., 2022; Katz, 2023). These methods are quantitative and interpretive representations of the design process and measure different aspects of design. The measure of design space quantifies the semantic similarity of words within corpora. For example, if a designer considers only design ideas about gray or green infrastructure, this likely reflects a smaller design space as opposed to a designer that discusses a hybrid approach. Furthermore, a large language model can be used as a qualitative research assistant that can ingest large corpora and be queried. For instance, some queries to assist qualitative research are to summarize the design ideas and themes within each transcript. Since this research discovered a gap in ways to analyze embodiment's impacts on the design process, both design space and assisted queries through the use of a large language model were performed and compared to a traditional approach for qualitative research through thematic content analysis.

Overview

This dissertation aimed to understand how embodied VR influences the human-nature connection during engineering design. The hypothesis of this dissertation was as a designer takes the perspective and embodies nature, the designer's human-nature connection increases and the influence of this human-nature connection leads to an increase in the incorporation of nature-based elements within design. A direct outcome of this research is to influence the utilization of nature-based solutions from embodied VR. Furthermore, a more general impact that this research provides is for future designers to uptake VR within their design capabilities regardless of technical prowess; the creation of virtual landscapes can impact design choices without extensive background knowledge in virtual design.

Throughout all three manuscripts (Chapters 2-4), a VR case study was used. The case study surrounded stormwater issues through combined sewer overflows (CSO) in Cincinnati, Ohio. More specifically, the case study targeted the South Fairmount neighborhood, which is the largest single-point emitter of CSO in Cincinnati. The Environmental Protection Agency (EPA) has placed a federal mandate on the city to minimize CSO. The experiment implored the participants to envision themselves as the designers, charged with meeting the federal mandate and to reimagine public blight in an open-ended design session.

The VR experiment consisted of three groups: a control group (no VR), an embodied self-lens (taking the perspective of oneself in first-person) VR group, and an embodied other-lens VR group (embodying a bird). All groups were given the case study and plan details of the area of interest for South Fairmount. The VR groups performed a virtual walkthrough (or fly-through) of the area of interest, whereas the control group was provided the plan set of the area of interest as a traditional plan review. Following the intervention, all groups were instructed to think aloud and ideate design components for South Fairmount on a blank template. All groups took a pre/post Connectedness to Nature questionnaire (Mayer & Frantz, 2004). The VR groups were also provided with a Virtual Reality Presence Questionnaire (iGroup, 2016).

Below is an overview of the research questions and hypotheses presented in Chapters 2-4:

Chapter 2's first research question was *how does the embodiment of nature through virtual reality change human-nature connection in the engineering design process?*

The hypothesis was that embodied VR can increase pro-environmental behaviors and the sense of imminence with the state of the natural environment (Ahn & Bailenson, 2012; Ahn et al., 2016), the human-nature connection may be positively influenced, such that the bird group (embodying a natural being) will experience a stronger connectedness to nature score as a proxy for the human-nature connection. The survey instrument used was the Connectedness to Nature Scale

(Mayer & Frantz, 2004), which is a scale that assesses one's sense of place and imminence within the natural world.

Chapter 2's second research question was *how does embodiment of nature through virtual reality change engineering design concepts for stormwater infrastructure?*

The hypothesis was embodiment leads to pro-environmental behaviors (Ahn & Bailenson, 2012; Ahn et al., 2016), represented in their engineering design ideas. Scurati et al. (2021) discovered an increase in preference for environmentally sustainable designs after an embodied experience, which could lead to more utilization of nature-based solutions in comparison to gray design.

Chapter 3's research question this manuscript addressed was *how does the embodiment of nature through virtual reality change engineering design ideas?*

The hypothesis was embodied participants' design ideas will include more elements of nature through the use of nature-based solutions. Past experiments with embodied VR have spurred involvement with environmental issues and altruistic behaviors toward nature (Ahn & Bailenson, 2012; Ahn et al., 2016) and the expectation was this VR intervention would lead to similar outcomes for engineering design. The instrument of analysis used for this research question was content analysis (Strauss & Corbin, 1994), in which cleaned transcript data for green, gray, and socioeconomic ideas were coded. Stormwater infrastructure design ideas are typically in a spectrum of green (nature based) or gray (man-made) (Bell et al., 2019). The implementation of socioeconomic improvements was an emergent code based on the review of participants' ideation sessions. For instance, designers would talk about the implementation of trees along the corridor but would discuss their function in terms of aesthetics rather than stormwater or heat mitigation.

Chapter 4's research question this paper seeks to answer is *how do automated natural language processing techniques compare to traditional qualitative methods for evaluating embodiment's impact on nature-based design ideas?*

The hypothesis was a large language model should closely mimic TCA based on its ability to generate design ideas (Katz, 2023), but will lack the rigor and context-driven analysis to compare groups and generalize themes that TCA proposes (Smith, 2015). A large language model that can serve as a valuable tool for analysis of textual data in the context of thematic content analysis. Tools such as large language models can help researchers uncover and refine thematic concepts and identify relevant terms. Furthermore, design space measures will be able to point out differences in semantic distance between groups (Gero & Milovanovic, 2020), which may indicate which groups presented more creative design ideation (Kenett, 2019; Kenett et al., 2017) as validated with output from a large language model and TCA. The VR groups will likely have wider design spaces since VR can increase creativity (Obeid & Demirkan, 2023), which should be reflected in their semantic distance scores.

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CHAPTER 2: THE IMPACT OF EMBODIMENT ON CONNECTEDNESS TO NATURE AND DESIGN IDEAS

Abstract

The human-nature connection impacts the built-environment and can be strengthened through nature-based solutions. Embodied virtual reality (VR) can be used as a design tool and help designers see nature, which may have an influence on the type of design ideas they produce during the conceptual design process. Embodied VR presents an approach to perspective-taking to spur empathy, which may curb the human-nature connection as a behavior change and increase nature-based solutions as a change in design space. Through an embodied VR experiment where VR participants traversed an area of interest within a case study about combined sewer overflow issues in Cincinnati, Ohio, the human nature connection and engineering design ideas were measured. Avatar representation through embodying both oneself (self-lens), a bird (other-lens), and no VR interaction (control) affects the human-nature connection. To measure behavior change, the Connectedness to Nature Scale (Mayer & Frantz, 2004) was used whereas a thematic content analysis approach (Smith, 2015) was extended to transcribed design sessions, binning design as themes “green”, “gray”, and “socioeconomic”. The embodied bird group reported a higher increase in human-nature connection scores compared to the self-lens and control group. Furthermore, the embodied participants were more likely to ideate green and socioeconomic themes during a think aloud brainstorming session for design themes based on the case study.

Introduction

Nature-based elements within infrastructure systems benefit human and environmental health (Beatley, 2016; Kellert, 1995, 2018), but are underutilized within the built environment. Common elements of nature within everyday life, especially through city planning and infrastructure, improves overall satisfaction with life, as well as overall attention restoration and stress recovery

(Chang et al., 2020). These common elements include sensory connections to natural landscapes, such as forests, mountain ranges, and seascapes. These natural spaces benefit physical and mental health for humans (Chavaly & Naachimuthu, 2020), which led to a movement to incorporate more elements of nature into everyday life through biophilic design (Kellert, 2018), specifically in urban areas. Designing with nature through biophilic principles encourages the designer to implement nature-based elements by considering the benefit of natural ecosystems toward end-users (Yang et al., 2013), however, these nature-based elements are underutilized compared to manmade infrastructure, causing gaps to urban resilience (Rosenbloom, 2018).

The underutilization of nature-based systems in the built environment could be due to a low human-nature connection (Schultz, 2002). Nature is often a passive stakeholder and requires more hard and soft approaches to improve its valuation within engineering design (Mok et al., 2021). A method to increase nature's valuation in design is through green infrastructure projects (also known as nature-based solutions), which aligns more interaction between the public and the natural environment (Church, 2018; van der Jagt et al., 2019). Nature-based solutions incorporate elements of nature *within* the built environment for stormwater conveyance (e.g., rain gardens, streams, and natural swales) whereas its counterpart, gray infrastructure, uses manmade structures (e.g., curbs, channels, and storage tanks) (Casal-Campos et al., 2015). While nature-based solutions are lauded for their impacts toward urban resilience (Rosenbloom, 2018; Staddon et al., 2018), public health benefits (Nazir et al., 2014), and environmental benefits compared to its gray counterpart (Klemm et al., 2017), nature-based solutions face notable barriers to adoption (Dhakal & Chevalier, 2017). One barrier is the pro-gray mindset for the public and governmental agencies (Dhakal & Chevalier, 2017; Wamsler et al., 2020). To overcome the pro-gray mindset, better stakeholder engagement platforms may be needed which strengthen the human-nature connection, which could change the type of design ideas that are produced during the design process (Johns, 2019; Parker & Simpson, 2020).

Modes of virtual reality (VR), such as through embodiment, may strengthen the human-nature connection and impact design ideas. Embodied experiences are a form of perspective taking within VR that can impact how one empathizes with a given perspective through the uptake of an avatar, such as a bird, fish, insect, or other human being (Bertrand et al., 2018a; Bertrand et al., 2018b; Gerry, 2017; Kors et al., 2020). In essence, avatars can produce empathy through perspective-taking by subconsciously encouraging the VR user to think and behave as the avatar might in real-life situations. This feeling of empathy can lead to altruistic behavior toward the environment when VR participants witness a detrimental virtual scenario, such as when an area is littered in garbage and waste (Bevan et al., 2019; Bertrand et al., 2018). Furthermore, within engineering design, Scurati et al. (2021) discovered a stronger preference for environmentally sustainable designs after an embodied experience in VR. While Spangenberg et al. (2022) presents a study of measuring embodiment's impact on the human-nature connection through surveys, less understood in current literature is the impact that embodied VR has on the human-nature connection for designers as well as the type of ideas they populate.

As designers become more attuned with nature, they may include more instances of nature-based solutions within their designs. Parker and Simpson (2020) developed the Human Nature Connection Theory (HNCT) to connect human affiliation with nature, pro-environmental behaviors, and the built environment. The HNCT centers pro-environmental behaviors toward urban design, marking the use of urban green infrastructure as the end-goal for connecting humans with nature in the built environment. Parker & Simpson (2020), present the HNCT through the following six principles, culminating in the use of green infrastructure:

1. Incorporating nature into the design of buildings, homes, and public spaces
2. Integrate elements of nature into everyday life, work places, and institutional settings
3. Provide opportunities for connecting with nature through urban green infrastructure
4. Restore and revegetate degraded land and environmental assets
5. Reclaim barren land and repurpose it for recreation and biodiversity
6. Advocate for opportunities of accessibility and diverse nature experiences through urban green infrastructure, nature trails, green roofs, and other instances of green building

The purpose of this research is to measure the impact of embodiment in VR on the human-nature connection and design ideas during the design process. This research is extended to engineering designers, surrounding a case study about stormwater infrastructure. This is meant to contribute toward the engineering design process with findings on the impact of embodiment on how a designer values nature. The next section delves into the background of embodiment's impact on the human-nature connection as well as modes of measuring the human-nature connection.

Background

Embodiment is a specialized form of perspective-taking in VR that spurs empathy toward the avatar. Through traditional perspective-taking in VR, the engineering design process has witnessed contributions from the public to encourage sustainability-focused infrastructure projects (Bartlett et al., 2005; Stauskis, 2014). For example, to encourage preference and feedback for smart cities, Jamei et al. (2017) uncovered how urban planners can take use of perspective-taking in virtual reality to facilitate the stakeholder engagement process and to collaborate with architects and engineers. Embodiment builds from traditional perspective-taking by adding a layer of empathy toward an avatar, which can lead to real-world altruism by having congruent experiences in VR that an avatar may face in nature (Batson et al., 1997; Gerry, 2017; Yee & Bailenson, 2006).

Embodied VR can boost altruistic behavior toward an avatar through two lenses (Batson et al., 1997): self and other. The self-lens displays the VR participant as a version of him or herself. For example, negative stereotyping of elderly individuals can be reduced by embodying young individuals as older avatars (Yee & Bailenson, 2006). The other-lens allows the participant to look through the eyes of another person or being. For example, altruistic behavior to curb beliefs on racism and patients with mental disorders were witnessed to increase from an embodied experience as a person of another race or with a mental disorder (Gehlbach et al., 2015; Żuromski et al., 2018).

Embodiment can spur proenvironmental behaviors and sense of imminence with nature, which could change how designers behave and ideate. Ahn and Bailenson (2012) discuss the imminence of embodiment, finding an increase in proenvironmental behaviors after cutting down trees in a virtual forest. In another example, embodying VR participants as an animal harmed by pollution increased concern for biospheric health, increasing the likelihood to promote action to reducing emissions (Schultz, 2000). Ahn et al. (2016) provide an additional example, finding a higher perception of imminence and risk within nature after participants embodied an animal. The other-lens through this research is an example of cognitive perspective taking by influencing the thoughts or beliefs of a VR participant (Healey & Grossman, 2018). This research intends to discover if embodiment impacts how a designer values nature and if it extends to nature-based design ideas between the self and other lenses of VR.

There is limited available research that compares the self and other lenses of VR, specifically toward the design process. Markowitz et al. (2018) reflects one instance of this research, but found no significant difference between the two groups in an experiment to measure climate change education after embodying a fish vs. embodying oneself. With such a lack of other research in this field, especially urged by Spangenberg et al. (2022), more research is needed to understand the impacts of an embodied vs. non-embodied VR scenarios. A breadth of research discusses the link between embodiment and the human-nature connection (Ahn & Bailenson, 2012; Ahn et al., 2016, p. 20; Gerry, 2017; Yin, 2019), but less known is how this impacts designers. To measure the impact of embodiment on human-nature connection for designers, both quantitative and qualitative instruments will be needed to track the impact on behavior during design.

Past research describes how to measure the human-nature connection through quantitative measures. These metrics constitute questionnaires and scales, such as the Emotional Affinity toward Nature (Kals et al., 1999), the New Ecological Paradigm (Stern et al., 1995), the

Connectedness to Nature scale (Mayer & Frantz, 2004), and the Ecological Identity conceptual framework (Walton & Jones, 2018). These questionnaires and scales are used to compare individuals' environmental beliefs, conceptions, and affinities to predict or understand various phenomena, such as the effect on pro-environmental behaviors, children's attitudes with nature, and overall well-being (Cervinka et al., 2012; Cheng & Monroe, 2012; Geng et al., 2015; Nisbet et al., 2011). While there are plenty of quantitative measures for the human-nature connection, other instruments may be useful to measure how a designer ideates. The end-goal of the HNCT – nature-based solutions (Parker & Simpson, 2020) – may present a metric of the human-nature connection within a design session.

Nature-based solutions are metrics within the built environment for measuring the human-nature connection that can revamp existing gray infrastructure (Randolph, 2003; van der Jagt et al., 2019; Van Oijstaeijen et al., 2020). An example of a large, urban green infrastructure project in action is the Cheonggyecheon Highway in Seoul, South Korea. Once a double-decker highway with over a dozen lanes and constant gridlock traffic, the highway was halved and replaced with a daylight stream – the Cheonggyecheon River (Kang & Cervero, 2009; Rao, 2011). Beyond redistribution of traffic, the green infrastructure project had notable societal co-benefits: reduction in urban heat island, improved water and air quality by incorporating nature, and large spikes in local property values as locals flocked to be near natural infrastructure (Kang & Cervero, 2009). By impacting the human-nature connection through nature-based solutions, nature flourished in the city and so did physical and socioeconomic conditions.

This research examines the impact that embodiment may have on the human-nature connection toward engineering designers. In an embodied VR experiment, Spangenberg et al. (2022) coupled both embodiment (VR group embodied a tree) and immersion (control group watched a video of a tree) as independent variables. The authors discovered small effects in the human-nature connection for both groups, with the control group having a slightly stronger increase in

connectedness to nature after the experiment, which countered the author's original hypothesis. This research expands Spangenberg et al.'s (2022) and Markowitz et al.'s (2018) works by incorporating separate lenses of VR: self and other, and uses the Connectedness to Nature Scale (Mayer and Frantz, 2004) as a proxy for the human-nature connection. Impacting the human-nature connection may change how designers incorporate elements of the natural environment, e. g., green infrastructure, in designs.

This research also evaluates the impact of embodiment on engineering design ideas, specifically surrounding nature-based solutions such as green infrastructure. Embodiment's impacts on pro-environmental behaviors (Ahn and Bailenson, 2012; Ahn et al., 2016) serve as theoretical frameworks for connecting engineering design ideas to pro-environmental behaviors after an embodied experience. Overall, the contribution of this research is toward engineering design and nature-based solutions; as designers think, see, and feel more a part of nature, this research explores how this can impact the ideas produced during design.

Research Questions and Hypotheses

The research questions focus on the impact of embodiment on human-nature connection and engineering design ideas. The first research question is *how does the embodiment of nature through virtual reality change human-nature connection?* The hypothesis was embodied VR participants should have a stronger human-nature connection from a pre-post analysis. As embodied VR can increase pro-environmental behaviors and the sense of imminence with the state of the natural environment (Ahn & Bailenson, 2012; Ahn et al., 2016), the human-nature connection may be influenced. Particularly, as stated in Tenets 1-3 of the Human-Nature Connection theory presented by Parker & Simpson (2020), the human-nature connection is impacted by the incorporation of nature into everyday life. The Connectedness to Nature Scale

(Mayer & Frantz, 2004) can be used as a metric to measure the connection to nature, which can be used before and after an embodied VR intervention (Nisbet et al., 2009).

The second research question was *how does embodiment of nature through virtual reality change green vs. gray design concepts?* The hypothesis was embodiment can change engineering design ideas to be more inclusive of nature-based solutions, such as green infrastructure. Since embodiment leads to proenvironmental behaviors, (Ahn & Bailenson, 2012; Ahn et al., 2016), these proenvironmental behaviors are hypothesized to connect to nature-based engineering design ideas. Scurati et al. (2021) discovered an increase in preference for environmentally sustainable designs after an embodied experience, which could lead to more utilization of nature-based solutions during an ideation session in comparison to gray design.

Methodology

The experiment was divided into three phases, illustrated in Figure 1. During Phase 1, engineering designer students read a case study about the Lick Run Greenway (included in the Appendix). Phase 2 consisted of the VR experience (for the VR groups). Phase 3 involved data collection for assessing the human-nature connection, presence, and a task for the designers to ideate solutions toward the stormwater problems presented in the case study.

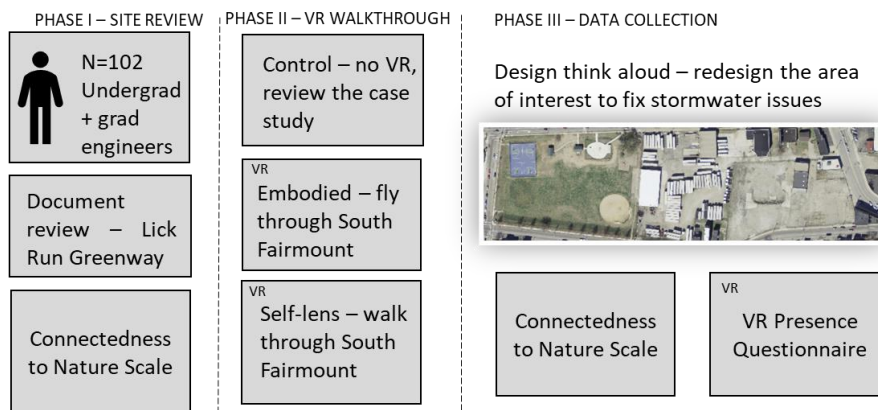


Figure 1 - Phased methods of the research in Chapter 2

Phase 1 - Pre-intervention and design experiment setup

To simulate the engineering design process, the experience that was created in VR was structured around the Lick Run Greenway case study (see Appendix) in the South Fairmount neighborhood of Cincinnati, Ohio. This river daylighting project takes place at the behest of an EPA consent decree (US EPA, 2004) which mandated the minimization of combined sewer overflow. Relevant information was given to the participants regarding the lead-up to project selection, including: surrounding geography, population dynamics, potential design options, costs, feasibility, timeframe, environmental impact, and social impact (Appendix).

Engineering design students (n=102) were recruited for this study and were prompted to read the case study and to complete a pre-intervention Connectedness to Nature Scale (Mayer & Frantz, 2004). The creators of the scale discuss the context of its creation as exploring social psychology based on, “self-other overlap, perspective taking, and altruistic behavior to the overlap between self and nature” (Mayer & Frantz, 2004), which meets the purpose of comparing the self and other lenses in this embodied experiment.

Participants were instructed to imagine their involvement with the case study as a designer and key stakeholder. The case study was summarized by the research team, the design experiment was explained, and participants were instructed that after review of the case study, they would be asked to provide design considerations for the area of interest discussed in the case study.

Phase 2 - Intervention

Engineering design students were randomly assigned to one of three groups. All groups were given the case study, which includes plan view drawings and descriptive figures of buildings existing in the South Fairmount area. The VR groups, human and bird (n=34 and 35, respectively) experienced a VR environment representative of the South Fairmount corridor.

Technical Equipment

To create the VR experience, a suite of pre-made VR assets were downloaded from the Unity Asset Store. These assets were used to create an assimilation of the infrastructure surrounding South Fairmount, live traffic, ambient sounds, public amenities, and avatars. Assets were edited and placed to mimic actual buildings in South Fairmount prior to the construction of the Lick Run Greenway. Figure 2 presents the VR rendering of South Fairmount.

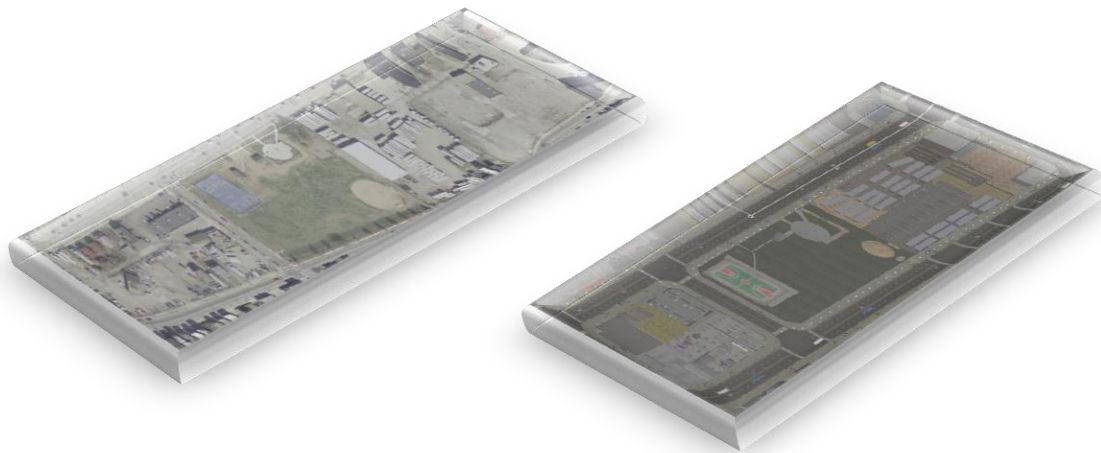


Figure 2 – Comparison of South Fairmount in 2011 (left) and the VR mockup of South Fairmount (right)

An HTC Vive with HTC Vive wand controllers was used for the VR experience. Sound output was provided through the HTC Vive over-ear headphones. The VR experience was simulated on an MSI GE76 Raider with NVIDIA GeForce graphics. The institutional wireless service provider, “eduroam”, provided sufficient speed to prevent lag within the experience. Experiments took place in a controlled laboratory environment, where the lighthouses (motion detectors) were placed at a sufficient distance to create an 8’x10’ play area.

The virtual walkthrough

Prior to the VR groups proceeding with the virtual environments in a controlled lab setting, a brief overview of VR was provided. During this overview, the basics of VR were discussed, such as what to expect during locomotion, the presence of teleportation, how to use the control sticks, and the possibility of lightheadedness (Bohil et al., 2011).

The VR experience was presented as a wayfinding exercise through the case study of the Lick Run Greenway. The virtual experience for both VR groups was gamified, which is the process or strategy of implementing game-like elements to a non-game application (Kim, 2014; Villagrasa et al., 2014). As discussed by Robson et al. (2015), a successful gamified experience is created through a blend of mechanics (structure and rules: participants were required to stay on course), emotions (a player's state of mind: participants embodied an avatar), and dynamics (how players can interact: participants either walked or flew). The gamified VR environment was presented as an interactive experience as suggested by Checa & Bustillo (2020). An interactive, gamified experience in virtual reality provides a participant with a structured objective which is seen to increase enjoyment and presence in the experience (Krause et al., 2015), while keeping interactivity free and mobility restricted to a defined course. Figure 3 provides an image of the VR environments traversed in both groups.

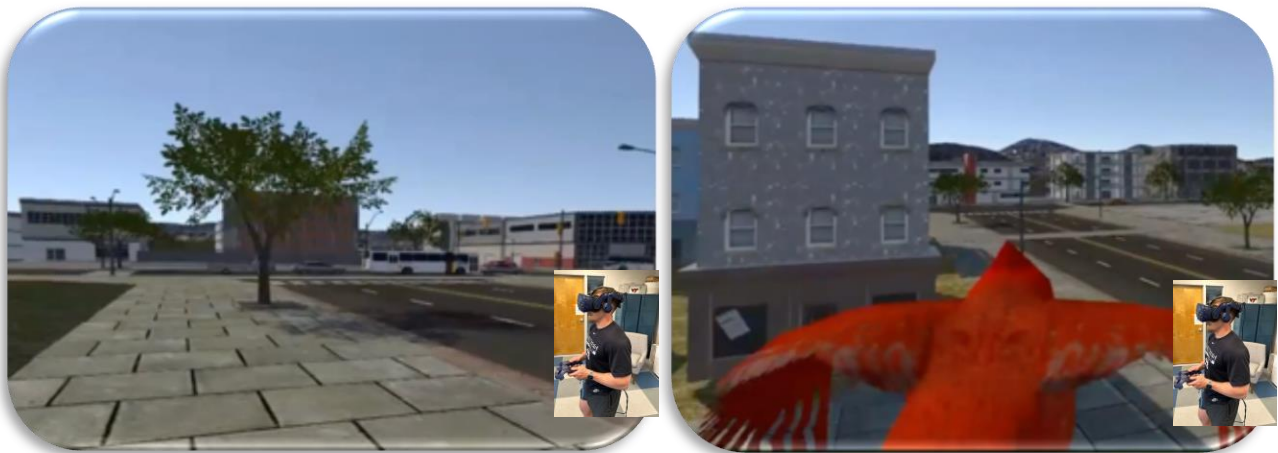


Figure 3 - Comparison of self-lens (left) and embodied (right) VR perspectives

Student designers were instructed to gather tokens that were conspicuously placed throughout the environment. These tokens plotted the course that designers were requested to follow for the experiment. To collect the tokens, designers moved in the virtual space directly on top of the token, reflecting in an increased score of 100 points for each token collected. The course plotted by the tokens created a form of control in the study by ensuring that designers were exposed to

the same aspects of the virtual environment and interacted with the same spaces of the environment.

Phase 3 - Post-intervention

Following the intervention, all student designers were instructed to ideate design solutions for the case study, to minimize the combined sewer overflows in South Fairmount. Verbal protocol analysis was utilized, which required the designers to think aloud as they designed (Atman & Bursic, 1998; Green, 1998). These design ideas were recorded and transcribed using nVivo, then read-through and corrected by hand to ensure accuracy. Following the ideation exercise, the designers retook the Connectedness to Nature Scale (Mayer & Frantz, 2004).

Presence was also measured between the groups. VR presence refers to the feeling of being physically in a virtual environment. It is the sensation that the virtual world being experienced is so convincing and immersive that the users brain and senses react as if they are actually there, even though they are physically located in a different place (Kober & Neuper, 2013).. The design students were instructed to fill in the Presence Questionnaire developed for VR by iGroup (2016). Measuring presence within VR is useful in understanding the persuasive effects of VR (Grigorovici, 2003). As Grigorovici (2003) discusses, as presence increases, a VR participant is less aware of the physical surrounding environment (e.g., a lab space), which can align participant behavior more with the virtual environment. The expectation was that both groups would feel equal levels of presence in the virtual environment whether experiencing the site as a human or bird avatar. A consistent level of presence helps ensure embodiment is the independent variable to measure how it affects designers' human-nature connection and design ideas.

No statistical difference was reported between the bird or human avatar groups based on a t-test (t-statistic = -0.4, p=0.70; means: 4.63, 4.61, respectively) based on the Presence Questionnaire developed by iGroup (2016).

Thematic Content Analysis

nVivo was used for the transcribing and coding of the transcripts. A priori codes were selected from existing literature to conduct a coding of themes (Smith, 2015). Since stormwater infrastructure has broad research pointing to gray versus green concepts as central themes (Bell et al., 2019), the first coding pass was taken to cluster their ideas into these themes and any emergent themes.

Codes used were “green”, “gray”, and “socioeconomic”. Examples of green-thinking design included ideas such as ponds, adding plants and trees, streams, and other riparian design ideas. An example quote of design ideas that were coded as “green” is:

“I’m going to add some trees in here along the roadway. Not as much for privacy as it is for healthiness of the community and even taking care of some of that excess water ... as many trees as possible, for sure. I like the idea of bushes too. Anything we can soak up some of that excess water or snow or anything else that’s going to accumulate on the ground ... maybe even get a creek going through”

Gray-thinking ideas included underground storage tanks, separating combined sewer infrastructure, and adding water treatment plants. An example quote of design ideas that were coded as “gray” is:

“To prevent the run off from the ground water getting into the water system and just the surrounding tributaries, I think we need to incorporate maybe some channels ... they could have like a drain, maybe in the middle that would lead to like something underground to store it for some sort of time”

An emergent code was identified when designers commonly mentioned ideas tailored to a revitalization of the South Fairmount neighborhood but did not explicitly link them to improving stormwater absorption. Instead, these ideas were focal to encouraging more socioeconomic activity in the area, such as incorporating mixed-use development, restaurants, walking and bike

trails, and remodeling buildings. These people-centric findings were given codes as “socioeconomic”. An example quote of “socioeconomic” design ideas is:

“My mind kind of goes to like a Central Park style type situation where you have a lot of green space ... maybe like some benches or something just to kind of enhance the space and encourage people to want to use it as is”

One-way ANOVA tests were used to measure the differences in recurrence of the codes between groups (embodied, self-lens, and control) and within groups (comparing green, gray, and socioeconomic within each group). A post-hoc Tukey test was used to find the difference between the three groups.

Both between-group measures and within group measures were compared because they report different outcomes. Between-group analysis measures if the VR embodiment had a significant impact on the number of ideas developed. The within-group measure focuses on the change in the types of ideas relative to the total number of ideas each student designer produced. In other words, the within-group measure helps us understand how the composition or quality of the generated ideas may have been influenced by the specific VR embodiment experienced by each participant. This allows for a more nuanced exploration of the potential impact of VR embodiment on engineering design.

Results

Connectedness to Nature

The embodiment of human or bird influenced engineering design students' perceived connectedness to nature. Students that embodied the bird avatar were significantly more likely to hold stronger connectedness to nature compared to the human avatar and control group based on one-way ANOVA tests on post-experiment scores ($F = 0.44$, $p < 0.0001$), with a small to

medium effect size (Cohen's $D = 0.46$). The effect score and effect size for each group is provided in Table 1.

Table 1: Connectedness to Nature Score Pre and Post Design Intervention

Group (n)	Pre-Score (STD)	Post-Score (STD)	% Difference (Pre-Post)	Cohen's D (group; post-score)
Control (33)	3.46 (0.37)	3.53 (0.31)	2.00%	0.46 (Bird); 0.19 (Human)
Human avatar (34)	3.53 (0.55)	3.62 (0.53)	2.52%	0.19 (Bird)
Bird avatar (35)	3.6 (0.45)	3.72 (0.47)	3.28%	-

Engineering Design Ideas

Between the three groups, the bird group included more socioeconomic ideas during their ideation process compared to the control through a one-way ANOVA test followed by a post-hoc Tukey HSD ($p < 0.01$, mean = 3.6). No statistical difference was observed between the self-lens and embodied bird group or the self-lens and control group ($p = 0.06$; $p = 0.76$). The results of the analysis for green, gray, and socioeconomic themes between and within groups can be seen in Figure 4.

Within groups, the embodied bird group significantly discussed green ($p < 0.01$, mean = 6.3 times) and socioeconomic ideas ($p < 0.01$, mean = 5.9) more often than gray ideas (mean = 3.4 times) based on a repeated measures ANOVA test with post-hoc Tukey HSD. There was no significant difference within the embodied human group in the number of green, socioeconomic, or gray ideas they discussed ($p = 0.07$; means: 5.3, 3.8, and 4.1) or control groups ($p = 0.14$; means: 4.8, 3.6, 3.6, respectively).

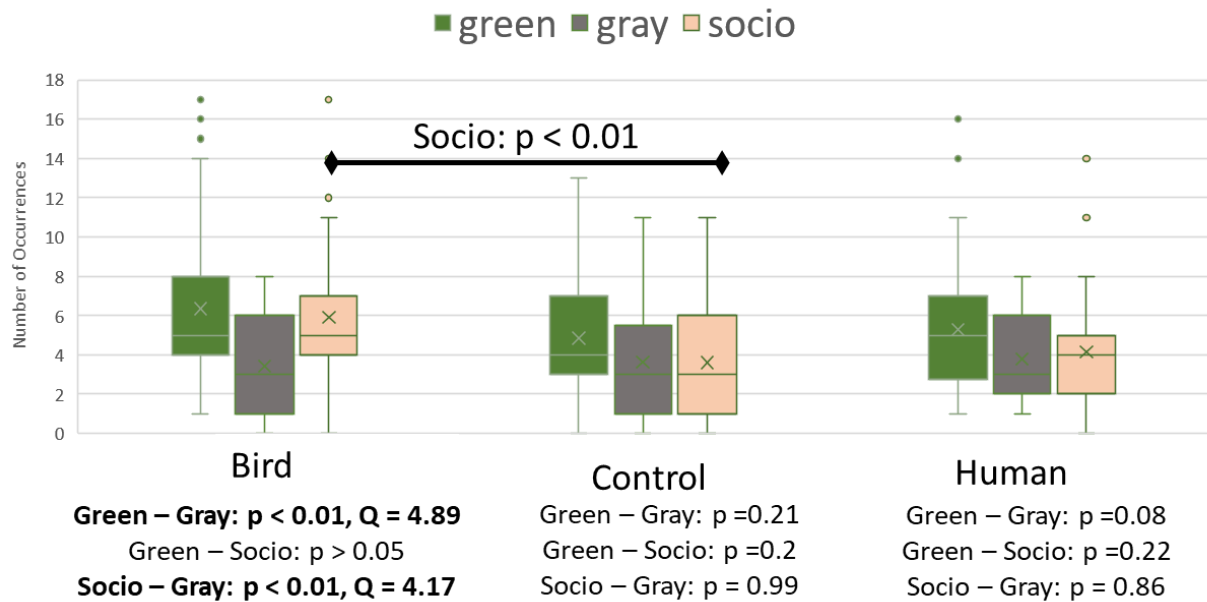


Figure 4 - comparison of green, gray, and socioeconomic codes during the first pass of thematic content analysis. Results are presented within each group as well as comparatively among the three groups.

Discussion

Taking the perspective of a bird, i.e., the embodied bird group, increases the human-nature connection more than the control group or embodied self-lens group. Embodiment is a form of perspective-taking, which can spur empathy toward a given subject, such as a bird avatar (Bertrand et al., 2018a; Gerry, 2017). This altered perspective may lead to increased empathy and a deeper connection to nature as it allows designers to appreciate the environment from a different angle and gain a better understanding of how the bird avatar interacts within the built environment. When a being of nature is placed in peril, such as by a bird flying around a heavily urban setting, cutting down trees in a virtual forest, or witnessing an animal suffer from climate-related impacts, proenvironmental behavior is spurred (Ahn & Bailenson, 2012; Ahn et al., 2016). Overall, proenvironmental behavior is spurred by this research and previous research by increasing environmental awareness through embodiment. Furthermore, this research builds from Markowitz et al.'s (2018) study by finding a difference between self-lens and bird

embodiment, which indicates that envisioning a perspective away from how one “sees” and “thinks” has a direct impact on behavior toward nature.

While a small effect size, embodiment of the other-lens increases the human-nature connection, which previous research did not find. Spangenberg et al. (2022) found no statistical difference in connectedness to nature based on the embodiment of a tree compared to other groups that received no VR intervention. The difference in findings between this research and Spangenberg et al. (2022) may be predicated by a difference in application. This research’s design experiment was placed around the engineering design process, encouraging participants to create design solutions that overcame existing infrastructure problems and to benefit the surrounding community. The embodied experience helps attain empathy through perspective-taking (Yee & Bailenson, 2006), which impacted the human-nature connection for designers by connecting socioeconomic and environmental benefits through green infrastructure (Randolph et al., 2003; van Oostaijen et al., 2020).

A second possible reason for the difference in human-nature connection between this research and Spangenberg et al. (2022) is for the mechanics and environment of the virtual space. Spangenberg et al. (2020) provided the embodied bird group with two separate virtual experiences of a tree: a sunny day vs. a forest fire disaster with limited interactivity, whereas this research presented the virtual environment as an uninterrupted gamified experience within an area of interest in a case study. By incorporating more interactivity and movement within virtual environment, presence can be increased (Krause et al., 2015). Presence is one’s subjective feeling of how the virtual world approximates the real world and is dependent of both how someone feels in the virtual space as well as how information is presented (Kober & Neuper, 2013; Grigovici, 2003). While there is some understanding of the stimuli that affect presence (Okeil, 2013), the mechanics of each VR application create new areas to expand scientific understanding of how individuals *feel* present within a virtual setting. Further research should

clarify which instances of VR mechanics and environments create more presence in the virtual setting, which could impact the participant's behavior such as in comparison to the human-nature connection.

The embodied self-lens group also had an impact on the human-nature connection when compared to the control group. The self-lens is also a form of embodiment, which could explain the increase in human-nature connection as a proenvironmental behavior from a standpoint of environmental stewardship (Gerry, 2017). Furthermore, as a stakeholder engagement tool, VR increases desirability of sustainable designs (Bartlett et al., 2005; Stauskis, 2014), which may have increased awareness of the issues of CSO in the case study and led to more appreciation of nature as witnessed in the human-nature connection outcomes.

Embodying a bird increased green and socioeconomic ideas relative to the total number of ideas each designer produced. Nature-based solutions through elements of green infrastructure is one example of biophilic design (Kellert, 2018; Parker & Simpson, 2020), which commonly includes co-benefits (Bell et al., 2019). The inclusion of socioeconomic ideas as an emergent code relates to literature about green infrastructure surrounding the co-benefits to society that green infrastructure provides (Casal-Campos et al., 2015). The literature about green infrastructure commonly calls upon the co-benefits of green infrastructure, such as improvements in air and water quality (Van Oistaijien et al., 2020; Randolph, 2003) which were mentioned in the design ideation sessions. Socioeconomic ideas were also discussed within the real-life case study of South Fairmount when design charrette participants urged decision-makers to spur more growth of restaurants, bars, walking trails, and mixed-use development (Project Groundwork, 2020).

Despite the increase in human-nature connection for both VR groups, the inclusion of nature-based solutions was mostly witnessed in the embodied bird group. Previous literature measures the impact of the other-lens on proenvironmental behaviors (Ahn & Bailenson, 2012; Ahn et al., 2016; Whitburn et al., 2020), but forego the use of the embodied self-lens. Markowitz et al. (2018)

found similar inconclusive results when comparing the self-lens and other-lens toward climate change education by embodying oneself vs. a fish in a sea impacted by climate change. More research is needed to compare the differences in design ideas between the self-lens and other-lens beyond initial thematic coding of “green”, “gray”, and “socioeconomic” to further investigate any plausible differences between the embodied lenses.

The embodied self-lens group did not include a significant increase in nature-based solutions. Based on the Human Nature Connection Theory (Parker & Simpson, 2020), as human-nature connection increases, so should instances of nature-based solutions (such as the case with the embodied bird group). Potentially, this could have been due to the increased influence of socioeconomic ideas during the ideation sessions. Typically, the perspective that is taken in VR leads to altruism toward that perspective (Batson et al., 1997). While socioeconomic ideas were not seen to have a significant increase in the embodied self-lens group, this presents an opportunity for future research to investigate other ways that the self-lens perspective impacts engineering design, such as a deeper dive into the design ideas themselves.

A limitation of this research is the use of engineering design students rather than active professionals. If professionals had been selected for the research sample, the design sessions could have entailed solutions that were more feasible or richer. However, students were selected for this research sample because students will be making real world engineering design decisions within the next year. Furthermore, given the relative nascency of embodied virtual reality within land development and civil engineering, VR may be a useful tool for these students to use in their professional careers. Within this research, a virtual environment was developed by a non-expert in virtual design, which impacted design concepts and the human-nature connection. The steps taken to develop a virtual world to aid the design process can be replicated by future designers, which might impact design concepts.

A further limitation of this research is the comparison of presence in multiple avatars. This limitation may have impacted the type of avatar that should be chosen to warrant a greater impact toward the collected results of human-nature connection and design concepts. A gap in knowledge exists in literature of embodied VR, specifically surrounding the comparison of multiple avatars (Spangenberg et al., 2022; Markowitz et al., 2018). While presence did not impact the human-nature connection (weak correlation: Pearson's $r < 0.2$ for both VR groups), future research should continue to compare different avatars and use presence as a construct to account for confounding variables, more specifically, the feeling of "being there". With a limited amount of comparable literature, this research chose an embodied other avatar of a bird since the mechanics of movement could be replicated from pre-existing assets and scripts.

Future studies based on this research should identify the efficacy of embodied VR on the quality of designs. While this research uncovered embodied VR's ability to impact both human-nature connection and the change in design ideas, less is known about the overall quality of the designs. For example, a potential research question for this research could be: does embodiment impact the sustainability of a design or the amount of sustainable features? Scurati et al. (2021) point to an increase in preference for environmentally sustainable design choices, but do not consider more granular design elements. Motivating sustainable design ideas is driven by context, such as in the case of sustainable design ideas within smart cities (Jamei et al., 2017). A deeper analysis of design ideas from an embodied VR experiment on the overall sustainability of design choices would link to Scurati et al.'s (2021) work and could encourage more sustainable design ideas.

Conclusion

Embodied VR impacts the human-nature connection. This finding could support nature-based solutions within design in future research, given the correlation between nature relatedness and proenvironmental behaviors (Ahn & Bailenson, 2016). More specifically, this may help with the ideation process, further exploring the mixed results in presence that this research discovered.

A dearth of literature exists on the effect of embodying oneself vs. another being, specifically with how the engineering design process is involved (Hu et al., 2021; Yin, 2019). This research presented a channel for the invocation of empathy within design thinking as a subunit of the engineering design process. Embodied VR met this channel of empathy through perspective-taking through two different perspectives: self and other. Further research in this field is plentiful, but should start with extending the impact of the human-nature connection to design elements.

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CHAPTER 3: THE IMPACT OF VIRTUAL EMBODIMENT TOWARD NATURE-BASED DESIGN IDEAS

Abstract

Engineering design thinking encourages designers to take the perspective of the end-user as a form of empathy, which can impact ideation. The increasing development of virtual reality (VR) technology over the last decade now enables more realistic immersive experiences, including the ability to embody another being. This form of perspective in the virtual world, may help influence design the real-world. To measure the effect of embodied VR experience on engineering design, engineering undergraduate students (n=102), received either an embodied VR experience (as a bird), a more standard “self-lens” embodied VR experience, or no VR. These design students were asked to develop a solution to a real-world case study about combined sewer overflows in Cincinnati, Ohio. The results found that designer students given the embodied VR experience were more likely to develop more detailed and richer solutions for the case study. The group of design students who received the bird VR embodiment were more likely to include design elements that included green infrastructure, often also shifting between justifying these green design elements for nature and the various socioeconomic co-benefits. Embodied VR had an effect on design thinking, specifically by more inclusion of nature-based components within land-based design when designers embodied a natural being, such as a bird.

Introduction

Design thinking maximizes engineering ideation to benefit the end-user. Design thinking follows four broad central tenets, that the design thinking process must be (Plattner et al., 2010): social in nature, ambiguous, incorporate redesign, and tangible. Due to its wide applicability, large corporations addressing different markets have taken advantage of design thinking (Liedtka, 2014): Toyota synergized sales team representatives to re-think call-center operations, SAP

implemented the process within the unveiling of their Web 2.0, and Intuit has merged design thinking into company culture by empowering engineers to think with experimentation to maximize customer satisfaction. While these Fortune 500 companies diverge in mission and vision, design thinking was employed to provide similar benefits: maximizing the ideation phase of design to provide the end-user with an enhanced product (Schmiedgen et al., 2016).

The engineering design process could be improved by more uptake of design thinking for most civil and environmental projects by focusing on empathy (Kouprie & Visser, 2009). McDonagh (2010) places the burden of stimulating empathy for the end-user on the designer, stating that the design-thinking process must *start* with empathy. Previous research in behavioral psychology illustrate that characterizing empathy is impacted by several factors, such as by thinking about how one feels (cognitive empathy) vs. feeling as one feels (affective empathy) (Cuff et al., 2016; Healey & Grossman, 2018). Perspective-taking is a proxy to achieve cognitive empathy, which spurs the engineer or designer to put his or herself “in the shoes” of the end-user (Köppen & Meinel, 2015). More literally, perspective-taking creates a construct in the design process through which the designer must ideate for the purposeful benefit of the end-user.

Perspective-taking can change how individuals behave or choose, which may impact the design process through virtual reality (Algra & Johnston, 2015). This act is the necessary building block to induce empathy between the designer and user by actively engaging with the design problem (Batson et al., 1997). As perspective taking becomes more affective, one is more likely to act in an altruistic behavior toward another party by building empathy (Oswald, 1996). In other words, choice can be altered by the form of perspective that is considered (Schultz, 2000), which could have implications for designers and the ideas that are produced as they take new perspectives. Virtual reality (VR) is a technology that enables perspective-taking at the first and third-person point-of-view (Okeil, 2017).

VR enables designers and end-users to interact with the design at-scale and is increasingly utilized in the engineering design process (Davila Delgado et al., 2020). VR provides a design and stakeholder engagement tool for architects, engineers, contractors, and the public to visually see designs before they are built as well as to recommend improvements that are driven by and end-user (Coroado, 2015; Ma et al., 2020; Makarova et al., 2015). Furthermore, VR also allows for the uptake of a different perspective beyond oneself, such as through an avatar, which is known as embodiment (Dewez et al., 2021).

Embodiment is a form of perspective-taking within VR that can stimulate a designer to take the perspective of any end-user or other stakeholder. Embodied experiences in VR allow vicarious interaction as another person or being, such as an end-user or other stakeholder within a design project (Kilteni et al., 2012). Through embodiment, a human or nonhuman avatar can produce feelings of empathy by considering various social perspectives that are presented in the virtual world that an avatar faces (Bertrand et al., 2018; Gerry, 2017; Kors et al., 2020). Avatars can be created through virtual reality software and provide users with the ability to see through a different set of eyes.

Embodied VR can boost altruistic behavior toward a given subject through two lenses: self and other (Gorisse et al., 2017; Loon et al., 2018). The self-lens (SL) displays the VR user as a version of him or herself. For example, negative stereotyping of elderly individuals can be reduced by embodying young individuals as older avatars of themselves (Yee & Bailenson, 2006). The other-lens (OL) allows a user to look through the eyes of another person or being. For example, altruistic behavior increased toward racism and mental disorders from an embodied experience as a person of another race or with a mental disorder (Banakou et al., 2016; Gehlbach et al., 2015; Żuromski et al., 2018). Similarly, the engineering design process stands as a potential opportunity to map empathic connections from embodied experiences to improve design.

The other-lens of embodiment can impact altruistic behavior toward the environment, which may impact the engineering design process. For example, embodying VR participants as an animal harmed by pollution increased concern for biospheric health, increasing the likelihood to promote action to reduce emissions (Schultz, 2000). As Ahn & Bailenson (2012) find through post-experiment surveys, pro-environmental behaviors can be altruistically curbed by performing harmful acts on a forest in VR. In other words, embodied users are more likely to act benevolently toward the environment after experiencing a scenario that places nature in peril. While it has been discovered that embodiment impacts the human-nature connection (Trump and Shealy, forthcoming, Chapter 2) and that proenvironmental behaviors can be spurred by embodiment (Whitburn et al., 2020), scant research extends this to design ideas.

Fundamentally, this research intends to discover if the hypothesized increase in human-nature connection within the engineering design process by Trump and Shealy (forthcoming, Chapter 2) extends to *design ideas*. Based on previous research surrounding embodiment, a small body of work exists around types of proenvironmental behaviors that embodiment can shift, even including design preferences as a measurement (Scurati et al., 2021). While beliefs, preferences, and behaviors toward nature have changed as a result of embodiment (Trump and Shealy, forthcoming, Chapter 2; Ahn & Bailenson 2012; Scurati et al., 2021), objective, measurable choices in designing with nature presents a gap in knowledge from existing literature. This research intends to connect design ideas as a metric for measuring the embodiment of nature's impact on the engineering design process, specifically surrounding the presence of nature-based solutions within design.

Background

Natural systems are often overlooked in design despite the benefits of nature-based solutions. Past theories emphasize the imperative to build with nature for human prosperity (Besthorn &

Saleebey, 2003; Grinde & Patil, 2009), which is reflected by several co-benefits not limited to: staggering returns-on-investment, improved air and water quality, and better health outcomes (Bertram & Rehdanz, 2015). However, engineers commonly design without leveraging the use of nature when developing urban settings, contributing to sprawl and increased carbon footprint (Randolph, 2003; Rosenbloom, 2018). Moreover, the general public tends to overlook the value of nature and sustainable infrastructure systems, opting for urban cityscape scenes based on familiarity and convenience (Wamsler et al., 2020). Nature-based design and urbanism are not necessarily disparate ideas; Scurati et al., (2021) argue that better communication platforms through VR, that enact nature-based design, may bridge this gap through more environmentally sustainable designs.

Nature-based design creates a connection to nature by incorporating nature-based solutions within the built environment. As residents report more desire for public green space due to its effect on well-being, decision-makers may be tasked with constructing projects that include this asset (Bertram & Rehdanz, 2015). For example, implementing more street trees within urban design can increase the human-nature connection as an example of a proenvironmental behavior (Church, 2018; Klaniiecki et al., 2018). These instances of nature-based design within infrastructure have been federally mandated in some engineering spaces, such as within stormwater infrastructure by requiring percentages of the design solution to be inclusive of green infrastructure (EPA, 2011). As Parker and Simpson (2020) discuss, biophilic design through nature-based solutions is one aspect of the human-nature connection, which was measured by Trump and Shealy (forthcoming, Chapter 2) in the engineering design process.

Human nature connection

The Human-Nature Connection Theory (HNCT) posits the fundamentals of biophilic design into the built environment. The HNCT was developed as a theoretical framework by Parker & Simpson (2020), and can be summarized by six main principles:

1. Incorporating nature into the design of buildings, homes, and public spaces
2. Integrate elements of nature into everyday life, work places, and institutional settings
3. Provide opportunities for connecting with nature through urban green infrastructure
4. Restore and revegetate degraded land and environmental assets
5. Reclaim barren land and repurpose it for recreation and biodiversity
6. Advocate for opportunities of accessibility and diverse nature experiences through urban green infrastructure, nature trails, green roofs, and other instances of green building

Measuring the impact of the human-nature connection within the built environment may require an assessment of design practices. While surveys present a benchmarkable form of data analysis (Brenner & DeLamater, 2016), they can lack the context behind the decisions made within the survey (Braun et al., 2021). Specifically within design, this context of a design decision can be crucial to understanding the function, behavior, and structure of design elements (Galle, 2009; Gero, 2009). A more subjective analysis is needed to measure design ideation, especially when measuring the human-nature connection (Spangenberg et al., 2022). A stronger human-nature connection typically leads to more pro-environmental behaviors in day-to-day life and preferences within the built environment (Kellert, 2018; Kellert et al., 2011; Whitburn et al., 2020), but a gap in knowledge exists around how the human-nature connection impacts design ideas.

Nature-based solutions may be an indicator of how the human-nature connection impacts the design process (Parker & Simpson, 2020). HNCT is rooted in the Biophilic Hypothesis (that humans must live within natural systems; Kellert, 1995), providing decades of theory into the following blended thesis: humans are impacted by nature as witnessed through the human-nature connection, which affects patterns and preferences with the built environment, such as through the use of gray (manmade) vs. green (nature-based) infrastructure.

Gray and green infrastructure

Gray infrastructure projects refer to solutions that primarily rely on concrete and steel to move or hold stormwater (Casal-Campos et al., 2015). These measures have been used for much of the 20th century and the vast majority of American infrastructure is comprised of these elements (Bell et al., 2019; Cettner, 2012; Science, 2015). Gray-thinking throughout the past century has led to

notable issues in infrastructure resilience and public health due to system rigidity against cascading, evolving disruptions to infrastructure design (Gaffield et al., 2003; Rosenbloom, 2018). Forward-thinking infrastructure can improvise and adapt to unforeseen disruptions, such as with green infrastructure (Staddon et al., 2018).

Green infrastructure projects use elements of nature to create stormwater solutions such as rain gardens, bioswales, porous pavements, green roofs, and stream daylighting to convey and infiltrate stormwater (Berland et al., 2017; Jayasooriya & Ng, 2014). These solutions have been tested to build urban resilience; green infrastructure posits a *natural* ability for communities to prepare for, absorb, recover from, and adapt to climate and weather-based threats (Van Oijstaeijen et al., 2020). As such, green infrastructure is commonly used in the new urbanist planning approach, which makes land use more intensive and is designed to minimize sprawl (Randolph, 2003).

Using embodied VR to impact gray vs. green thinking for stormwater infrastructure

Virtual reality has been used in prior studies to impact preference for infrastructure. Through VR as a tool to boost the interactivity of stakeholder engagement, the engineering design process has witnessed more fruitful contributions from the public toward sustainability-focused infrastructure projects (Bartlett et al., 2005; Stauskis, 2014). For example, to encourage preference and feedback for smart cities, Jamei et al. (2017) uncovered how urban planners can take use of virtual reality to facilitate the stakeholder engagement process and to collaborate with architects and engineers. In turn, as public opinion and awareness toward the technology have increased, using VR as an embodiment platform increases preference for more environmentally-conscious designs (Scurati et al., 2021). Does this finding of impacting preference levy toward ideation as well, such that designers may include more nature-based attributes in conceptual designs?

This research examined the impact that embodiment has toward design thinking and nature-based solutions. VR acts as a communication platform for all members in the engineering design process and embodiment nudges the participant to think, see, and hear in the mindset of another being. This research aims to build upon Trump and Shealy (forthcoming, Chapter 2) by further evaluating the authors' inclusion of "design concepts" to a more granular assessment of design ideas. The relationships and generalizations built from this research will identify how virtual embodiment changes ideation for nature-based solutions within the built environment. As embodied VR can impact infrastructural preference, this research discovered if design ideas are also impacted by embodiment.

Research Question and Hypothesis

The research question is: *how does virtual embodiment change engineering design ideation for nature-based design ideas?*

The hypothesis is designers who have an embodied VR experience will include more elements of nature during the design ideation process. Past experiments with embodiment in VR have proven the feeling of imminence with the natural environment, which can be used to spur involvement with environmental issues (Ahn & Bailenson, 2012; Ahn et al., 2016). This hypothesis extends the feeling of oneness in nature to engineering design thinking by impacting how embodied participants ideate toward greener solutions and to place more value in environmental impact.

Methodology

The experiment was setup in three phases illustrated in Figure 5. During Phase 1, participants read a case study about the Lick Run Greenway (Appendix). Phase 2 consisted of the VR experience. Phase 3 involved verbal protocol analysis as participants ideated design solutions to

rectify the issues discussed in the case study. Following the protocol analysis, transcripts were developed and hand-corrected in nVivo and thematic content analysis was employed to code the transcripts.

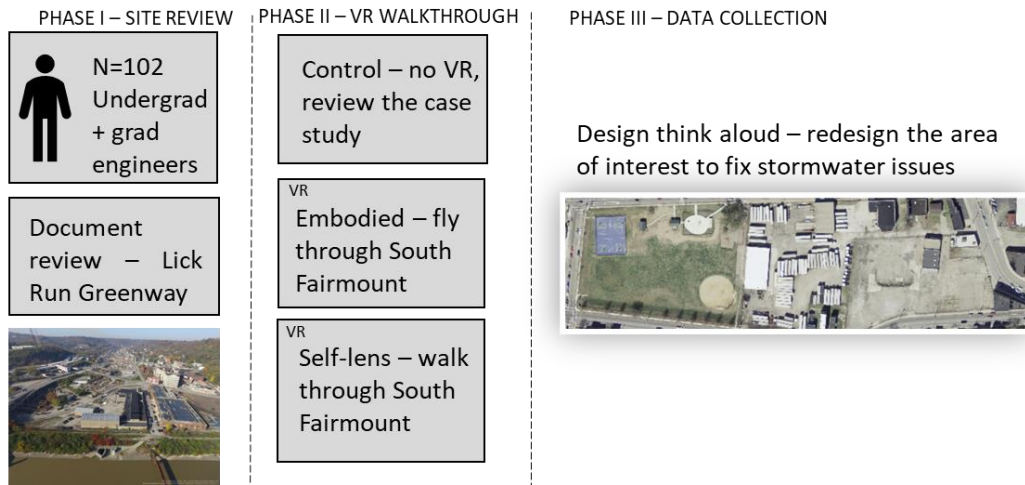


Figure 5 - Phased methods of this research

Phase 1 - Pre-intervention and design experiment setup

To simulate the engineering design process, the experience that was created in VR was structured around the Lick Run Greenway case study (see Appendix) in Cincinnati, Ohio (Project Groundwork, 2012, 2020). This river daylighting project takes place at the behest of an EPA consent decree (US EPA, 2004) which mandated the minimization of over 200 million gallons combined sewer overflow (CSO) in the neighborhood per year. Relevant information was given to the participants regarding the lead-up to project selection, including: surrounding geography, population dynamics, economic conditions, results from stakeholder focus groups, potential design options, costs, feasibility, timeframe, environmental impact, and social impact (Appendix). Participants were instructed to imagine their involvement with the case study as a designer. The case study was summarized by the research team, the design experiment was explained, and participants were instructed that after review of the case study, they will be asked to provide design considerations for the area of interest discussed in the case study.

Phase 2 - Intervention

Following the case study participants were randomly split into three groups. The control group (n=33) was given the case study information, which included plan view drawings and descriptive figures of buildings existing in the South Fairmount area (also given to all groups). The control group was instructed to analyze all of the case study documents including the plan review to provide design ideas in Phase 3.

The self-lens group and bird group (n=34 and 35, respectively) experienced a VR environment representative of an urban stormwater system as a human or as a bird. This environment replicated the South Fairmount corridor. Participants either walked or flew through the representation of South Fairmount in VR and were then instructed to provide design ideas based on the case study in Phase 3.

Technical Equipment

An HTC Vive with HTC Vive wand controllers were used for the VR groups. Sound output was provided through the HTC Vive over-ear headphones. The VR experience was simulated on an MSI GE76 Raider with NVIDIA GeForce graphics. The institutional wireless service provider, “eduroam”, provided sufficient speed to prevent lag within the experience. The VR experience took place in a controlled laboratory environment, where the lighthouses (motion detectors) were placed at a sufficient distance to create an 8’x10’ play area.

To create the VR experience, a suite of pre-made VR assets were downloaded from the Unity Asset Store. These assets were used to create an assimilation of the infrastructure surrounding South Fairmount, live automobile traffic, ambient sounds, public amenities, and avatars. Assets were edited and placed based on pictures and Google Earth images of South Fairmount prior to the construction of the Lick Run Greenway.

The virtual walkthrough

Prior to the VR groups proceeding with the virtual environments, they were given VR instructions. They learned the basics of VR, such as expectations during locomotion, the presence of teleportation, how to use the control sticks, and the possibility of lightheadedness due to vertigo. The VR experience was presented as a wayfinding exercise through a portion of the South Fairmount neighborhood. The VR experience was also gamified. Gamification is the process of implementing game-like elements to a non-game setting, such as a design walkthrough (Kim, 2014; Villagrasa et al., 2014). Participants were instructed to gather tokens that were conspicuously placed throughout the environment. These tokens plotted the course that participants were requested to take for the experiment. To collect the tokens, participants moved in the virtual space directly on top of the token, reflecting an increased score of 100 points for each token collected. The course plotted by the tokens created a form of control in the design study by ensuring that participants are exposed to the same aspects of the virtual environment and interacted in the VR environment similarly. The comparison of embodied vs. self-lens environments can be seen in Figure 6.



Figure 6 - A comparison of the self-lens (left) and the embodied lens (right) for the VR wayfinding exercise of an area of interest within South Fairmount.

Phase 3 - Post-intervention

Following the VR experience for the intervention groups, and only reviewing the written documents for participants in the control group, all participants were instructed to ideate solutions that eliminated CSO that residents of South Fairmount would prefer based on the case study. Participants were given a blank template of the neighborhood, illustrating existing surface conditions and were asked to revamp this area as an area of interest for new stormwater projects. Participants were instructed to think aloud as part of verbal protocol analysis (Atman & Bursic, 1998; Green, 1998); this audio was recorded, transcribed, and coded for design ideas.

Thematic Content Analysis

An nVivo license was used for the transcribing and coding of the transcripts, which were corrected by hand. A three-step qualitative coding process for thematic content analysis was employed for the transcriptions (Cantelmi et al., 2021; Creswell & Poth, 2018; Smith, 2015). Since stormwater infrastructure has broad research pointing to gray versus green concepts as central themes, design concepts were grouped by green, gray, and socioeconomic ideas. The second round of coding further broke down these themes into sub-themes, e.g., green >> planting trees to absorb stormwater, and the final round of coding built contextual patterns of each ideation session to determine relationships among design ideas across participant groups. To ensure uniformity, coding was performed by a research associate and 10% of the coded transcripts was compared by the author's established codes.

The second coding pass identified full design ideas within each participant's design session. The design ideas identified functions of the concepts generated, taking the initial parent-code (socioeconomic, green, or gray) and adding the base function. For example, if the first-pass highlighted a blurb within the transcript as "green", the second-pass would break this down further based on the function of the design idea, such as: "planting trees to absorb stormwater". Common

design ideas were lumped together in this phase and connected to the parent code, seen in Table 2, below. The full set of design ideas can be seen Appendix.

Table 2 - Overview of the design ideas based on green, gray, and socioeconomic parent codes through thematic content analysis.

Parent Code	Lumped Design Idea
gray-thinking ideas	Adding concrete or cement surfaces for flow of stormwater into inlets/outlets
	Adding surface parking for stormwater to flow into inlets/outlets
	Adding treatment plants or underground tanks for stormwater storage, underground storage
	Construction of buildings and commercial spaces that include underground storage of stormwater
	Drainage and sewers – upgrades and increased size to convey stormwater
	Filtration system – cleaning stormwater before it is emitted into a water body
	Impervious surfaces – artificial fields to capture or transport stormwater
	Management or organization of controls in underground system, tanks, and pipes
	Roadwork, roadways, traffic, tunnels, bridges – considerations of stormwater conveyance surrounding other infrastructure
green-thinking ideas	Adding bike paths or walkways that are permeable for stormwater infiltration
	Adding or maintaining parks or recreational spaces to increase soil permeability
	Adding or modifying green roofs or rooftop detention
	Adding permeable pavers or permeable surfaces for better soil absorption
	Adding trees, greenery, shrubbery, or a garden for stormwater absorption
	Environmentally conscious thinking – overall concern with nature and a proclivity to design with nature-based elements
	Green infrastructure or maintaining green spaces based on aesthetics and function for stormwater
	Green technology, LEED certified buildings
	Product or source control – modifying tributary systems to collect stormwater within South Fairmount
	Stormwater collection material - repurposed, renewable, recyclable resources to prevent stormwater contamination
	Bioswales or grade modifications - taking land's natural layout, landscaping, and natural resources into account for better stormwater conveyance and infiltration
Water collection into a body of water, retention pond, or sustainable water intake	
socio-economic improvement ideas	Adding or maintaining parks or recreational spaces for public enjoyment
	Adding parking spaces or areas for increased access to South Fairmount
	Community consideration with housing, water availability, and construction
	Creation of commercial space, job opportunities, bringing socio-economic or money to the area
	Improving or maintaining water, air quality, smell, and noise
	Modernizing or revitalizing the buildings, houses, landscape, or town
	Reduce traffic – lane removal or rerouting highway systems
	Relocation of individuals in the community
Economic growth considerations for increasing livelihood metrics within South Fairmount	

	Taking neighborhood demographics, crime rates, loitering, safety, and other community factors into consideration
	Reduce urban heat island effect

The final coding pass was utilized to ground results into generalizable theory, which is presented in the Results section. Strauss and Corbin (1994) represent a method for transferring actual data into concepts, which can then be generalized. Through this theory, this research employed the axial coding technique to group codes based on green, gray, or emergent forms of thinking. Ultimately, the final pass of coding for this research intended to discover generalizable differences between groups (control, human, and bird) to understand how embodied VR changes design ideas based on inclusion of nature-based solutions.

To develop generalizable findings, the outcomes of design ideas from the second-pass were used. The design ideas for each participant were compared within group to identify commonalities and between groups to discover differences based on embodiment. For example, the control group was compared to both VR groups to discover differences in design ideas and the bird group was compared to the self-lens group to uncover differences based on perspective-taking. While the statistics presented from the first-pass were helpful to direct initial discoveries, these statistics did not capture the full depth and context of the design ideas that were mentioned in the transcript data. Thus, this final pass made generalizations across common occurrences based on embodiment and was grounded in the qualitative analyses from each participant’s design transcript.

Results

Themes were developed based on both quantitative and qualitative evidence. From a quantitative perspective, the metrics presented in Table 3 were used to guide the number of occurrences necessary to deem a common finding as a theme as an additional two standard deviations from the average. Based on the highest average number of design idea occurrences and highest

standard deviation presented in Table 3 (bird group, green ideas), a 95% confidence interval was constructed with the upper bound of 7 occurrences.

Table 3 - Average number of design ideas and standard deviations for each group

	Green (average; std. dev.)	Gray (average; std. dev.)	Socioeconomic (average; std. dev.)
Bird	6.34; 4.13	3.43; 2.45	5.91; 3.77
Self-lens	5.29; 3.70	3.79; 2.58	4.15; 3.43
Control	4.85; 2.93	3.64, 1.94	3.61; 2.81

While a quantitative evaluation aided in an initial identification of possible themes, qualitative review provided richer context to aggregate the most apparent themes. Themes were developed among groups to identify the impact that virtual embodiment has on the incorporation of nature-based solutions during design. These themes are presented below in bold, with supporting evidence from session excerpts following. The session excerpts that are selected serve as representative samples that adequately exemplify the theme and are treated as just one occurrence.

Theme 1 – The control group gravitated toward gray design decisions

The control group mentioned the desire to design with nature-based solutions, but still tended to implement elements of gray stormwater infrastructure as an anchor for minimizing CSO.

Participant 5 (C5) began the design session, stating:

“I have one of two options - I can go underground, but I can go above ground. Above ground would would help, but not as much. So I'm thinking above ground ... there's different elements that I could approach. I have nature, but what can I do with nature? ... I think I would just add more pipes, I don't I don't know what other approach I could take”.

C5 went on to ideate onsite treatment plants to reroute stormwater based on switch systems. This participant supported an additive approach for gray-thinking ideas; a limitation was identified early

based on a perceived mental barrier with green ideas, but gray-thinking ideas – adding extra storage through pipes and additional treatment plants – began picking up inertia throughout the ideation session. C64 reflected a similar transition from green to gray, preferring the gray alternatives as a recommended approach to minimize CSO:

“Outflow is a big issue in this town, so I think an upgrade would be needed ... part of me wants to ... put a park right here. I'm not so sure entirely yet, but I think a park here generally would be fine just as a buffer zone ... now I'm looking at this area again. Scratch the park here, make that commercial ... I think the best thing was is I think it would be better if we can try to find a way to separate water and sewage in places ... have all the sewage again, find its way back to the water treatment plant”.

In the above example, C64 highlighted a socioeconomic and potentially green idea through a park, but had notable difficulty in ideating the solution with numerous pauses, sidebars, and ultimately a scrap of the idea. However, once C64 navigated the ideation session back to gray-thinking ideas, the flow of the design session was more linear: separating stormwater and sewage lines underground to alleviate stress at the treatment plant, and this idea seemed straightforward.

Participants in the control group also discussed the socioeconomic benefits they expected from a green idea, but were unable to provide characteristics of the green idea itself, reverting back to gray solutions. C76 provided one instance of this, mentioning the early desire for a nature-based solution through the essence of a park and the vast socioeconomic benefits it would bring. However, this participant deflected from the park's creation for CSO minimization, ideating storage tanks instead:

“Well, I definitely think that I want to do some sort of natural solution first ... I definitely want to incorporate a park in here with a lot of greenery ... And I feel like this would also create a spot in the community for people to gather ... To prevent the run off from the

ground water getting into the water system and just the surrounding tributaries, I think we need to incorporate maybe some channels ... they could have like a drain, maybe in the middle that would lead to like something underground to store it for some sort of time”.

The above excerpts presented a common theme among the control group to focus on a green idea initially, but eventually build up a gray idea as the driving solution for CSO minimization. Kickoff green ideas mostly included one or both of a park (17 participants) and a pond (11 participants), whereas some combination of expansion or separation of underground stormwater sewers occurred in 21 out of ideation sessions. Expansion or additional wastewater treatment plants were also mentioned and were typically the final source for consideration of stormwater treatment and distribution (7 participants). Trees, bushes, and shrubs were considered often (12 participants), but commonly lacked clarity on their intended purpose.

Theme 2 – The bird group fused socioeconomic benefits to nature-based ideas

The embodied (bird) group tended to melded socioeconomic benefits into green ideas, attempting to alleviate environmental constraints from CSO alongside co-benefits for the local neighborhood. Participant 59 (B59) wrapped a host of socioeconomic benefits around a central park and pond:

“What I would like to do is keep a park in the area but move it to the center of the block so that it's more of a centralized location and not kind of just on the edge that no one uses. And then the first thing about the park is I want it to have trees ... having the trees I'm assuming will make for ... infiltration into the ground and then in the middle. And the biggest thing is that there's going to be a pond in the park area. ... the east and west sides bordering this centralized green area park area I would basically put in mixed use development”.

B59 further discussed exercise facilities surrounding the area, drawing from previous experience from an area on Virginia Tech's campus as inspiration. Design inspiration was common among

the bird group, with numerous participants expanding upon projects such as Central Park to focus on socioeconomic benefits, with stormwater improvements surrounding the descriptions. B86 is a representative example of this concept, expanding his design inspiration of Central Park toward socioeconomic benefits and green solutions through best management practices (BMPs):

“My mind kind of goes to like a Central Park style type situation where you have a lot of green space ... maybe like some benches or something just to kind of enhance the space and encourage people to want to use it as is ... To kind of improve some of the economics of the area or, like, you know, socio economic status of the area, you can add in maybe some convenience stores or something that's going to be useful, like a grocery store or something like that and then maybe have like a green roof or rain barrels or anything that can kind of help those alternative BMPs that can kind of help reduce runoff because you are kind of maintaining that impervious”

Multiple of the ideation sessions for the bird group were centrally focused around green ideas. These ideas commonly included the expansion of park space (commonly referred to as “green space”), more inclusion of native flora (trees, shrubs, and bushes), placement of retention ponds, and meandering creeks through the area of interest. B99 encapsulated these ideas throughout her design ideation session, noting the lack of “anything green” in the area:

“I want to kind of keep that park and just incorporate some more green features and make this pretty much one big green space ...I want to add some kind of a retention pond or even just a regular pond for fishing, you know, just something that can collect water, but also encourage community and gathering. one thing that I noticed in the situation is that there is an absolute lack of anything green, so I'm going to add some trees in here along the roadway. Not as much for privacy as it is for healthiness of the community and even taking care of some of that excess water ... as many trees as possible, for sure. I like the idea of bushes too. Anything we can soak up some of that excess water or snow or

anything else that's going to accumulate on the ground ... maybe even get a creek going through".

Inclusion of gray ideas occurred in the bird group but were typically only briefly discussed in the ideation sessions. However, these ideas carried importance within the participants' designs for removing stormwater from the CSO infrastructure in Cincinnati. Often, the focus of these sessions shifted attention from the gray ideas, leveraging the benefits of different socioeconomic improvements that would attract more people to the area. B69 reflected one instance, beginning his ideation session with dialogue on the inclusion of vegetation, a pond, and community facilities, then cushioning the implementation of underground storage options before more discussion on vegetation and bioswales.

Theme 3 – The VR groups provided more robust descriptions of nature-based ideas

Based on a one-way ANOVA from data presented in Table 3, no statistical difference existed between groups for the number of nature-based design ideas ($p = 0.17$), the quality of the descriptions were noticeably different between the VR groups and the control group. In instances, the control group provided ideas, but the VR groups provided more detailed ideas. The VR groups tended to expand on ideas to include more detail that the control group often omitted. For example, the following side-by-side comparison of higher-quality ideation transcripts from the human group and control group reflects this difference in quality, where bolded words indicate design ideas and underlined words provide context surrounding the design ideas:

H18:

*"I want there to be a **park**. Whether that be a **playground** ... more **crosswalks** can access the park to be in between these two roads right there, so there's going to be a playground. And I want there to be a lot of **dirt and plants** around the playground ... to help absorb storm water... then this block needs a **water treatment plant**. And actually, I'm going to*

*keep this segment for playgrounds. Put the water treatment plant on the right side. And I think that. We can put in some more **natural water intake options** ... well, **bioswales** ... **a community garden** with sustainable water intake options ... what can I add here that would help more water be like sustainably ...”*

C10:

*“Well, my first idea was to make some sort of **pond for the storm water**, but if it's also mixed with wastewater, I don't think it's a good idea. So I'm not entirely sure how to approach. Right, so looking going to look for another map real quick so I can get an overview of the town runs off to. Gotcha. There's a creek somewhere in this area, so I think the first thing I want to do is a **park** over here. I'll probably expand this to a more medium sized pond just for the storm water - just to try to stop the volume of output ... I'd probably try to clear out over, just extend that into. Maybe something else more recreational. Yeah, probably more recreation. So maybe just some **benches** and stuff. Probably, yeah, something going around just like surrounding the **public walkway** or something ...”*

In the above comparison, a difference that exists between the groups is the specificity of ideas. While C10 develops a vision of expanding a park with some recreational elements, this representative example of the control group presents a lack of specificity. With a lack of design elements, the participant struggled to link elements together into a cohesive vision. However, H18 began the ideation task with the playground, presenting feedback loops for both gray and green ideas to support their idea.

Building from specificity, other differences between the VR groups and the control group that emerged from the ideation transcripts were uniqueness and depth. The control group did not offer

any ideas that were not mentioned by the VR groups. At least 7 ideas were mentioned by the bird and self-lens groups that were not mentioned by the control group (Table 4):

Table 4 - Ideas offered by embodied and self-lens groups that were not provided from the control group

Participant	Idea	Quote
H3	Smart stormwater system	<i>"once [the pipe] reaches capacity, it stops the gates and then after that, it keeps on adding it in once it reaches a sort of barrier so that it doesn't overflow"</i>
B22	Hydrologic based design	<i>"Since this [existing] pipe does go straight through - another thought is to possibly reroute the pipe in favor of these water basins, so large ones are all the same size and reroute the pipe. This angle might also slow down as well ... and then there would be some, possibly some points of control over here during heavy rainfall"</i>
H25	Pond-centric design	<i>"my design would probably be like a pond that kind of brings community more together ... There's tons of trees around it, too, they try to keep the forest intact, so I guess new trees and then make a path around the pond so that people can ... go on walks, while it also helps with the drainage of stormwater"</i>
H26	Stream daylighting	<i>"And then I think on the outside by the sidewalk, there should be like kind of a stream alongside that can come up and show and then you can hide it underground for a little bit and then show up again, kind of like a sewage system ... So it would go like alongside the sidewalk and down, maybe wherever, like on the side, it would go under and then it would come back up for a while. And go under again ..."</i>
B58	Quadrant-based planning; Dual-use of tanks	<i>"I'm going to do a little bit for quadrant kind of kind of deal. I shall do like a coordinate system that makes one north eastern side Quadrant two in the northwest, quadrant three near southwest, and Quadrant four in your southeast. So, four quadrants - I'm certain quadrant two is the quadrant to my idea is to redesign as a park is the farthest quadrant away from the main arteries going into the city, so it might be a little bit quieter. You don't have as many outsiders coming into it, and it's safer, presumably safer area for kids to play for the storm water solution. I do really like the idea of the skate park with the water storage tanks underneath. It's a dual purpose people most likely won't realize that their their storage tanks are even there, so I probably put the storage tanks like right near the middle ..."</i>
B59	Road diet solution	<i>"the first thing I would do, even though the both these roads on the north and south, the big have high traffic volumes, I would say I notice they have four lanes and two lanes in each direction for each of these roads, and I would honestly make it overall a one lane in each direction for both with street parking, in addition ... it would allow us to do like a landscaped area between the road and then the sidewalk."</i>

		<i>Which also makes it safer to walk, but then it's just increasing overall green landscaped area, because there's literally no green or vegetated area.</i>
B77	Community-center based design	<i>"I'd like to put in more of a community center over here ... Since this is a lower income area, they probably don't have access to a lot of funding and just public infrastructure in general. So I'd like to kind of establish this as kind of a center so then you could kind of incentivize more housing coming in and also making sure it still aligns with affordable housing and all that ... And for the park and stuff you can add. More lighting everything just to make it more inviting and then going towards a community center, we can have more trails and maybe create a little more sloping towards those trailers so the trail can kind of start. Near the crosswalks, loop around, you can end up at the community center".</i>

The ideation sessions for the VR groups were richer in description of individual ideas and offered deeper analysis of the problem. The control group involved multiple design sessions that were brief and provided superficial design ideas. These design ideas were generic and did not develop past broader initial concepts. For example, C35 is one representative example:

"I was thinking that you would probably want to put some of underground because if you're trying to get more people in the area, like for the sessions from a socioeconomic perspective, you probably wouldn't want all this crappy storm water like just all above ground ... So I would try channel underground ... You probably want more vegetation if you want to be able to treat the storm water ... A over in this like commercial area, like more of the vegetation or whatever, but trees and plants, all that stuff. And then you would channel using like pipes like underground with like some storage stuff, some like tank or something to keep the stormwater underground"

Conversely, the VR groups typically provided greater detail in explaining how design elements contributed to a large concept of their design idea. B58 had the most instances of design elements (106 total) of all participants, reflecting her design around a quadrant-based approach to take advantage of green and gray infrastructure:

“At the North End here, I would probably do two different kinds of parks, so on. Oh, and a walking trail, so you see me walking trail, that's going to go all the way around it. Permeable pavers, obviously around it. Put in trees along like on both sides of the walking trail and then in the center. Of the walking trail, we're going to have like a two to five year old park and then like a six to 12 year old park, many different things, and they get to have different stuff, so that's going to be like want to bring people in because like now you have something for a little bit for everyone. You have something for your small kids, your middle aged kids like the skate park and basketball court, you have stuff to do if you don't do things like this nice walking trail, trees you can kind of ignore in the city, but like, you're kind of now. Having a little oasis and an area one, since it is like a little bit higher trafficked along that arterial, I'm thinking more community garden. It'll give you inner air and a place for the rainwater to go. But also like supporting the people who do still live in that community. I think studies have shown that in Brooklyn, having those community gardens actually brought people like wanting to move to Brooklyn instead of being like, Brooklyn is gross. ... so community garden out here. And then within that community garden have ... so we've taken care of like the vegetation part, but like actually bringing economic growth back in”.

Discussion

The results conclude that the embodiment of nature leads to more green design ideas during the engineering design process, but also included the inclusion of socioeconomic design ideas. Mapping socioeconomic design ideas on top of green ideas is discussed in previous literature surrounding the benefits of implementing urban green infrastructure (Casal-Campos et al., 2015), embodied VR (Ahn & Bailenson, 2012), and design thinking (Plattner et al., 2010). The co-benefits of green infrastructure are commonly presented as drivers to adoption in real-life designs (Dhakal & Chevalier, 2017; Van Oistaijien et al., 2020; Randolph, 2003) which were also mentioned in the

design ideation sessions. Participants lumped socioeconomic advantages of green infrastructure as co-benefits as well: spurring of mixed-use development, inclusion of restaurants and bars, and neighborhood makeovers, which are all benefits of green infrastructure.

Furthermore, the emergence of socioeconomic ideas is also supported by literature about the use of embodiment and embodied VR, supporting the uptick of green and socioeconomic ideas in the bird group. Successful instances of embodiment can invoke empathy for the avatar and change affective behavior (Bertrand et al., 2018; Gerry, 2017; Kors et al., 2020). From the lenses of the VR participants, the influence of behavior was not only pro-environmental as hypothesized (Scurati et al., 2021; Ahn & Bailenson, 2012), but also socioeconomic. This inclusion, empathizing both for and beyond the embodied avatar could be due to the nature of design thinking (Köppen & Meinel, 2015), but future research should consider the plausibility of co-benefits from embodiment. More specifically, as nature-based ideas are spurred more from embodiment, the range of co-benefits that these ideas can provide generally increase, such as benefits to air and water quality as well as socioeconomic improvements (Randolph, 2003).

The design ideas mentioned by both VR groups were also more descriptive than those presented by the control group. VR is an immersive platform that facilitates robust design ideas (Coroado, 2015; Ma et al., 2020; Makarova et al., 2015). Embodied VR can prompt more vividness within design feedback that a VR participant provides (Herrera et al., 2018). Both the embodied and self-lens groups discussed design ideas that were more descriptive and vivid, while also presenting design ideas that were never mentioned during the control group's ideation sessions. From this finding, embodied VR may even increase ingenuity of design ideas, which substantiates embodied VR's role within the engineering design process.

The engineering design process created an outlet for perspective-taking, which was benefitted by embodied VR. As design-thinking encourages the start of the design process with empathy (McDonagh, 2010), which was bridged through perspective-taking during this experiment.

However, perspective-taking is not required to be limited to one individual or being; perspective-taking in the engineering design process can extend to any stakeholder facing the problem to be addressed (Plattner et al., 2010). Land-based designs involve many stakeholders, ranging from organizations, individuals, wildlife, etc., and the particular case study of CSO placed these stakeholders in turmoil. Through the design charrette that was introduced to spur design-thinking (i.e., the design ideation activity), all participants started with an establishment of a need – to minimize CSO – and to benefit the surrounding environment. In other words, this experiment placed each participant as a designer faced with a design problem: to minimize CSO in a neighborhood in Cincinnati, however, perspective-taking through embodiment impacted how the participants responded to the design challenge.

The control group's general inability to connect broader ideas to more granular design elements stands in contrast to the VR group's depth and specificity. VR enabled the designers to better "see" a problem and provide more robust ideas, which served to benefit the design process (Corrado, 2015; Ma et al., 2020; Makarova et al., 2015). Thematic content analysis of all three groups' design ideation transcripts substantiated prior research that VR helped to enable deeper design considerations and inclusions compared to a more standard plan review (Xiang et al., 2021).

Scant research studies have compared how different lenses of VR change environmental concern, with little prior investigation exploring the impact on the design process. Markowitz et al. (2018) contrast other versus self-lens VR (embodied vs. human) to determine the impact on climate change education among children, but found no difference in embodiment as an independent variable. Not all user groups and not all cognitive processes may be similarly influenced by this form of perspective-taking. The research presented here did find a difference between the human and bird groups: the bird group was more likely to include green and

socioeconomic ideas than gray ones in their ideation sessions. With only Markowitz et al.'s (2018) study and this research, more instances of comparing embodiment types are needed.

The human-nature connection is impacted by embodied VR, which is highlighted during the engineering design process. Trump and Shealy (forthcoming, Chapter 2) found that embodied VR increases connectedness to nature, while this present research expands this finding to measure not just the designers' connections with nature but how it influences their design ideas. Since design thinking is iterative (Plattner et al., 2010), future research should identify the impact of design iteration on this finding – do repeated trials of embodied VR have more impact on the type and quality of designs developed during the engineering design process?

A limitation of this research is the selection of engineering undergraduate students rather than design professionals. The use of design professionals may have provided greater design ideas and could have been more aligned with how current engineers ideate during the design process, which could have impacted the amount of nature-based design ideas that were generated. However, engineering undergraduates were purposely chosen for two primary reasons: 1) they will be in the industry making similar project decisions and 2) for many design professionals and firms, VR isn't accessible. As VR becomes more user-friendly, mobile, and immersive, the sample pool chosen will have the necessary background of using VR during conceptual design.

Conclusion

This research builds upon Trump and Shealy's (forthcoming, Chapter 2) finding that found an increase in connectedness to nature due to embodied VR. Embodied VR shaped the amount of detail and emphasis on green design ideas that led to substantially different design outcomes. Embodying nature through the perspective of a bird influenced design ideas to include more instances of green thinking and socioeconomically-driven design elements.

VR can be employed as a tool for designers to influence how decisions are made for all stakeholders in the design process. Embodied VR provides a tool for perspective-taking that positively shifts design thinking. Future research should explore the temporal aspects of embodied VR on design, how embodied VR can influence other stakeholder groups, and how levels of vividness or realism may relate to the level of influence it has on design. For example, it was discovered that embodiment shifts design ideas in favor of the avatar that was embodied. In other words, participants that embodied an aspect of nature were more likely to design with benefits of nature in mind. Furthermore, it was also discovered that any type of VR perspective notably impacts the level of robustness within a design task. Embodied VR offers a relatively inexpensive approach to shape how designers think about design, offering them a new perspective, and potential more descriptive and detailed design ideas that also offers an approach to prioritize green design ideas through the perspectives of other stakeholders not usually considered during design.

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Appendix

Design ideas from thematic content analysis

Table 5 - Design ideas from thematic content analysis for all participants

Participant	Design Ideas
b1	<ol style="list-style-type: none"> 1. Add and maintain parks and recreational spaces 2. Improve and maintain water quality through water purification 3. Add parking spaces 4. Add underground treatment plants for storage 5. Input mangagement for underground water retention
c2	<ol style="list-style-type: none"> 1. Input a system of underground storage containers with layered pipes 2. Create a lake or pond for stormwater retention

	<ol style="list-style-type: none"> 3. Input street drains 4. Water heaters to turn water into steam 5. Add filtration system to rid smells 6. Change grades to allow for better runoff 7. Material changes for concrete, steel, or rock
h3	<ol style="list-style-type: none"> 1. Add green infrastructure for water absorption 2. Change grades for water runoff to go to central drains 3. Add concrete for water runoff 4. Keep recreational fields 5. Remove excess space from dirt patch 6. Add piping system with check system to adjust stormwater movement 7. Reduce parking, but still keep a parking presence on the space 8. Add in additional green space for recreation as a playground 9. Add in green infrastructure
b4	<ol style="list-style-type: none"> 1. Storage may not be a good long term solution, source control should be considered 2. Separate sewers to prevent overflows 3. Possibly add in green infrastructure, but sewer separation should be sufficient 4. Add in storm inlets that connects to the storm sewers
c5	<ol style="list-style-type: none"> 1. Above ground helps the stormwater issue, but not as much. 2. Above ground - add in elements of nature, but too much water may be detrimental. 3. Underground: add more pipes 4. Need to consider surrounding people and traffic 5. Tradeoffs between having water vs. concrete on the surface 6. Input a water filtration plant to clean stormwater. 7. Underground pipes holding stormwater runs into the filtration plant 8. Ability to change water direction
b6	<ol style="list-style-type: none"> 1. Reroute pollutants into a plant that can reuse byproducts, such as for biofuels 2. Make space for recreational activities 3. Bury waste and byproducts 4. Add filtration systems and sewage treatment plants 5. Repurpose byproducts into something useful 6. Add jobs through this process of trying to make cleaner stormwater
h7	<ol style="list-style-type: none"> 1. Add trees to absorb water 2. Keep the basketball court for recreational space 3. Add in forestry and pond space 4. Water system within the pond for water retention 5. Add in storm inlets 6. Put in storage tanks where there is open space 7. Improve rooves on houses 8. Water systems for each house, consideration of economic barriers to get there
c8	<ol style="list-style-type: none"> 1. Could consider a source control option such as the inclusion of a river 2. Consideration of economics that might go into including a source control solution 3. Rivers and streams would get polluted 4. Move park space to allow for stormwater pipes 5. Implement underground detention for stormwater 6. Add filtration to clean underground water

h9	<ol style="list-style-type: none"> 1. Add storage underneath the area 2. Add green spaces and parks 3. Add green spaces for stormwater absorption 4. Add in trees and shrubs 5. Add in a water filtration system
c10	<ol style="list-style-type: none"> 1. Add in a stormwater pond 2. Add in a park 3. Increase the size of the pond to allow for more stormwater capacity 4. Add in recreational amenities such as benches and walkways 5. Add in storm inlets 6. Add in pavilions and keep the basketball court to make the town seem more friendly 7. Input a wastewater treatment plant, which will also add jobs to the community 8. Add in storage tanks 9. Implement stormwater reuse features
h11	<ol style="list-style-type: none"> 1. wouldn't want to implement a treatment plant to infringe on the green space. 2. Add plants and vegetation to help with air quality and water absorption 3. Remove the trailer park, add green space 4. Incorporate underground storage tanks 5. Add in a natural channel for stormwater collection
c12	<ol style="list-style-type: none"> 1. Create a manmade pond to collect runoff 2. Add fish into the pond 3. Add in underground storage tanks 4. Need to consider available budget for the scope of the water storage projects 5. Add in a retention pond
h13	<ol style="list-style-type: none"> 1. Storage is not a good idea for fixing the solution 2. Add in green technologies to alleviate the stormwater issues 3. Green technologies will slow down water runoff speeds and help create jobs 4. Construction needs to be environmentally conscious 5. Add retention ponds 6. New underground water systems
b14	<ol style="list-style-type: none"> 1. Add more trees 2. Add in a bike path along the trees 3. Convert the existing trailer space into water storage space 4. Add in playgrounds 5. Add in fields 6. Add in large storage containers
b15	<ol style="list-style-type: none"> 1. Add in a garden or vegetation for stormwater 2. Keep the park and softball fields 3. Separate the sewers underground 4. Consider a new wastewater treatment plant 5. Increase park size to benefit the community 6. Renovate the basketball court
c16	<ol style="list-style-type: none"> 1. Difficult to use natural ways to fix the stormwater issue 2. Add in treatment plants, potentially multiple 3. Remove old infrastructure and housing 4. Add diversion pipes 5. Add plants on the surface

b17	<ol style="list-style-type: none"> 1. Keep the park and expand it 2. Add public amenities - basketball, baseball, tennis courts 3. Add public bathrooms 4. Add sustainable areas for runoff 5. Add in a central drain for water diversion 6. Add greenery and trees for public use and stormwater absorption 7. Add in a police station to aid with high crime 8. Add in a pond 9. The entire design should be centered around one central park
h18	<ol style="list-style-type: none"> 1. Add in an accessible park in the center of the space 2. Input a playground with dirt, plants, and rubber pellets for stormwater absorption 3. Keep the basketball court for public use 4. Input water treatment plants 5. Add in natural water retention features, such as bioswales 6. Add in a community garden 7. Add in hills for elevation differences 8. Add in water storage tanks
c19	<ol style="list-style-type: none"> 1. Make a Central Park themed design 2. Include a lot of vegetation and trees for water absorption 3. Add in sidewalks 4. Include a pond with fish 5. Add in a park - include baseball and softball fields to help the community 6. Include underground storage options
h20	<ol style="list-style-type: none"> 1. Add in trees and greenery 2. Include a stream 3. Incorporate a Main Street, include plants and bushes 4. Include trails, under the trails put in underground storage features 5. Add in walk through stores to make the area feel more livable, similar to Columbus, Ohio
b21	<ol style="list-style-type: none"> 1. Tear down all existing infrastructure except the basketball court 2. Include more trees for stormwater 3. Add in restaurants, mall space, and commercial space 4. Incorporate an offsite water treatment plant 5. Include water storage features 6. Incorporate public amenities - chairs and trees
b22	<ol style="list-style-type: none"> 1. Change the soil material for better permeability 2. Consider altering soil terrain for better elevations 3. Input a small dam 4. Reroute the pipe in favor of the amount of water received by each water basin 5. Input water control points 6. Consider business options - repurpose homes to make the area feel more like a Main Street
h23	<ol style="list-style-type: none"> 1. Demolish existing infrastructure 2. Make the park a more vibrant ecosystem that's walkable 3. Rebuild local houses 4. Input extra storage tanks and widen underground pipes 5. Make the area feel more livable

c24	<ol style="list-style-type: none"> 1. Include bioswales and green space 2. Add in a community commercial space that is walkable 3. Rebuild homes and buildings to be more sustainable 4. Add green space and underground storage
h25	<ol style="list-style-type: none"> 1. Add in a pond-centric design that takes in stormwater and helps bring the community together 2. Add in a lot of trees with paths to walk on 3. Remove impermeable surfaces such as asphalt and parking lots
h26	<ol style="list-style-type: none"> 1. Keep basketball and tennis courts 2. Add in open space and fields 3. Add in ponds that connect to each other 4. Add in sidewalks 5. Include a meandering stream that daylights and goes underground 6. Concern with local behavior and littering 7. Add trees and flowers to make the area seem more open and inviting 8. Add in a garden, include signs for native species for locals 9. Add in wayfinding with the ponds, include sitting and walking areas
b27	<ol style="list-style-type: none"> 1. Expand the green space and include more plants for stormwater 2. Incorporate a park for community 3. Incorporate a pond for more biodiversity and to encourage people to come to the area 4. Include vendors
c28	<ol style="list-style-type: none"> 1. Include shrubs and bushes into the green space 2. Add a communal park space that can infiltrate stormwater 3. Incorporate the basketball court for community 4. Add food trucks for economic encouragement
b29	<ol style="list-style-type: none"> 1. Make the space a park space to limit flooding potential 2. Incorporate more permeability within the soil 3. Tree-centric design 4. Could input a sewer system, but probably isn't necessary 5. Add in a fountain
b30	<ol style="list-style-type: none"> 1. Reconfigure roads and consider some underground improvements 2. Add in a garden to incorporate some vegetation 3. Keep the basketball courts 4. Consider a central stage or park 5. Add in a rock walkway, not asphalt
c31	<ol style="list-style-type: none"> 1. Include underground storage and separation 2. Include a park
b32	<ol style="list-style-type: none"> 1. Incorporate more vegetation 2. Include a central park that can be walked around 3. Keep the basketball court 4. Redevelop buildings and put in small stores, such as coffee shops 5. Add in trees and gardens 6. Update the underground system
c33	<ol style="list-style-type: none"> 1. Put stormwater underground because it isn't appealing to the public eye 2. Add in pipes that flow outward from the roads and are all connected 3. Add big tanks underground 4. Add in a central building for maintenance of the tanks and access

	<ol style="list-style-type: none"> 5. Add in a connected sewer system 6. Get rid of a few roads 7. Maximize soil surface area for stormwater absorption
h34	<ol style="list-style-type: none"> 1. Add in stormwater ponds 2. Include shrubs and grass to clean stormwater 3. Include riparian zones 4. Renovate the park 5. Separate the sewer systems 6. Include a stormwater pond in the middle of the area
c35	<ol style="list-style-type: none"> 1. Incorporate an underground solution to leave stormwater away from the surface 2. Include vegetation to beautify the area 3. Include more pipes and tanks underground
h36	<ol style="list-style-type: none"> 1. Improve the area by making it more of a community 2. Add in recreation - basketball and baseball 3. Add in a central pond 4. Add un underground storage tanks 5. Add in commercial space for restaurants
c37	<ol style="list-style-type: none"> 1. Combine sewer system 2. Add in underground storage 3. Add in trees and plants for stormwater absorption
h38	<ol style="list-style-type: none"> 1. Keep the basketball court, remove everything else 2. Depress the land slightly in some parts to make a wetland 3. Water sequestration into the ground 4. Change areas into dirt lots 5. Include a multilevel storage facility 6. Add in new apartment complexes
b39	<ol style="list-style-type: none"> 1. Input underground tanks 2. Above ground - line with trees and vegetation 3. Sidewalks - add in divots for water absorption 4. Include bioswales to line the park 5. Include an underground tank 6. Add in two sets of pipes with underground storage
c40	<ol style="list-style-type: none"> 1. Use nature to gather stormwater 2. Include a stream and pond 3. Add in trees and vegetation 4. Create a central park
h41	<ol style="list-style-type: none"> 1. Keep the basketball court to get the community together 2. Keep all the grass/bushes 3. Add in underground storage options 4. Add in a park with trees around to absorb stormwater and allow for playgrounds for kids 5. Add in fences and street lights
h42	<ol style="list-style-type: none"> 1. Expand the sewer system 2. Remove tractor trailer space 3. Jobs for expanding the sewer system will come to the area 4. Add in water retention banks - bioswales 5. Add in a water diversion to limit the amount of stormwater going through the area

	<ol style="list-style-type: none"> 6. Add in a central park - maybe will help with socioeconomic issues 7. Stored water can be used in times of crisis
h43	<ol style="list-style-type: none"> 1. Add in plants, vegetation, and bushes for surface stormwater control and to make the area more aesthetically pleasing 2. Add in another wastewater treatment plant 3. Add in underground storage of stormwater 4. Reuse some of the stored stormwater for other applications
c44	<ol style="list-style-type: none"> 1. Add in apartment complexes with grocery stores and fast food restaurants 2. Include park space and open area around anything impervious, such as sidewalks and roads 3. Change the elevation of the area 4. Add in a pond for stormwater retention as well as for community aesthetics
b45	<ol style="list-style-type: none"> 1. Add in a large pond 2. Include trees and a large open space for recreation 3. Add in walkways 4. Add in a waste management center 5. Add in underground storage options 6. Consider removing some of the unused buildings 7. Picnic areas for communal engagement 8. Add in a dog park
c46	<ol style="list-style-type: none"> 1. Add pipes and tunnels undergroundf
h47	<ol style="list-style-type: none"> 1. Remove the basketball court and replace it with stormwater retention pond 2. Add in greenery around the pond 3. Add more drainage inlets 4. Repurpose the central building to be more community focused 5. Add in trees and water features 6. Add in a rainwater harvesting system
h48	<ol style="list-style-type: none"> 1. Add in slope to the area to allow rainwater to navigate to an underground detention system 2. Add in an access structure 3. Add in a park with stone paths 4. Add vegetation
c49	<ol style="list-style-type: none"> 1. Incorporate a park that can absorb stormwater and alleviate socioeconomic issues as a two birds one stone approach 2. Add in a court and a pavilion 3. Include greenery, trees, and shrubbery 4. Add permeable pavement 5. Consider solar energy 6. Add in bioswales 7. Add parking with permeable pavement
c50	<ol style="list-style-type: none"> 1. Add a wastewater treatment plant 2. Include more trees in the area 3. Incorporate more slopes 4. Add in a park
h51	<ol style="list-style-type: none"> 1. Include a lot of grass for increased permeability 2. Fence in the area 3. Add in extra lighting

	<ol style="list-style-type: none"> 4. Change elevations, include swales for water retention and absorption 5. Add in soil spots to separate areas within the area of interest 6. Add in an underground system - pipes and tanks
h52	<ol style="list-style-type: none"> 1. Input underground detention systems 2. Include walkable shops 3. Implement green rooves on new and existing buildings 4. Incorporate a park for community enjoyment 5. Add in a stormwater pond for both community and stormwater use 6. Add in more trees 7. Place parking underground
b53	<ol style="list-style-type: none"> 1. Keep the basketball court in place 2. Add in a public use trail 3. Add in picnic benches with a lot of sidewalk space to encourage people to come to the area 4. Add in trees 5. Community improvements - coffee shops and grocery stores 6. Incorporate green rooves on buildings for stormwater absorption 7. Utilize green space as a soccer field for more stormwater absorption
b54	<ol style="list-style-type: none"> 1. Keep the basketball court for public use 2. Renovate the baseball field 3. Tree-centric design - incorporate trees all throughout the space for stormwater absorption 4. Incorporate various types of vegetation
b55	<ol style="list-style-type: none"> 1. Transition the space into a park with a pond 2. Add a bike path with trees all around it 3. Add a bridge for the bike path 4. Put in underground storage on one side of the area of interest to keep the other side more recreational 5. Build in offsite treatment to keep smells away
c56	<ol style="list-style-type: none"> 1. Make the park multi-use and purposely flood it to turn it into a pond during heavy rain events, based on existing knowledge from the Netherlands 2. Incorporate more commercial space in the area 3. Add in slopes to change up the elevation 4. Add in a park as part of a movement for urban redevelopment 5. Change soil types to clean the stormwater
c57	<ol style="list-style-type: none"> 1. Keep the park while changing the soil type for better infiltration 2. Add in another treatment facility 3. Separate the sewers
b58	<ol style="list-style-type: none"> 1. Change up the street design to maximize space 2. Remove any existing housing and blight 3. Implement a quadrant system where quadrants closer to the city are livelier and quadrants farther from the city are quieter 4. add in underground storage while putting a skate park on top for community enjoyment 5. Storage tanks need to feed into the existing sewer system somehow 6. Keep the basketball court, but make it a permeable pavement 7. Add in swathes of permable pavement as a walking trail 8. Add a community garden that is maintained by a local club - referenced Brooklyn

	<p>as a successful case for community acceptance</p> <ol style="list-style-type: none"> 9. Add a community shed with shared tools for garden upkeep 10. Encourage mixed use development with shops and apartments 11. Add a permeable paver parking lot 12. Add in trails and trees - considered the plight of wildlife and the bird 13. Add in a retention pond with fish 14. Encourage a revitalization of the area so people can enjoy the neighborhood more
b59	<ol style="list-style-type: none"> 1. Implement a road diet solution to remove lanes 2. Make the previous lane street parking 3. Add in landscaped areas to improve safety and to attribute to the overall greenness of the space 4. Referenced New York City, then discussed the addition of a central park with a lot of trees planted 5. Add in a pond 6. Add in bench style seating and steps, referenced VT's campus as an example 7. Add in mixed use development and grocery stores 8. Add in ditches that lead to the pond 9. Include underground detention 9. Add bike paths and bike lanes
h60	<ol style="list-style-type: none"> 1. Make the space more livable as a priority 2. Incorporate more multifamily residential buildings 3. Allow water to come to the center of the area 4. Separate the sewers 5. Add in a creek
c61	<ol style="list-style-type: none"> 1. Add in a lot of vegetation and trees in the space to help with stormwater and community aesthetics 2. Input underground detention basins
h62	<ol style="list-style-type: none"> 1. Remove road space to allow for more design 2. Add in a wastewater treatment plant 3. Incorporate underground detention with upgraded pipe systems 4. Place a park atop the space
h63	<ol style="list-style-type: none"> 1. Place a pond where the existing storage space was 2. Improve crosswalks 3. Add in trees 4. Consider separating the sewer system or upgrading it
c64	<ol style="list-style-type: none"> 1. Keep anything industrial near the water 2. Add in a wastewater treatment plant near outflow locations 3. Add a park with a buffer zone, model it after Central Park 4. Add in more sewer lines and separate the system
h65	<ol style="list-style-type: none"> 1. Add a park with a pond 2. Add underground storage 3. Include mixed use development 4. Add multilevel parking 5. Add gardens along the road
h66	<ol style="list-style-type: none"> 1. Remove truck space and replace it with housing 2. Add in swales and a pond for above ground stormwater management 3. Add new pipes and tanks underground

	<ol style="list-style-type: none"> 4. Include commercial space for safety reasons 5. Add trees and bushes
c67	<ol style="list-style-type: none"> 1. Try to break up the visual cues within the space 2. Add in recreational fields 3. Add in sidewalks 4. Add in businesses 5. Add in stormwater BMPs
b68	<ol style="list-style-type: none"> 1. Maintain commercial space 2. Keep existing infrastructure - basketball court and central building because resources were invested 3. Add in new recreational fields that help stormwater infiltration 4. Add in trees 5. Add in new affordable housing 6. Improve public transit - bus lines
b69	<ol style="list-style-type: none"> 1. Add in new vegetation 2. Keep the basketball court because it's good for the community 3. Add in a pond 4. Include underground storage 5. Put vegetation along the road 6. Add in swales to alleviate stress going to the wastewater treatment plant
b70	<ol style="list-style-type: none"> 1. Add in recreational fields 2. Include retention ponds to separate the fields 3. Add in a duck pond with riparian vegetation to also encourage parkgoers 4. Add in housing to get more people coming to the area 5. Add community features - benches, seating areas, and gazebos 6. Fence the area 7. Incorporate fish into the pond 8. Add storm drains 9. Change the elevation of the recreational fields to allow for purposeful flooding in heavy rain events 10. Add picnic tables and picnic benches 11. Add taller trees and vegetation
c71	<ol style="list-style-type: none"> 1. Add more pipes 2. Include more wastewater treatment with added chemicals 3. Include underground storage tanks
h72	<ol style="list-style-type: none"> 1. Change the grade of the streets so they aren't so flat 2. Separate the sewers 3. In the green space, add a pond 4. Beautify the area with benches and trees, which would also absorb stormwater 5. Expand the pond into unused land 6. Include storage tanks
c73	<ol style="list-style-type: none"> 1. Source control is a viable option to handle stormwater at the point where it has the most potential to cause downstream problems 2. Include a retention pond and trees 3. Expand the park 4. Consider changing the gradients for better water flow 5. Add retention facilities in underused places, such as the current storage location

h74	<ol style="list-style-type: none"> 1. Move the existing storage space 2. Add in a new treatment facility 3. Add in more piping systems 4. Change the elevations of the area to allow for better stormwater runoff and infiltration 5. Add drainage basins, which filter to the wastewater treatment facility
h75	<ol style="list-style-type: none"> 1. Remove road space and implement more area for bike lanes 2. Implement more green area and green space with trees, use this as a park 3. Add in a pond, incorporate a tree-centric design around the pond 4. Implement commercial space 5. Add in a downtown area with plenty of vegetation to encourage people to gather and eat 6. Add in underground parking 7. Add in underground storage space 8. Add in new piping systems
c76	<ol style="list-style-type: none"> 1. Start with a natural system to use grasses and vegetation to take in stormwater 2. Convert commercial space to park space since this will also help with community building 3. Keep recreational fields 4. Add in shaded spots 5. Add channels that leads to a central drain for underground storage
b77	<ol style="list-style-type: none"> 1. Add stormwater management space as vegetation and parks 2. Include underground tanks 3. Add in a community center 4. Add in affordable housing since the local area has economic hardship 5. Implement a playground on permeable pavement 6. Add in better lighting and trails to make the space more inviting 7. Manipulate sloping 8. Community center design - everything should lead to this community center
b78	<ol style="list-style-type: none"> 1. Keep recreational facilities 2. Add turf fields 3. Include a creek that collects stormwater and routes to a treatment facility 4. Include vegetation and flowerbeds 5. Add in bridges and gazebos to beautify the area 6. Underwater drainage systems that lead to the creek
c79	<ol style="list-style-type: none"> 1. Make the area a park - good for the environment and the local economy 2. Include lots of trees and a pond 3. Include restaurants, souvenir stores, bathrooms, food trucks, and parking 4. Capture stormwater underground
c80	<ol style="list-style-type: none"> 1, Expand the stormwater pipes 2. Separate the sewers
h81	<ol style="list-style-type: none"> 1. Keep the park as-is and add trees 2. Include a treatment plant 3. Consider implementing underground tanks for storage, but this may be infeasible 4. Surface improvements are largely the best option
c82	<ol style="list-style-type: none"> 1. Add in bioswales since vegetation will help absorb stormwater 2. Revamp the park with vegetation to make it more inviting so people will come

	<ol style="list-style-type: none"> 3. Add in shrubs and trees to absorb stormwater 4. Add in a retention pond 5. Need to be mindful with adding in too much impervious surface
h83	<ol style="list-style-type: none"> 1. add a Sheetz of a WaWa 2. Consider a pond and connect it to the sewer, but this may overflow 3. Add in a park with tables
h84	<ol style="list-style-type: none"> 1. Make the best use of the space since it feels divided 2. With one side, make either a series of ponds or one large pond 3. On the other half, implement new piping that will lead to a treatment plant
c85	<ol style="list-style-type: none"> 1. Expand the park and add more trees 2. Implement detention basins 3. Purchase any commercial areas and focus on increasing the quality and size of the park
b86	<ol style="list-style-type: none"> 1. Maintain the green space and put in swales to direct stormwater 2. Don't do any type of pond because they can get nasty and may not be able to hold that much water 3. Focus on encouraging people to use the space because it's green 4. Add in BMPs - trees and pervious surface to beautify the area to encourage people to gather but also for better infiltration 5. Fence in the area for crime reasons 6. Add in walking paths 7. Add in a playground 8. Model the area after Central Park for plenty of greenery and activities 9. Put in convenience stores to encourage more socioeconomic activity 10. Implement alternative BMPs like green rooves 11. Add in grocery stores 12. Add in a community center that offers classes and community garden to make the area more inviting, encourage people to come, and potentially reduce violence
b87	<ol style="list-style-type: none"> 1. Add in a pond 2. Add an underground detention center 3. Add a drain in the pond that connected to the underground detention center 4. Plant trees to slow down water 5. Add in a series of ponds
c88	<ol style="list-style-type: none"> 1. Add vegetated medians to add more pervious area 2. Incorporate a series of ponds that are fed by inlets and connect to an underground drainage system
b89	<ol style="list-style-type: none"> 1. Reformat the road design for more pedestrian focused development 2. Add in shops and a mall for the pedestrian feel of the area 3. Add underground storage beneath walking areas 4. Reduce impervious surfaces 5. Rely on underground detention to slow down the movement of stormwater
c90	<ol style="list-style-type: none"> 1. Add in water efficiency systems that takes into account rain amount for distribution - references VT and Blacksburg for this 2. Add in trees and other absorption measures to slow down water flow 3. Input diversion techniques to manipulate where water is going with innovative technologies 4. A lot of job opportunities can come because of this project 5. Recirculate water supply for reuse

h91	<ol style="list-style-type: none"> 1. Separate the sewer system 2. A dam could work, but the area likely isn't big enough to constitute the need for a dam 3. Add in a pond for stormwater retention 4. Add in trees 5. Add a park to attract more people
h92	<ol style="list-style-type: none"> 1. Remove everything and divide the land based on its intended use 2. Add a stormwater treatment facility, which will add jobs 3. Make sure the facility is LEED certified and sustainably built 4. Add in piping systems underground since the topography is flat 5. Add in filtration systems to remove harmful contaminants 6. Add in roadblocks - concerned with the amount of heavy traffic in the area
c93	<ol style="list-style-type: none"> 1. Implement an indoor water park 2. Use rainwater, treat it, then redirect it to a water park to help with community and jobs in the area, similar to Six Flags 3. Add in a 500 person parking garage 4. Add in a green roof on the facility
h94	<ol style="list-style-type: none"> 1. Separate the sewer system 2. Increase the amount of grassy space and include more trees 3. Add in a pond 4. Put in benches to observe wildlife in the area
b95	<ol style="list-style-type: none"> 1. Remove the storage space and replace it with a large park 2. Add in a pond, where excess water can be diverted elsewhere, such as to a tank 3. Add in plenty of trees and vegetation 4. Revamp the sewer system with smaller upgrades since this can be very costly 5. Implement a small stream that leads to the pond 6. Revamp the wastewater treatment facility
b96	<ol style="list-style-type: none"> 1. A big issue with traffic - we need to consider how to make people want to stay around 2. Tear down and rebuild all of the houses 3. Need to consider tradeoffs in cost and performance between updating the treatment facility and separating the sewers 4. The above will help get more jobs in the area 5. Move forward with improving the treatment facility as a stopgap measure 6. Add in vegetation, trees, and a pond 7. Need to keep considering separated sewers
b97	<ol style="list-style-type: none"> 1. Increase park green space to be much larger to help with stormwater absorption and to encourage people to use the space 2. Implement underground storage tanks 3. Improve the treatment facility depending on the types of contaminants coming in 4. Increase biodiversity in the area 5. Add benches
b98	<ol style="list-style-type: none"> 1. Add in a mixed use green space that holds an entertainment center 2. Add in a surface water feature, maximize the green space as a park for stormwater absorption 3. Add in trees 4. Include underground storage tanks underneath the entertainment center 5. Parking is difficult, include a lot of walking spaces

	<ol style="list-style-type: none"> 6. Add in a garden 7. Daylight a stream that can be an outlet directly to the receiving river
b99	<ol style="list-style-type: none"> 1. Build off the park concept and add more green features 2. Add in a retention pond as a stormwater feature but also for community purposes 3. Add in trees along the road for community and stormwater 4. Add in various other types of vegetation 5. Keep the basketball court - the impermeable footprint won't be too much 6. add in a creek that runs through the center of the area and put a bridge over it 7. Add bike trails and walking paths
b100	<ol style="list-style-type: none"> 1. Add in trees for stormwater, the community, and for wildlife 2. Move existing trailer storage space 3. Upgrade the sewer system - the current method of having them combined is outdated
b101	<ol style="list-style-type: none"> 1. Keep a park-centric theme with park amenities, including paths, a basketball court, and a playground 2. Put in trees and shrubbery 3. Be mindful of noise pollution - a city planning video game brought this to mind 4. Try to separate housing from commercial areas 5. Consider implementing drug stores 6. Grade the topography toward the center of the park for water collection 7. Separate the sewer system
b102	<ol style="list-style-type: none"> 1. Extend the park to be more inclusive of the space and keep the basketball court 2. Add in water features like water fountains, bird baths, or a manmade stream 3. Add in more recreation in the area 4. Add in meandering walking and bike paths for good views 5. Add in trees

CHAPTER 4: THE IMPACT OF EMBODIMENT ON ENGINEERING DESIGN IDEAS USING AUTOMATION IN NATURAL LANGUAGE PROCESSING

Abstract

Building with nature is an imperative within engineering design but is often underutilized. The research in this paper explored how to overcome this barrier during engineering design through embodied virtual reality (VR). Embodied VR provides a different perspective through a virtual avatar, which can spur the designer to “think” and “feel” as the avatar and influence decision-making. Within engineering design, embodied VR can lead to a stronger human-nature connection and may shape infrastructure preferences toward more environmentally sustainable design. Measuring the impact of embodied VR on nature-based design is complex and could benefit from multiple modes of analysis. The ideas developed by design engineers who were given a VR lens, one as a bird avatar and another as one’s self, were compared to a group not using VR. The design task asked them to develop solutions to minimize combined sewer overflows (CSO). Multiple natural language processing (NLP) techniques were used to explore differences in design ideas among the three groups. The semantic similarity of concepts measured the ontological structures used in each group and served as an indicator of creativity. In parallel, a large language model (LLM) was used to automate the clustering of design concepts without introducing subjective bias or a priori codes. The outcome of the LLM was compared to human-based thematic content analysis of design concepts. Embodiment, as oneself or a bird, widened the ontological structure of the design space and changed the frequencies of select words. Embodied VR also shaped the type of ideas generated: the bird group was more likely to ideate nature-based solutions with synergy to community growth, whereas the self-lens mostly focused on solutions for optimizing urban connectivity. The control group noted the need for environmental sustainability through building with nature yet gravitated toward gray infrastructure

solutions that involved mechanical systems, concrete pipes, and pumps. The use of NLP techniques to measure both the ontological structure of designing and automating the clustering of ideas through LLMs aligned with the findings of the human-based thematic content analysis. These methods can help augment or serve as additional measures to more traditional, resource-intensive thematic content analysis processes.

Introduction

The presence of nature in the built environment provides a synergistic relationship between human health and the environment but is underutilized to solve complex challenges with infrastructure systems (Cervinka et al., 2012; Chavaly & Naachimuthu, 2020; Grinde & Patil, 2009). For example, integrating green spaces such as parks, gardens, and green roofs can help mitigate the urban heat island effect, improve air quality, and reduce stormwater runoff (Casal-Campos et al., 2015; Randolph, 2003). This integration not only enhances the aesthetic, biophilic appeal (Kellert, 2018) of the environment but also provides tangible benefits to human health and well-being. Additionally, incorporating nature-based solutions such as green stormwater infrastructure and natural water management systems can help address climate change, water scarcity, and biodiversity loss. Leveraging the presence of nature in the built environment can create more sustainable and resilient infrastructure systems that benefit both people and the natural environment.

United States federal regulatory requirements require design practitioners to include some level of nature-based solutions in the design of the built environment (US EPA, 2015, 2013). Yet, barriers to adoption persist, including perceived higher initial costs compared to traditional infrastructure, a lack of standardized guidelines for implementing nature-based solutions, and limited awareness of the benefits among stakeholders (Dhakal & Chevalier, 2017). Virtual 3D modeling can enhance visualization capabilities and may help change awareness and

perspective-taking during design (Fernández-Alvarado et al., 2021; Ma et al., 2020). Virtual reality (VR) offers a communication platform to facilitate collaboration among stakeholders and decision-makers. It allows them to experience and understand the benefits of nature-based solutions in a more immersive way for designers to take the perspective of the end-user (Abbas et al., 2019; Davila Delgado et al., 2020). This type of perspective-taking can help overcome feasibility barriers for adopting nature-based solutions by spurring more creative decision-making during the design process (Colding et al., 2020; Ma et al., 2020; Obeid & Demirkan, 2023).

Previous studies warrant a closer look at changing one's perspective through embodiment. Embodiment is the process by which individuals take on the perspective of another entity or inhabit a different body. Embodiment through VR can help change real-life decision-making by making designers more altruistic toward their VR avatars (Afroogh et al., 2021; Banakou et al., 2016; Bertrand et al., 2018; Reinhard et al., 2020; Schultz, 2000). For example, a prior VR embodiment study measured altruistic tendencies and attitudes when elements of nature were placed under duress by cutting down a virtual forest. The study then measured user behavior after the VR embodiment experience finding the experience led to more pro-environmental decisions (Ahn & Bailenson, 2012; Ahn et al., 2016; Herrera et al., 2018). Most prior research exploring the use of embodiment in nature-based thinking uses questionnaires, which have led to mixed results in explaining embodiment's influence on the human-nature connection (Ahn et al., 2016; Bertram & Rehdanz, 2015; Markowitz et al., 2018; Spangenberg et al., 2022).

Using questionnaires to measure the impact of embodiment in nature-based thinking can be problematic because questionnaires often lack the context necessary to understand the responses. They may fail to account for individual differences and situational factors that may influence design. Measuring *how much* impact virtual embodiment can have on nature-based solutions during design is underexplored and difficult to validate through questionnaires (Trump

and Shealy, forthcoming, Chapter 2; Colding et al., 2020; Parker & Simpson, 2020; Scurati et al., 2021).

This research aims to fill this gap by comparing multiple measures of design cognition between design engineers given a VR embodiment experience and those without this experience. While methods like thematic content analysis provide an understanding of changes in designers' cognition (Smith, 2015), there are several potential limitations, including the subjective interpretation of the data, and identifying patterns and themes using pre-established, a priori codes. The recent development of natural language processing tools enables new types of analysis. Semantic distance is one of these measures (Kan & Gero, 2018; Sopher et al., 2022). Semantic distance provides a measure of the similarity or difference between concepts based on their semantic meaning. Unlike thematic content analysis, which relies on subjective interpretation and pre-established codes, semantic distance analysis uses computational algorithms to quantify the distance between concepts more objectively. Comparing semantic distances between concepts of engineers with and without VR embodiment experiences can provide new insights into how embodiment influences the way designers think about and approach design problems. This approach allows for a more nuanced understanding of the cognitive changes induced by VR embodiment, beyond what traditional qualitative methods offer. Semantic distance analysis also opens new possibilities for analyzing large datasets and identifying patterns that may not be apparent through manual coding. This can help uncover subtle changes in cognition that may have been overlooked with traditional methods.

Large language models (LLMs) offer a different approach to understanding changes in design cognition (Anakok et al., 2022; Gamielidien et al., 2023; Katz, 2023). LLMs can be used to analyze design think-aloud protocols to uncover patterns and insights that may not be easily discernible through other methods. LLMs can help identify themes and relationships between concepts. Unlike semantic distance analysis, which focuses on quantifying the distance between concepts

based on their semantic meaning, LLMs can capture the richness and complexity of language use in design cognition. These models can recognize nuances, context, and subtleties in the way designers express their thoughts and ideas, providing a more detailed understanding of design cognition (Anakok et al., 2022; Gamielien et al., 2023; Katz, 2023). LLMs can also handle large datasets and can help uncover patterns and trends in design cognition that may not be apparent with smaller datasets or traditional qualitative methods.

Using these relatively new approaches may offer new measures that both streamline qualitative coding procedures and provide new insights into the effect of embodied VR on design. These multiple methods were used to explore changes in design cognition. The following section offers more background into various methods of measuring design ideas in other fields, and how they can translate to measuring the impact of embodied VR toward ideating nature-based solutions.

Background

Various methods exist for measuring and evaluating design. For example, questionnaires and surveys can be used to measure aspects of design cognition, such as design thinking styles, problem-solving strategies, and creative thinking abilities (Braun et al., 2021; Sarkar and Chakrabarti, 2011). Eye-tracking technology can also be used to measure visual attention during design tasks. Tracking where designers look and how long they spend on different elements of a design, provides insights into the cognitive processes underlying visual perception and decision-making (Hollander et al., 2020; Zhang et al., 2018). Cognitive modeling and computational modeling can be used to create formal representations of the cognitive processes involved in design (Carteni et al., 2022; Cascetta et al., 2015). These models can help simulate and predict how designers might approach different design tasks, providing valuable insights into the underlying cognitive mechanisms.

However, the use of surveys and interviews are limiting because they often rely on self-reporting, which can introduce biases in responses (Brenner & DeLamater, 2016). Additionally, surveys may lack the depth and granularity needed to fully capture the intricate and sometimes subconscious aspects when designing (Schmiedgen et al., 2016). As such, they can provide valuable insights into overall impressions, but as Gero (2011) explained, these insights must be evaluated *within* the design itself, which encourages more direct involvement with the designer.

Protocol analysis involves observing and analyzing designers' thought processes as they work on design tasks. This method provides insights into how designers approach and solve problems (Atman & Bursic, 1998; Green, 1998). Protocol analysis is useful because it allows researchers to capture the "real-time" thinking of designers as they engage in design tasks. It has been used in VR studies to measure how designers navigate complex design challenges (Zhang et al., 2018). Furthermore, verbal protocol analysis has been deployed for evaluating decision-making for real-world behavior in the built environment, such as in virtual scenarios depicting post-earthquake evacuation strategies (Feng et al., 2020).

Thematic content analysis (TCA) has been used in quantifying and understanding the data collected through protocol analysis. TCA involves systematically coding the data to identify recurring themes, concepts, or ideas (Smith, 2015; Strauss & Corbin, 1994). A priori codes can help in the thematic content process, which are predetermined categories or themes that are established before analyzing the data. In the context of stormwater design, a priori codes could include categories related to green infrastructure (e.g., rain gardens, permeable pavement) and gray infrastructure (e.g., pipes, concrete channels).

One issue with thematic content analysis is the interpretation of protocol data can be influenced by the researchers' own biases and perspectives. This can potentially lead to subjective judgments about the significance of certain cognitive elements over others (Critchfield, 1998; Cohn et al., 2008). Prior techniques to mitigate this issue, include inter-rater reliability checks,

where multiple researchers independently code the data and then compare their coding to ensure consistency. Another approach is reflexivity, acknowledging and reflecting on their own biases and how they may influence their interpretation of the data. Relatively new methods have been developed to help quantify and compare differences in what designers think and ideate. These are further discussed in the next section.

Other methods for measuring design ideas

Methods leveraging natural language processing and network science have emerged to enhance the analysis of verbal protocol data. Natural language processing and network science provide a more comprehensive and objective understanding of the cognitive dimensions of design in VR. While many of these methods are rooted in decades of work within linguistics, advancements through computer-driven approaches have streamlined previous laboriousness (Crowston et al., 2012). These advancements offer a promising pathway for researchers to quantify and qualify the impact of VR on design.

Characterizing the design space through quantitative metrics

The creation of the “design space” is a recent method that has been used to measure semantic distance. Gero and Milovanovic (2023) define the design space as the ideas and concepts that designers develop over time, which develop into a design artifact. Within the design space, semantic distance measures how close concepts are, for example, an idea of a “rain garden” may be semantically more similar to a “natural stream” rather than an “underground sewer”. Within full design sessions, semantic distance scores can be illustrated through linkography, which connects all design ideas in a transcript based on their semantic similarity (Goldschmidt, 2014). These quantified, objective scores can represent the overall creativity of designs based on a scale of 0 to 1 (Kan & Gero, 2018; Kenett, 2019): scores closer to 0 represent a wider design space, which could indicate a more creative design, whereas scores closer to 1 are potentially less creative and more linear in design cognition (Gero, 2010). Within large research settings, this form of

analysis can fast-track time-intensive review of large corpora, pointing out generalizable design findings surrounding creativity that traditional analysis may overlook (Kenett, 2019; Kenett et al., 2017).

Large language models can be used to generate design spaces. As Gero and Milovanovic (2020) present, large language models can be used as a tokenizer for semantic distance scores through the SpaCy package in Python. Other Python packages can be used to map the design space as a network. Networkx and Holoviews were used to create structured networks that visually represents design space (Sopher et al., 2022). These networks can take the form of force graphs (Gero & Milovanovic, 2023), allowing for the visualization of connections and relationships between design concepts through the construction of a formal network.

Follow-up quantitative analysis of qualitative datasets can provide benchmarks for comparison among groups but should be used alongside textual analysis. For example, identifying word count and word frequency can be employed to assist with identifying creative or novel design ideas during a design session as well as to consider general outcome-based differences among multiple groups (Toh & Miller, 2014a, 2014b, 2015). However, word count and word frequency represent standalone metrics that must be considered in context of the design experiment. These metrics quantify elements of textual analysis, but cannot provide deeper analysis needed through sentiment analysis to understand how emotion can change why patterns like word frequency occur (Taboada, 2016; Taboada et al., 2011). Content analysis provides researchers with necessary context from a design session (Bernard & Ryan, 1998), but may be streamlined through nascent qualitative methods, such as the use of large language models.

Large Language Models and AI to assess in measuring design ideas

Large-language models can be used to assess and synthesize qualitative datasets. LLMs ingest data across the Internet, such as from Wikipedia pages and can respond to a variety of real-time prompts on most topics (Ray, 2023). LLMs have revolutionized data science, building and

summarizing complex data sets (Hassani & Silva, 2023). As commercialized LLMs like GPT4 and Bard have become more advanced, it can accurately respond to concise tasks, such as asking the tool answers for exams (Fijačko et al., 2023). LLMs can provide qualitative analysis as well and could be a useful tool in streamlining qualitative research.

While the use of an LLM in qualitative research is nascent, this technique has presented promising results in summarizing large qualitative datasets. Previous NLP-driven techniques for qualitative coding have been assisted through tools such as ChatGPT or Bard, which is able to capture context of transcripts and respond to user-based queries (Anakok et al., 2022; Katz, 2023). From this contextual analysis, an LLM has been previously used for thematic coding by summarizing design ideas (Gamielien et al., 2023). While reflecting promising results based on accuracy compared to traditional thematic content analysis, as Gamielien et al. (2023) discuss, technologies such as queried LLMs require more studies on the advantages and limitations. Notably, the authors discuss the granularity and accuracy of design ideas paired with the overall speed of such an analysis. However, a greater understanding of the limitations of such an automated approach vs. human-in-the-loop coding procedures may direct more optimal research methods toward qualitative coding, specifically regarding engineering design ideas.

The assessment of embodiment's impacts on design ideas using various measures is ill-explored. This research examined the impact that embodiment may incur on design ideation, specifically evaluating the use of nature-based solutions and concepts through an LLM. Furthermore, this research analyzed design spaces to assess differences in semantic distance because of embodiment. Following, further quantitative measurements of the design transcripts were used to assess other indicators that embodiment may have, such as word counts and word frequencies. Findings from these quantitative methods were compared to a traditional qualitative review of design ideas from thematic content analysis with a priori codes for green and gray design ideas.

Research Question and Hypothesis

The research question this paper seeks to answer is *how do methods using large language models (LLMs) compare to thematic content analysis (TCA) when evaluating embodiment's impact on nature-based design ideas?* The hypothesis is methods that methods with LLMs provide complementary findings to TCA (Katz, 2023), but will lack the rigor and context-driven analysis that a human-in-the-loop assessment provides (Smith, 2015). Methods with LLMs can serve as a tool for the analysis of text data that builds on thematic content analysis.

The use of an LLM can also provide novel insight that differs from thematic content analysis. By measuring the semantic similarity between words, LLMs can provide a proxy for the design space (Gero & Milovanovic, 2020). The differences in design space between groups will differ from thematic content analysis (Kenett, 2019; Kenett et al., 2017). The expectation is the VR groups will use more semantically different words (Obeid & Demirkan, 2023), reflected in their semantic distance scores.

Methodology

The experiment was divided into three phases (Figure 7). During Phase 1, participants read a case study about the Lick Run Greenway (Appendix). Phase 2 consisted of the VR experience. Phase 3 involved a verbal protocol analysis to collect engineering design ideas, followed by data analysis measuring the differences between groups using TCA, an LLM, and design space.



Figure 7- Phased methods of Chapter 4's research experiment

Phase 1 - Pre-intervention and design experiment setup

To simulate the engineering design thinking exercise, the experience that was created in VR was structured around the Lick Run Greenway case study (Appendix) in Cincinnati, Ohio (Project Groundwork, 2013, 2020). The case surrounds the South Fairmount neighborhood, which implemented a stream daylighting project in response to a city-wide requirement to minimize over 200 million gallons of combined sewer overflows (CSO). Relevant information was given to the participants regarding the lead-up to project selection, including: surrounding geography, population dynamics, economic conditions, results from stakeholder focus groups, potential design options, costs, feasibility, timeframe, environmental impact, and social impact (Appendix). Participants were told to pretend they were a designer for the area of interest in the case study. The case study was summarized by the research team, the design experiment was explained, and participants were instructed that after review of the case study, they were asked to provide new design ideas to alleviate the issues with combined sewer overflows.

Phase 2 - Intervention

Following the case study, participants were split into three groups. The control group (n=33) was given the case study, which includes plan view drawings and descriptive figures of buildings existing in the South Fairmount area (also given to all groups). The bird group and self-lens group (n=34 and 35, respectively) experienced a VR representation of the South Fairmount neighborhood along with the plan review materials.

Technical Equipment

For the VR groups in the experiment, the same equipment was used: an HTC Vive with HTC Vive wand controllers. Sound output was provided through the HTC Vive over-ear headphones. The VR experience executed on a MSI GE76 Raider with NVIDIA GeForce graphics. The institutional wireless service provider, “eduroam”, was used in an on-campus laboratory setting. Lighthouses (motion detectors) were placed within an 8’ x 10’ space to form the playspace.

The Unity Asset Store was used to build the virtual environment and avatars. These assets were used to create an assimilation of the infrastructure surrounding South Fairmount, live traffic, ambient sounds, public amenities, and avatars. Assets were edited and placed based on pictures and Google Earth images of South Fairmount prior to the construction of the Lick Run Greenway. A side-by-side comparison of the virtual environment and the inspiration from the South Fairmount neighborhood can be seen in Figure 8.



Figure 8 -Comparison of the virtual environment loosely depicting South Fairmount and a street photograph from South Fairmount.

The virtual walkthrough

Prior to the VR groups proceeding with the virtual environments in a controlled lab setting, a crash course in VR occurred. During this crash course, the basics of VR were discussed, such as expectations during locomotion, the presence of teleportation, how to use the control sticks, and the possibility of lightheadedness. The perspective taken between the two groups can be compared in Figure 9:

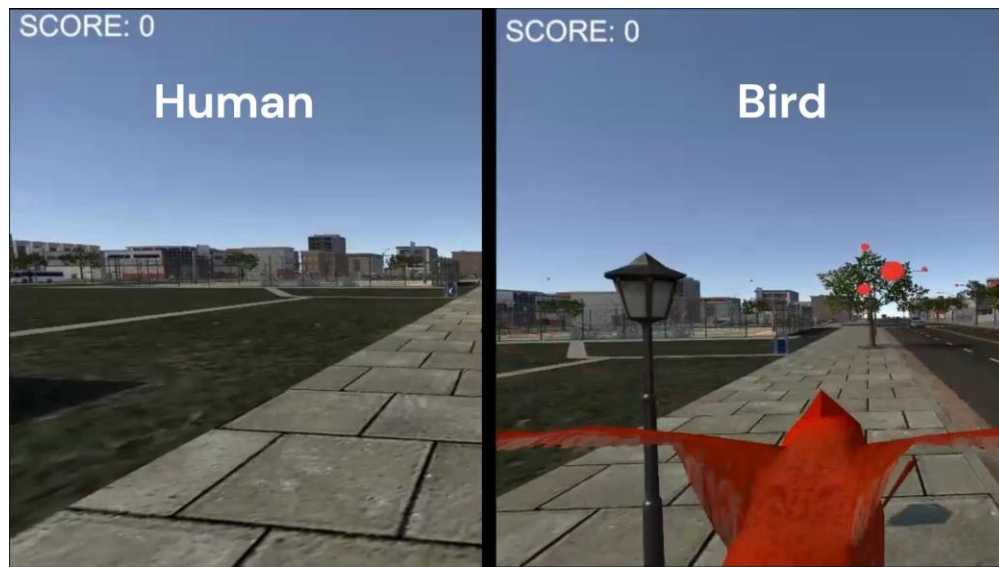


Figure 9 - The comparison of embodied (right) vs. self-lens (left) perspectives in the VR environment for this research.

The VR experience was presented as a wayfinding exercise through a portion of the South Fairmount neighborhood and was gamified. Gamification is the process of implementing game-like elements to a non-game setting, such as a design walkthrough (Kim, 2014; Villagrasa et al., 2014). Participants were instructed to gather tokens that were conspicuously placed throughout the environment. These tokens plotted the course that participants were requested to take for the experiment. To collect the tokens, participants moved in the virtual space directly on top of the token, reflecting an increased score of 100 points for each token collected. The course plotted by the tokens created a form of control in the design study by ensuring that participants are exposed to the same aspects of the virtual environment and interacted similarly.

Phase 3 - Post-intervention

Following the intervention, all participants were instructed to ideate solutions that eliminated CSO that residents of South Fairmount would prefer based on the case study. Participants were instructed to think aloud using verbal protocol analysis (Green, 1998); this audio was recorded and transcribed using nVivo, which was manually corrected. Participants were allowed to reference any of the case study and ask questions about the case during the ideation session.

Following the ideation sessions through verbal protocol analysis, NLP methods were used to assess the design ideas mustered between groups and how the outcomes compare to a traditional TCA. An analysis of design space was used to act as an early indicator for a potential increase in creativity after virtual embodiment. A LLM was also used to synthesize the large corpora from the verbal protocol following the design sessions, which reflects the process taken by traditional, human-in-the-loop TCA. Altogether, these methods were combined to summarize the impact that embodiment has on engineering design ideas through multiple metrics.

Thematic Content Analysis

nVivo was used for data management and transcriptions, which were corrected by hand. A three-step qualitative coding process for thematic content analysis was employed for the transcriptions (Cantelmi et al., 2021; Creswell & Poth, 2018; Smith, 2015). Since previous literature for stormwater infrastructure presents most ideas on a spectrum of gray and green decision-making (Bell et al., 2019), these codes were used for a first evaluation of design ideas as “gray” vs. “green”. Trump and Shealy’s (forthcoming, Chapter 2) work for lumping green, gray, and socioeconomic ideas was used on the same dataset and was represented as the first “pass” for thematic content analysis. The second round of coding further broke down these design concepts into design ideas e.g., green >> planting trees to absorb stormwater, and the final round of coding built contextual patterns of each ideation session to determine relationships among design ideas

across participant groups. To ensure uniformity, coding was performed by a research associate and 10% of the coded transcripts was compared by the author's established codes.

The final coding pass was utilized to ground results into generalizable theory, which is presented in the Results section. Strauss and Corbin (1994) represent a method for transferring actual data into concepts, which can then be generalized. Through this theory, this research employed the axial coding technique to group codes based on green, gray, or emergent forms of thinking. Ultimately, the final pass of coding for this research intended to discover generalizable differences between groups (control, human, and bird) to understand how embodied VR changes design ideas based on inclusion of nature-based solutions.

Since the main objective of this research was to discover differences in methodological approaches for evaluating embodiment's impact on design ideation, generalizations were focused on the evaluation between groups. Design ideas were counted for each group to point toward possible themes for the researcher to analyze further. While counts for design ideas were useful, the main element of TCA for this research was its ability to produce context-based insight into the process of design. The process that was of most interest for this research was how each participant produced design ideas over time to minimize CSO. Themes were generated based on the analysis of this process.

Natural Language Processing

Previous work in NLP-driven methods for conducting qualitative analysis were used in this study. First, Gero and Milovanovic's (2020) process of using SpaCy as a proxy for the design spaces. The large English language model of SpaCy was downloaded in Python and was used to calculate semantic distance scores for each participant. At the end of the design space analysis, each participant's verbal protocol (transcript) was given a score ranging from zero to one. Semantic distance scores closer to zero indicate a greater semantic distance between design words. Wider design spaces may indicate more creativity (Kenett, 2019). Scores closer to one indicate a smaller

semantic distance, meaning the design space that was explored was narrower, which may be more ideal for process-driven design tasks that require uniformity. ANOVA tests were used to compare all three groups to assess differences in design spaces.

Follow-up statistics were also measured on the transcripts. As a measure of effort, word count of each participant's transcripts was compared through ANOVA tests. Furthermore, word frequencies were assessed, aiming to identify any change between groups for the number of words spoken and the occurrence of singular words (e.g., park, tree, and water).

Following this analysis, design ideas were compared to the design ideas discovered by traditional coding during TCA. The method highlighted in Gamielien et al. (2023) and Katz (2023) for a LLM's use in qualitative thematic coding was utilized to feed ChatGPT as the selected LLM with all design transcripts and instruct it to identify all design ideas. The prompt that was provided was: "What are all of the design ideas in these transcripts?" The design ideas for each participant that the LLM provided can be seen in the Appendix. Furthermore, the design ideas that the LLM provided were further broken into design themes through the prompt for each group: "Based on these design ideas, what are the key themes from all of the design ideas?" All data was anonymized, such that the only information provided to the LLM was the corrected transcripts with no identifiable information.

Reflection of Traditional vs. Automated Qualitative Research Methods

This research compares multiple methods for evaluating the impact of embodiment toward engineering design ideas. While traditional, human-in-the-loop coding techniques through TCA have been utilized for decades, advancements in qualitative research for NLP have ventured toward automation. Following the review and comparison of embodiment's impacts on engineering design ideas through multiple methods, this research presents possible benefits of incorporating newer, even emergent methods in automating the qualitative review process. Some of these benefits, as discussed by Gamielien et al. (2023) and Milovanovic and Gero (2020), are

improvements in speed of review, rapid scalability for any inquiry, replicability, the provision of quantifiable benchmarks of qualitative data, and the increase in scale of data ingestion with fewer resources. For example, this research presents an analysis of design space's ability to serve as an early, loose indicator for design creativity in this qualitative research with a large sample size. The use of a LLM is analyzed for its ability to summarize large corpora, identifying design ideas in the large corpora from a design ideation session. Broad implications that these newer methods of automation may have to the broader field of engineering design ideation are discussed.

Results

The results below are organized to present an overview of TCA results in comparison to automated methods. Following the analysis of design ideas using a LLM, the semantic distance results with follow-up quantitative metrics are presented.

Thematic Content Analysis

Themes were developed among groups to identify the influence that virtual embodiment had on the incorporation of nature-based solutions during design. These themes are presented in Table 4, with supporting evidence of design ideas and excerpt text following. An overview of each of the design themes can be described as:

- Theme 1 – The control group gravitated toward gray design decisions: Based on contextual analysis, the control group explored a desire to build with nature-based thinking, but ultimately relied on gray infrastructure to minimize CSO
- Theme 2 – The bird group fused socioeconomic benefits to nature-based solutions: After flying in VR, the bird group ideated quality of life improvements that could be made possible by nature-based design ideas
- Theme 3 – The VR groups provided robust descriptions of nature-based design ideas: In comparison to the control group, the VR groups had more occurrences of nature-based

design ideas on average and provided a richer description of how nature could be used to minimize CSO

The supporting design ideas to each of these themes are presented in Table 6, with their number of occurrences and a supporting excerpt providing additional data that aided the discovery of the theme. In this content analysis, the number of occurrences pointed to repeated design ideas that were generalized by the reviewer after a contextual analysis of how the design ideas were discussed for their use in minimizing CSO. Overall, the goal was to identify generalized design differences at the group level to uncover embodiment’s impact on the design process.

Table 6 - Overview of design ideas and themes from thematic content analysis

Theme 1 – The control group gravitated toward gray design decisions	
Representative design ideas – gray design decisions	Number of occurrences
Adding concrete or cement surfaces for flow of stormwater into inlets/outlets	11
Adding surface parking for stormwater to flow into inlets/outlets	2
Adding treatment plants or underground tanks for stormwater storage, underground storage	23
Construction of buildings and commercial spaces that include underground storage of stormwater	7
Drainage and sewers – upgrades and increased size to convey stormwater	24
Filtration system – cleaning stormwater before it is emitted into a water body	0
Impervious surfaces – artificial fields to capture or transport stormwater	1
Management or organization of controls in underground system, tanks, and pipes	44
Roadwork, roadways, traffic, tunnels, bridges – considerations of stormwater conveyance surrounding other infrastructure	8
<p>Representative excerpt: <i>“I have one of two options - I can go underground, but I can go above ground. Above ground would help, but not as much. So I'm thinking above ground ... there's different elements that I could approach. I have nature, but what can I do with nature? ... I think I would just add more pipes, I don't I don't know what other approach I could take”.</i></p>	
Theme 2 – The bird group fused socioeconomic benefits to nature-based solutions	
Representative design ideas – nature-based solutions	Number of occurrences
Adding bike paths or walkways that are permeable for stormwater infiltration	39
Adding or maintaining parks or recreational spaces to increase soil permeability	94
Adding or modifying green roofs or rooftop detention	1
Adding permeable pavers or permeable surfaces for better soil absorption	25
Adding trees, greenery, shrubbery, or a garden for stormwater absorption	88

Environmentally conscious thinking – overall concern with nature and a proclivity to design with nature-based elements	2
Green infrastructure or maintaining green spaces based on aesthetics and function for stormwater	19
Green technology, LEED certified buildings	0
Product or source control – modifying tributary systems to collect stormwater within South Fairmount	2
Stormwater collection material - repurposed, renewable, recyclable resources to prevent stormwater contamination	2
Bioswales or grade modifications - taking land's natural layout, landscaping, and natural resources into account for better stormwater conveyance and infiltration	14
Water collection into a body of water, retention pond, or sustainable water intake	52
Representative design ideas – socioeconomic ideas	Number of occurrences
Adding or maintaining parks or recreational spaces for public enjoyment	94
Adding parking spaces or areas for increased access to South Fairmount	6
Community consideration with housing, water availability, and construction	24
Creation of commercial space, job opportunities, bringing socio-economic or money to the area	28
Improving or maintaining water, air quality, smell, and noise	2
Modernizing or revitalizing the buildings, houses, landscape, or town	10
Reduce traffic – lane removal or rerouting highway systems	1
Relocation of individuals in the community	2
Economic growth considerations for increasing livelihood metrics within South Fairmount	8
Taking neighborhood demographics, crime rates, loitering, safety, and other community factors into consideration	1
Reduce urban heat island effect	2
<p>Representative excerpt: <i>“My mind kind of goes to like a Central Park style type situation where you have a lot of green space ... maybe like some benches or something just to kind of enhance the space and encourage people to want to use it as is ... To kind of improve some of the economics of the area or, like, you know, socio economic status of the area, you can add in maybe some convenience stores or something that's going to be useful, like a grocery store or something like that and then maybe have like a green roof or rain barrels or anything that can kind of help those alternative BMPs that can kind of help reduce runoff because you are kind of maintaining that impervious”</i></p>	
Theme 3 – The VR groups provided robust descriptions of nature-based solutions	
Representative design ideas – nature-based ideas	Number of occurrences – both groups
Adding bike paths or walkways that are permeable for stormwater infiltration	54
Adding or maintaining parks or recreational spaces to increase soil permeability	151
Adding or modifying green roofs or rooftop detention	5
Adding permeable pavers or permeable surfaces for better soil absorption	34
Adding trees, greenery, shrubbery, or a garden for stormwater absorption	151
Environmentally conscious thinking – overall concern with nature and a proclivity to design with nature-based elements	11

Green infrastructure or maintaining green spaces based on aesthetics and function for stormwater	44
Green technology, LEED certified buildings	3
Product or source control – modifying tributary systems to collect stormwater within South Fairmount	3
Stormwater collection material - repurposed, renewable, recyclable resources to prevent stormwater contamination	7
Bioswales or grade modifications - taking land's natural layout, landscaping, and natural resources into account for better stormwater conveyance and infiltration	21
Water collection into a body of water, retention pond, or sustainable water intake	109
<p>Representative excerpt: <i>“I want there to be a park. Whether that be a playground ... more crosswalks can <u>access</u> the park to be in between these two roads right there, so there's going to be a playground. And I want there to be a lot of dirt and plants around the playground ... to help <u>absorb storm water</u>... then this block needs a water treatment plant. And actually, I'm going to keep this segment for playgrounds. Put the water treatment plant on the right side. And I think that. We can put in some more natural water intake options ... well, bioswales ... a community garden with <u>sustainable water intake options</u> ... what can I add here that would help more <u>water be like sustainably</u> ...”</i></p>	

Seven design ideas were mentioned by the VR groups that were not mentioned by the control group. These ideas include:

1. The adoption of a smart stormwater system that can reroute stormwater in heavy flow conditions
2. Redesigning the stormwater system in favor of South Fairmount's natural hydrological characteristics
3. Creation of a pond-centric design that serves as a focal point for South Fairmount
4. Stream daylighting as a nature-based conveyance system for stormwater
5. Improved land-use planning to be more receptive of South Fairmount's community and ability to uptake nature-based and gray solutions
6. Implementation of a road diet to alleviate traffic
7. Community center adoption to encourage socioeconomic diversity in South Fairmount

LLM Compared to TCA

The LLM presented granular design ideas when compared to TCA. Excerpt 1 (Appendix) presents a mix of green and gray ideas, bisecting the area of interest with water features against piping systems and a new water treatment plant. The LLM summarized the design ideas as follows:

1. *Divide the large area into two sections: park area and industrial storage area.*
2. *Create a series of retention ponds or one large pond in the park area to collect stormwater.*
3. *Install piping to transport stormwater from the retention ponds to the second half of the lot.*
4. *Construct a smaller, auxiliary water treatment plant in the industrial storage area to handle excess stormwater during heavy storms.*

5. *Connect the outflow from the auxiliary water treatment plant to the main storm sewer system.*

The above design ideas from Excerpt 1 present a chronological flow of ideas from the ideation session. This flow was representative of ideation sessions that were linear, i. e., when participants would connect one idea to the next without circling back to previous ideas. In this instance, the LLM identified basic design ideas, removing the rationale behind why the design was selected. For instance, in Excerpt 1, Participant H84 discussed his reasoning for connecting a piping system from the retention ponds to a local water treatment plant because of a cost trade-off for materials needed for a bigger piping system overhaul. This level of detail was omitted from the LLM's feedback.

The LLM technique incorporated more background and context. For example, the discussion of the auxiliary water treatment plant involved more context. The design ideas from the TCA analysis are more concise, identifying analysis of behavior within the space and plotting design ideas in their respective areas.

Organization of Ideas

During the ideation sessions, participants would often mention one design idea, consider other possibilities, and then either connect the ideas or build on the first idea. An example of this organizational pattern is seen in Excerpt 2 (Appendix):

1. *Re-route the eastern road to create a large open space.*
2. *Remove side streets and houses to create a central area for people to gather.*
3. *Divide the area into four quadrants:*
 - a. *Quadrant 1: Community garden with a shed and tools for residents.*
 - b. *Quadrant 2: Park with a skate park, water storage tanks, basketball court with permeable pavers, walking trail, and separate play areas for younger and older children.*
 - c. *Quadrant 3: Trails, trees, and a detention pond with wildlife, connecting to the walking trail in Quadrant 2.*
 - d. *Quadrant 4: Mixed-use development with shops on the bottom and apartments on top, with a permeable paver parking lot and stormwater runoff directed to holding tanks.*
4. *Incorporate permeable pavers and green infrastructure throughout the design to manage stormwater and create a more sustainable environment.*
5. *Focus on creating a people-centric space that also supports the needs of animals and the environment.*

Excerpt 2 presents a complex design idea. The LLM summarized the ideas into an organized structure, identifying more granular design elements through the quadrant-based design against

broader design themes in design ideas 4 and 5. In this analysis, design details were omitted that may be important to a design's feasibility or creativity. Participant B58 ideated a series of stormwater holding tanks underground that would hold a skate park on its surface. In this example, both the skate park and the water storage tank in design idea 3b, but assumed mutual exclusivity rather than synergy.

In comparison to TCA, the design ideas presented by the LLM seem to be more organized.

Below is an overview of the design ideas coded through TCA for the same participant:

1. *Change up the street design to maximize space*
2. *Remove any existing housing and blight*
3. *Implement a quadrant system where quadrants closer to the city are livelier and quadrants farther from the city are quieter*
4. *add in underground storage while putting a skate park on top for community enjoyment*
5. *Storage tanks need to feed into the existing sewer system somehow*
6. *Keep the basketball court, but make it a permeable pavement*
7. *Add in swathes of permeable pavement as a walking trail*
8. *Add a community garden that is maintained by a local club - referenced Brooklyn as a successful case for community acceptance*
9. *Add a community shed with shared tools for garden upkeep*
10. *Encourage mixed use development with shops and apartments*
11. *Add a permeable paver parking lot*
12. *Add in trails and trees - considered the plight of wildlife and the bird*
13. *Add in a retention pond with fish*
14. *Encourage a revitalization of the area so people can enjoy the neighborhood more*

The LLM lumped all of the design ideas neatly based on the quadrant system proposed by the participant. In the TCA coding, while the quadrant system was noted, design ideas were organized by order of occurrence and did not lump them into a categorical structure based on location.

Accuracy of Ideas

The use of an LLM was similar in its assessment of design ideas compared to the the TCA. Similar to Gamielien et al.'s (2023) process, Cohen's Kappa was measured by evaluating the amount of observed agreement in design ideas (LLM) vs. the amount of expected agreement (TCA). Of the 12 random design sessions selected, the LLM recognized 54 occurrences vs. TCA's 47 occurrences across 10 unique design ideas. From the output of this analysis Cohen's Kappa = 0.81, which denotes a high degree of similarity between the LLM and TCA design codes. Table 7 presents a comparison of the LLM identified design ideas and the results from TCA:

Table 7 - Comparison of LLM vs. TCA design ideas

LLM Design Ideas	TCA Design Ideas
1. Reduce road lanes to one in each direction for both north and south roads, allowing for street parking and landscaped areas.	1. Implement a road diet solution to remove lanes
2. Make sidewalks narrower to reduce impervious surfaces.	2. Make the previous lane street parking
3. Move the park to the center of the block and add more trees for better soil infiltration.	3. Add in landscaped areas to improve safety and to attribute to the overall greenness of the space
4. Include a pond in the centralized park area.	4. Referenced New York City, then discussed the addition of a central park with a lot of trees planted
5. Add bench-style seating and exercise steps around the pond.	5. Add in a pond
6. Develop mixed-use buildings on the east and west sides of the park, with apartments, stores, and office spaces.	6. Add in bench style seating and steps, referenced VT's campus as an example
7. Create a ditch in the landscaped areas on either side of the road to slow down water and reduce concentration.	7. Add in mixed use development and grocery stores
8. Install underground detention for stormwater management.	8. Add in ditches that lead to the pond
9. Eliminate parking within the plot of land, relying on street parking instead.	9. Include underground detention
10. Add a safe and well-designed bike lane to the road.	10. Add bike paths and bike lanes

A difference presented in Table 7 between the LLM and TCA is the context-driven discernment of new design ideas. For instance, Participant B59 in Excerpt 3 started the design ideation session with the desire to increase parking through a road diet. Later in the design session, she circled back to this idea, proclaiming the need for street parking, but did not add anything that was not already stated previously. The LLM did not discern this context and instead put this as two separate ideas around the context of parking. The full table of design ideas can be seen in the Appendix.

Themes were developed for individual groups based on the design ideas produced by the LLM. Each group's full set of design ideas were prompted back into the LLM with the goal to produce

a generalized set of themes for each group. The query used was “What are the themes for the following design ideas?” Table 8 presents the siloed themes for each group.

Table 8 - Overview of themes for each group

Bird group (Bird)	Self-Lens Group (Human)	Control
1. Stormwater management and environmental sustainability	1. Stormwater management and green infrastructure	1. Integration of nature and green infrastructure
2. Community engagement and recreation	2. Community development and revitalization	2. Utilization of gray infrastructure
3. Greenery and aesthetics	3. Sustainable and eco-friendly solutions	3. Urban redevelopment and community engagement
4. Sustainable urban planning	4. Aesthetic enhancement and community well-being	4. Sustainable design and water management
5. Water treatment and quality control	5. Underground infrastructure and technology	5. Separation and management of sanitary and stormwater systems
6. Accessibility and safety	6. Traffic and road management	6. Balancing environmental, social, and economic impact
7. Collaboration with nature	7. Environmental considerations	7. Incorporation of water treatment plants and filtration systems
8. Innovative design solutions		8. Innovative approaches and long-term planning

To develop overarching themes between groups similar to the approach used for TCA, the design ideas and siloed design themes from the LLM were assessed by a reviewer. Differences between groups were assessed, which resulted in the following themes:

1. The bird group tended to ideate toward the benefit of both nature and the surrounding community, gravitating to a synergistic relationship through minimizing stormwater runoff.
2. The self-lens group was concerned about environmental sustainability, but encouraged more ideas toward community planning and management wins
3. The control group discussed the importance of nature-based design, but commonly called upon gray infrastructure through separating sewer systems and the inclusion of new water treatment plants

Implications of Using a LLM for Analyzing Design Ideas and Themes

The use of a LLM notably sped up the structured process for content analysis and generated results that were nearly identical and even more robust than traditional TCA. However, prompts entered into an LLM were required to be as specific as possible, avoiding too many unnecessary words that were not descriptive of the task (Lynch et al., 2023). In some cases, the LLM used in this research may have double-counted a few design ideas by not picking up on the iterative design process. For example, when a participant discussed the development of a park and ideated different features the park should have, the LLM presented the idea of a park more than just once. However, there did not appear to be any recognizable pattern to this double-counting and it was rare in comparison to the overall accuracy of ideas compared to TCA.

The structure of an LLM was best situated for design ideas rather than cross-comparing design themes among groups. After the creation of the siloed design themes, notable researcher time was required to review the design ideas and siloed design themes to fully develop a comparison of group-based themes. Final design themes identified by the LLM compared to the TCA seemed to share many similarities, however, the burden of proof was placed on the researcher for producing design themes during the final review process. Moving forward, an LLM can streamline the qualitative review process for design ideas and can deduce embodiment's impact on these ideas. However, the production of design themes is more appropriate for traditional, human-in-the-loop coding procedures to create generalized findings between groups.

Conception of Design Space: SpaCy and Supporting Statistics

Embodiment changes semantics. Table 9 presents an overview of semantic distance scores between groups using the full transcripts: the bird group witnessed significantly lower semantic distance scores, which is a proxy for larger design spaces (words spoken were semantically less similar than in the human or control groups). The reported effect size was small (Cohen's $D = 0.05$).

Table 9 - SpaCy semantic distance results

Group A	Group B	p	Means (Group A; Group B)
Bird avatar	Control	<0.001	(0.312; 0.321)
Bird avatar	Human avatar	<0.001	(0.312, 0.321)
Control	Human avatar	-	(0.321, 0.321)

To supplement Table 1, a follow-up analysis of each transcript’s semantic distance results was also explored only using nouns. Common prepositions, adjectives, and articles were removed from the transcripts that did not expressly relate to a theme or a design idea. Table 10 presents these results, which agree with the findings from Table 10: the bird group presents a larger design space than the control or human groups.

Table 10 - Noun-only semantic distance results

Group A	Group B	p	Means (Group A; Group B)
Bird avatar	Control	<0.001	(0.289; 0.295)
Bird avatar	Human avatar	<0.001	(0.289, 0.295)
Control	Human avatar	-	(0.295, 0.295)

With the finding that the design spaces explored is larger, the next consideration was the *depth* of the ideation sessions, using word count as an initial metric. Table 11 presents these results of the average word count within the transcripts for each group and their standard deviations. No significant change was found between groups.

Table 11 - Word count results

Group A	Average Word Count	Standard Deviation	p-value
Bird avatar	470	264	p=0.58
Human avatar	405	246	
Control	403	259	

Several words were stated more or less frequently. The results from the LLM provided backing for the selection of certain words that appeared commonly in the design ideas. Table 12 presents an overview of six representative words that were stated significantly more or less between the groups: tank, grass, park, pipe, water, and tree. The bird group stated the words “grass”, “park”,

and “tree” significantly more than the control. Other comparisons are presented in Table 12, with small effect sizes between each comparison (Cohen’s D = 0.05 – 0.1).

Table 12 - Word frequencies between groups

Word	B-C (mean difference, p-value)	B-H (mean difference, p-value)	C-H (mean difference, p-value)
“Tank”	0.005; 0.03*	0.006; 0.01*	0.001; 0.95
“Grass”	-0.001; 0.01*	-0.000; 0.99	0.006; 0.02*
“Park”	-0.011; 0.00*	-0.000; 0.96	0.011; 0.00*
“Pipe”	0.004; 0.08	0.006; 0.01*	0.002; 0.68
“Water”	0.006; 0.03*	0.007; 0.00*	0.001; 0.86
“Tree”	-0.006; 0.02*	0.001; 0.90	0.007; 0.01*

Implications of using design space analysis with TCA

The findings measuring the semantic similarity of words aligns with the findings of the TCA. The bird and self-lens groups presented much more detailed design ideas compared to the control group. In comparison to the results of the TCA, both VR groups provided design ideas that the control group did not.

With a sample of 102 designers, the automation of semantic distance scores helped point toward the existence of a difference in the ideas generated. However, the burden was still placed on the researcher to verify and discover the nature of that difference. While simple statistics for dominance of ideas (e.g., word count and word frequency) help to uncover the nature of these differences, the semantic similarity between designers provides an additional insight.

Discussion

Embodiment encourages nature-based solutions. For the bird group, nature-based solutions were contextually more geared toward benefitting the environment itself. As this group embodied a bird that flew in an urban setting, more consideration for nature-based solutions and socioeconomic improvements arose, presenting more altruism based on the avatar (Bertrand et al., 2018; Reinhard et al., 2020). In the case for this research, not only did the bird group ideate toward nature-based solutions, but the overall themes were geared toward environmental sustainability.

Comparing this finding to the self-lens group, while nature-based solutions were also a theme, they were geared toward anthropological benefit, such as through community benefit and restoration. In relation to previous literature surrounding nature-based solutions, co-benefits toward communities are commonly discussed to spur sustainable city development (Casal-Campos et al., 2015). The self-lens group mostly ideated around these co-benefits, which were tied to nature-based solutions.

This research contributes to existing literature by discovering a difference in design and pro-environmental behavior from the lens of embodiment: self vs. other. Markowitz et al. (2018) reflects one of the only other instances of comparing multiple lenses of VR (self and other). However, the authors were unable to discern a difference between groups based on climate change educational studies as a metric. This research has revealed that a difference does exist between self and other lenses (human vs. bird, in this case), which is presented during design. In the instance of this research, the self-lens was more inclined to focus on community-based benefits through urban planning, whereas the embodied lens implemented more instances of green thinking and fused the ideology toward community development.

In comparison to TCA in this research, which utilized a traditional approach for thematic content analysis of the design ideation transcripts, these themes are notably similar. The bird group blended environmental and community benefits and was more likely to incorporate green ideas into their designs. The control group was more likely to be rooted in gray design, while calling upon the penchant for more nature within urban planning. Both the self-lens and the bird groups were more likely to include community-based ideas into their ideation sessions, is described as an emergent theme for socioeconomic benefits.

The benefits of using large language models for automating methods for qualitative data are process-specific. Automated large language models substantially shorten the time and researcher requirement for qualitative content analysis, specifically surrounding the three-step coding

method (Creswell & Poth, 2018; Smith, 2015). The results of this study confirm the implications of using a LLM for identifying design ideas toward embodiment (Gamielien et al., 2023): the ideas generated are granular, accurate, and organized as this research discovers. However, to create cross-group generalizations, a burden is placed on the researcher to fully analyze the design ideas and individual design themes between groups in order to adequately assess group-based differences. While TCA is time and resource-intensive as a qualitative review method, it provides a researcher with a substantially better understanding of the interconnections within the data *because* the researcher was responsible for their discovery.

To provide a rationale for using large language models for qualitative research, this automated method can be used under certain conditions with important caveats. If generalization is the goal of the research, TCA should be chosen because the process immerses the researcher within the data to enable him or her with the ability to adequately generalize the findings. If, however, the research's goal is to provide specific endpoints, like a cumulative list of design ideas, the speed and robustness that LLMs provide can be more useful than TCA.

Alone, the LLM was unable to compare and contrast the vast amount of design data between all three groups but was useful in synthesizing design ideas (Katz, 2023). Human input and comparison of the design themes generated by the LLM was required for a cross-comparison between groups.

The synthesis of design ideas from the LLM's aligns with previous literature on the use of VR to influence design cognition. As Ahn and Bailenson (2012) discuss, pro-environmental behaviors can be curbed by embodied VR. Schultz (2000) provides further evidence, discovering an increased likelihood to promote action toward limiting emissions after embodied participants viewed an animal living in polluted air. Pro-environmental behaviors are extended to design thinking through the use of biophilic design, which is spurred by the human-nature connection (Trump and Shealy, forthcoming, Chapter 2; Bertram and Rehdanz, 2015).

The use of SpaCy to quantify the semantic distance of design concepts also aligns with prior research that embodiment shaped the breadth of ideas when designing. Herrera et al. (2018) find the link between perspective-taking in VR to trigger more robust design considerations and output due to the vividness that VR provides. Embodiment further heightens this type of immersion and may help spur empathy toward an avatar (Bertrand et al., 2018).

More work is needed surrounding the characterization of the design space through semantic distance. The semantic distance method developed by Gero and Milovanovic (2020) helped quantify the difference between ideation sessions between groups in a new way. A limitation of this approach is the potential for oversimplification when reducing complex design concepts and ideas to single words or phrases. One-word comparisons may lack the nuance and context necessary to fully capture the richness of design thinking and the subtleties of the design space. Additionally, the reliance on single-word comparisons may overlook important relationships and associations between concepts, leading to a less comprehensive understanding of the design process. Sentiment analyses with n-grams could help track strings of design ideas beyond singular words and trace emotional connotations (Dey et al., 2018). Furthermore, network-based approaches could be created to map a network of all of the design ideas based on first occurrence, deriving how design ideas change over the full period of the design session (Gero & Milovanovic, 2023; Sopher et al., 2022).

Overall, the use of methods that employ LLMs presents a supplemental technique to aid thematic content analysis. The synthesis of design ideas that the LLM provided was more granular, organized, and approximately as accurate as the synthesis of design ideas produced through TCA. Furthermore, an LLM can synthesize the process of analyzing the influence of embodiment on design ideas much faster than TCA. The conclusions drawn by the LLM surrounding design themes could only be considered on an individual basis as opposed to comparing the themes between groups.

Conclusion

Embodied VR influences how ideas are generated during engineering design. With different forms of embodiment, the type of ideas that are generated also change. This was observed in both the TCA, synthesis of ideas from the LLM, and change in semantic distance of design concepts. Embodied avatars were useful in helping designers provide more detailed design ideas and using larger, more semantically different words in describing their concepts. The use of LLM tools serves as a viable supplement to aid thematic content analysis. However, these methods should not be used alone; thematic content analysis provides the ability for cross-comparison between groups the LLM was not able to adequately compare between groups. The comparison between groups was possible through measuring the semantic similarity of words using SpaCy but this approach lacked the contextual details that TCA provides.

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Appendix

Representative Transcript Excerpts

- Excerpt 1 – H84

“So the first thing I noticed walking around was just how large that area was. I kind of noticed that it was kind of split into two areas, one where the park sat and the other where the industrial storage was at. So what I was thinking, since it's a pretty flat area, the half with the park half basically you can make that into like a either a series of retention ponds or just one large pond. So kind of like. And I like that. And that's where you will collect extra storm water that's coming down during the storm. And then with that, you can have piping that will transport that, that water to the second half of the lot, which I want to see like a water treatment plant. More. So this one doesn't have to be as big as the main one, like we were talking about earlier, we can make it like an auxiliary system where you'd only activate it when you can see that the load would be too too big for your main plan. For example, like when there's a storm coming in, then you could pipe all that water from the retention ponds. To that water treatment plant, so that'll save you a ton of money and having to build out a whole new piping system to take that water, to treat it at the main plant. And then from here you can make like the like an outflow connect to your your main storm sewer. But that's pretty much my idea.”

- Excerpt 2 – B58

“All right, so we have these two main roads in the Cincinnati that are really cutting off. The bigger it's really chunking up the space. So my plan would be to keep this the northern road where it's at. But this was the east. I'd actually probably bring it down. More towards the bottom and then link it back in. It may seem inefficient, but then that gives us this nice big open space. I would take out of the road going west to east until you hit that main artery and close that off. This would get rerouted. This is all gone. East Side roads take them out. They're not really like if this is just being used right now. As. Three Affair. I want to make a center that people want to stop at. Right? So these side streets gone. There's no houses. They're taking out the houses of houses and any more people are living in them. They're eyesore. They're probably going to be considered blight soon anyways and not to be taken down. So in this redevelopment, we're going to take them out. With that, so in I'm going to I'm going to do a little bit for quadrant kind of kind of deal. And we're all quadrant one. I shall do like a coordinate system that makes one north eastern side Quadrant two in the northwest, quadrant three near southwest and Quadrant four in your southeast. All right. So. Four Quadrant, I'm a certain quadrant two in Quadrant to my idea is to resign as a park is the farthest quadrant away from the main arteries going into the city, so it might be a little bit quieter. You don't have as many outsiders coming into it, a safer, presumably safer area for kids to play for the storm water solution. I do really like the idea of the skate park with the water storage tanks underneath. It's a dual purpose people most likely won't realize that their their storage tanks are even there, so I probably put the storage tanks like right near the middle. Storage tank. Skip work. And those storage tanks would then feed into the door sewer system. But at a later point in time when the system isn't as overwhelmed during a rain event, some were holding tanks then. Storage, really, OK. And then so I say, all right, now that they have like a kickball field and like a basketball court. I would probably keep the basketball court next to it, but instead of having as like an actual basketball court having as a permeable paper court, it might have a little bit more mate and associated to it. But it's not going to be like a massive flat area for water to gather and

not go anywhere. Permeable pavers. Here and then at the North End here, I would probably do. Like. Two different kinds of parks, so on. Oh, and a walking trail, so you see me walking trail, that's going to go all the way around it. Permeable pavers, obviously. Around it. Put in trees along like on both sides of the walking trail and then in the center. Of the walking trail, we're going to have like a. A two to five year old park. And then like a six to 12 year old park, many different things, and they get to have different stuff, so that's going to be like want to bring people in because like now you have something for a little bit everyone. You have something for your small kids, your middle aged kids like Skate Park Basketball Court, you have stuff to do if you don't do things like this nice walking trail, trees you can kind of ignore in the city, but like, you're kind of now. Having a little oasis and an area one, since it is like a little bit higher trafficked along that arterial, I'm thinking more community garden. It'll give you inner air a place for the rainwater to go. But also like supporting the people who do still live in that community. I think studies have shown that in Brooklyn, having those community gardens actually brought people like wanting to move to Brooklyn instead of being like, Brooklyn is gross. And let's do that. So Community Garden out here. And then within that community garden have. Look, a little a little community shed some industry tools out, but like accessible to. A club or something that's going to run this. So three quadrant student for only a little bit of trying to bring life back into this area, so we've taken care of like the vegetation part, but like actually bringing economic growth back in. And so quadrant or since it is like right at the intersection of these two main arterial highways, I would probably put like a mixed use. So like shops in the bottom, apartments on top. Now you have people living, working, playing, making it a centralized community, actually. So like shops on bottom. But. And I'd probably only make it three to three stories, like nothing like massively huge three stories steps, two rows of two things apartments, one of shops. And now you have great access from these. Interstates into. The city and into this area, keeping with our theme of permeable pavers, we're going to have a permeable paver parking lot that is also like this storm water that's generated from this parking lot, even though it is permeable pavers like it doesn't clearly collect everything. So this storm water runoff is going to go into this holding tank. So. Erm, they've. Working. And then this water outfall is going to go into this holding tank. Like the only holding tank or, however, many of the things that are in there to make a. You get. And then this last quadrant three. Honestly, I want to return it back to like having just like more trails, put big trees in there trying to to bring life back to this area. Taking out the. The trash, the. The Mobile Homes Trailer Park thing that was happening over there. And and making it like a place where. The wildlife has no place to go. Like the little bird trees around here in the trees that line the streets are a good start, but I still think there's going to need to be more especially like since it's near Cincinnati. And like, I don't know the smog levels, but I'm sure there's something for like just having like this as like a. An imitation old growth forests. But with the trails going through, it's like all of a trail that connects the. The walking trail around the park to. The deeper Israel's going through and then within that, we can have a detention pond in the corner. I probably won't put it in the skate park or detention pond over here in the corner again, helping with what's the difference in the retention detention pond? One of them has fish. I think the same thing for him or whichever one like allows you to, like, keep wildlife alive and these ponds like, that's what we're going to put in, like we have like a little like a little fish pier. I don't know how much people in Cincinnati fish, but it's good you'll have like Cattails, like cattails rolling on the edges. You have a surge spot for that storm water to come in and out trees all along this, like more walking trails and paths, really making it like an inviting area to come. To shop to eat. Take a walk afterwards. Take your kids to the park. Have a garden like really revitalizing it into human folk like people centric. But. With the needs of animals and the storm water kind of getting like"

- Excerpt 3 – Participant B59

“OK. I don't know if it allowed. But the first thing I would do, even though the both these roads on the north and south, the big have high traffic volumes, I would say I notice they have four lanes and two lanes in each direction for each of these roads, and I would honestly make it overall a one lane in each direction for both because with part with street parking, in addition. So that would look like that. And the reason for this is that it would allow us to do like a landscaped area. Between the road and then the sidewalk. Which also makes it like safer to walk, but then it's just increasing overall. Green landscaped area, because there's literally no green or vegetated area. So do that for both sides and then. OK. And then a sidewalk, the sidewalk, I want to make dinner because there was a lot of pavement, which is. Impervious or thought it ever was. And I need to draw. And I think even though I just the world looks really big, really wide for me, considering there's literally like this area is not even being used that much, it's not like a place that people actually stop. And I'm thinking about New York City, and it seems like the roads and then in general, the right of ways were even larger than like New York City, and that seemed a little bit unnecessary. And then, in addition, the park I would like to. What I would like to do is keep a park in the area, but move it to the center of the block. So that it's more of a centralized location and not kind of just on the edge that no one uses. And then the first thing about the park is I want it to have trees that are actually which more trees should be planted, but eventually, hopefully they'll get a lot taller. And this will like having the trees I'm assuming will make for better soil in general is that there will be no, this isn't one of the aspects that we're focusing on, but for infiltration into the ground and then in the middle. So it's kind of going to be a centralized park with buildings around it. And I would say, given that no one is use, look, I'm just going to scratch out all the truck storage and all that stuff. And the biggest thing is that there's going to be. A. Pond. In the park area, that's about above ground, what kind? Then something that I think would be. Also, can it focus only buildings are just storm water, so you do whatever you want. OK, OK. Something that I think would be nice is like similar bench style seating to outside of the The new construction building on campus. So it's like stepped place where you can sit or it's also exercise steps around the pond so people can sit and enjoy that area. Another thing that. OK, so then we're on to the edges, kind of. So like the east and west sides bordering this centralized green area park area. I would basically put in. Mixed use development. Pretty simple standard apartments on the East Side. I do apartments with stores and bottom, maybe a grocery store and then the left side. I would do something similar, but except office buildings on the top. And then same thing stores on the bottom. OK, now into the actual storm water issue stuff I would put. A. OK. Running along in the landscaped area, actually on either side of the road. I would make it sort of a ditch. And I don't know how much this would really. I know it would slow down the water, so I think that could be beneficial and that the pond is already going to be actually containing the volume of water, but putting making it a sort of ditch to slow down water produced some concentration and increase current concentration. So on either side, landscaped area is a pitch. And um, I think that. Given we're already going to do construction on the road, we can go ahead and put in underground detention, especially considering this is already like a. A low point secret underground detention, one of those like weird ones we had to go see for like the orange things. But that would be actually you can really just choose one side and just do a bunch of underground detention. Um, I'm trying to think of what would really make me want to come other than that. OK, I would eliminate entirely. There's going to be no parking on either side, like in this whole plot of land. It's all going to be street parking. And then really make. I guess in that case, we'd run out of Bike Lane to the road. Like a safe and nice bike lane, just because if we're not providing parking and we're cutting down parking, that could be good and then add street parking”

Appendix: Design Ideas Generated from the LLM

Table 13 - Design ideas generated from the LLM

b1	<ol style="list-style-type: none"> 1. Underground water tanks along the perimeter of the area. 2. Management and control system for the water tanks. 3. A park with a playground, bathrooms, and fields for recreational activities. 4. A parking area for cars. 5. Water purification or quality control system to make the collected water drinkable.
c2	<ol style="list-style-type: none"> 1. Underground drainage system with multiple layers of pipes to collect water. 2. Drainage containers on the surface to pick up water. 3. Pipes arranged horizontally or vertically, depending on the drainage system. 4. Large lake-like system at the bottom for water collection and filtration. 5. Drains in the corners and center of the area. 6. Consideration of using steam to filter water, but concerns about smell and relocation of nearby residents. 7. Potential use of filtration tubes on the surface to prevent air pollution and bad smells. 8. Surface design with a dip and slanted edges for efficient water runoff. 9. Use of non-porous materials like gneiss for the drainage system to prevent smell absorption and allow water to run through.
h3	<ol style="list-style-type: none"> 1. Implement green infrastructure to absorb stormwater runoff and prevent flooding. 2. Create drainage spots in strategic locations to manage water flow. 3. Use concrete material for surfaces that can float easily. 4. Utilize space efficiently by rearranging sports facilities, such as basketball courts and softball fields. 5. Remove unnecessary dirt patches and replace them with functional spaces. 6. Install underground pipes to manage water flow and prevent overflow. 7. Gradually reduce the size of parking lots to create more green space. 8. Add extra green spaces for playgrounds and other community needs. 9. Incorporate green infrastructure within the gated sports facilities.
b4	<ol style="list-style-type: none"> 1. Implement source control for stormwater management instead of storage, as it can be applied in various situations. 2. Separate combined sewers into two systems: one for stormwater and one for sanitary sewer. 3. Design stormwater collection systems with inputs from the surface, such as storm inlets, to connect to the separated sewer underground. 4. Include stormwater treatment in the separated sewer system. 5. Connect sanitary sewer systems to houses and other buildings. 6. Consider preserving some overgrown areas for potential green infrastructure integration.
c5	<ol style="list-style-type: none"> 1. Above ground approach: Incorporate nature and green infrastructure, but consider the potential negative effects of too much water on plants. 2. Underground approach: Add more pipes to distribute water and improve circulation. 3. Consider the surrounding environment, such as cars and houses, when designing the infrastructure. 4. Explore the possibility of adding concrete to stabilize the area and support a building or structure. 5. Consider constructing a water management center (not a factory) on top of the stabilized area to better direct and control the flow of water. 6. Employ a team of scientists or experts to manage the water flow and make informed decisions about its distribution.
b6	<ol style="list-style-type: none"> 1. Construct a cleaning plant to filter and clean the water, reducing environmental impact and bad odors.

	<ol style="list-style-type: none"> 2. Utilize byproducts, such as methane, for power or fuel generation. 3. Separate good and bad products, with good products being released and bad products being transported or used in some way. 4. Create jobs for the local community through the construction and operation of the plant. 5. Address potential issues with smell and location by considering the surrounding environment. 6. Explore options for repurposing waste materials, such as rubber or trash, for positive uses. 7. Investigate the possibility of storing waste deep underground to minimize impact on waterways.
h7	<ol style="list-style-type: none"> 1. Retain water by planting more trees and vegetation in the empty space between the basketball court and the community area. 2. Create a small pond in the middle of the green space for water retention and community enjoyment. 3. Improve the water drainage system by adding sewers or canals on the side of the road. 4. Utilize unused spaces between houses for water storage tanks, which can be hidden by trees or placed underground. 5. Reuse collected water for irrigation systems or refilling the pond. 6. Improve roof designs on houses to better manage water flow. 7. Install water pipes and individual water systems for each house, allowing residents to water their gardens without additional cost.
c8	<ol style="list-style-type: none"> 1. Implement storage solutions for rainwater in a smaller area. 2. Consider using sewer drains in the design. 3. Incorporate multiple sewer drains for filtering and overflow management. 4. Combine green and grey infrastructure elements. 5. Explore the possibility of filtering water underground and connecting it to a water stream. 6. Focus on underground storage for rainwater.
h9	<ol style="list-style-type: none"> 1. Conveyance and storage system underneath the area 2. Addition of green spaces and parks for community benefit 3. Incorporation of stormwater management in park design 4. Planting trees and shrubs to help collect water 5. Creation of a filtration building for water treatment 6. Improvement of the general infrastructure in the area
c10	<ol style="list-style-type: none"> 1. Create a stormwater retention pond in a park area to reduce the volume of output. 2. Expand the park area to include recreational facilities such as benches, a public walkway, a basketball court, and a pavilion. 3. Install an inlet and an underground outlet for the stormwater system. 4. Locate the stormwater retention pond away from the main town area to reduce odor issues. 5. Place a new wastewater treatment plant near the river to improve water quality and create jobs for the community. 6. Consider ways to replenish groundwater, such as treating and storing stormwater in water tanks located away from the public view.
h11	<ol style="list-style-type: none"> 1. Preserve the existing green space in the area and avoid building a treatment plant that would be invasive. 2. Enhance the green space with plants and vegetation to help alleviate water issues.

	<ol style="list-style-type: none"> 3. Remove the trailer park and add more green space with plants that can help with water management. 4. Install underground storage tanks on the side to maintain the park's appearance. 5. Create a natural channel for water to flow out of the park, directing it towards a drain to prevent clogging.
c12	<ol style="list-style-type: none"> 1. Create a manmade pond on the left side of the park to help with runoff and storm sewage, potentially attracting attention to the area and serving as a recreational spot. 2. Introduce manmade fish into the pond for community enjoyment. 3. Install underground water tanks for storage of rainwater, with the number of tanks depending on the area's rainfall. 4. Consider adding more storage tanks if the area experiences heavy rain. 5. Implement stormwater retention ponds and underground tanks to utilize the area properly. 6. Ensure the underground tanks are secure and compatible with the area's high crime rate. 7. If the budget allows, add another stormwater treatment facility in the area.
h13	<ol style="list-style-type: none"> 1. Create a new type of system to slow down the rate at which water gets processed and reaches the treatment plant. 2. Utilize underground space for the new system to manage wastewater and stormwater. 3. Bring more jobs to the community through construction and implementation of the new system. 4. Ensure the solution is environmentally conscious and avoids issues like E. coli and dysentery contamination. 5. Utilize empty space in the area for multiple applications, such as retention ponds to manage overflowing and prevent mixing of rainwater with stormwater. 6. Implement new green technologies to improve the efficiency and sustainability of the water management system.
b14	<ol style="list-style-type: none"> 1. Add more trees around the park and in the empty spaces. 2. Create a tree line around the park near the trailers and storage area. 3. Convert the storage area into stormwater storage containers. 4. Revamp the park to make it more family-friendly and suitable for children. 5. Add a playground beside the existing court. 6. Resurface the existing court. 7. Refinish the fields and create a walking path for people. 8. Install two or three large stormwater storage containers for handling larger storms.
b15	<ol style="list-style-type: none"> 1. Incorporate garden or vegetation in the design. 2. Consider the existing park with a court and softball field. 3. Add vegetation around the perimeter of the area. 4. Implement underground sewers for wastewater management. 5. Enhance the park for community gatherings. 6. Renovate the basketball court. 7. Utilize available land for additional sports, such as soccer. 8. Include open spaces and goalposts in the design.
c16	<ol style="list-style-type: none"> 1. Utilize grey infrastructure by installing treatment plants in urban areas with limited space for natural solutions. 2. Consider tearing down existing structures to make room for treatment plants. 3. Install diversion pipes to connect the underground pipe to the treatment plants. 4. Ensure the surface is suitable for placing plants on top of the treatment plants.

b17	<ol style="list-style-type: none"> 1. Maintain the central park location for revitalization. 2. Add a basketball court, baseball field, and tennis court. 3. Include a bathroom facility in the park. 4. Implement a water treatment system with sustainable runoff drainage. 5. Increase greenery, such as trees and hammocking spaces. 6. Add a police box in the corner triangle for safety and easy access. 7. Create a central area with essential services and walkways. 8. Incorporate a pond to absorb rainwater.
h18	<ol style="list-style-type: none"> 1. Park with a playground: Located in the middle of the block, accessible by crosswalks, and featuring a surface that allows water absorption. 2. Greenery around the playground: Dirt, plants, and grass to help absorb stormwater. 3. Basketball court: Retain the existing basketball court in the corner. 4. Water treatment plant: Positioned on the right side of the block. 5. Bioswales and community garden: Located on the opposite side of the playground, featuring sustainable water intake options. 6. Grassy area for events: A large grassy area for community events and gatherings. 7. Hill on the left side: A hill to prevent water from piling up and to provide more dirt for water absorption. 8. Storage tanks near the water treatment plant: Tanks to store water from the sewage system.
c19	<ol style="list-style-type: none"> 1. Central Park-inspired design with abundant trees and natural vegetation. 2. A pond with sidewalks for walking around and a fish habitat with treated water. 3. Trails surrounded by water-thriving vegetation. 4. Well-maintained park to benefit the neighborhood and attract people. 5. Sports facilities such as soccer fields and baseball fields within the park. 6. Underground water storage beneath the vegetation and pond for water treatment and storage.
h20	<ol style="list-style-type: none"> 1. Preserve a good portion of green space. 2. Add trees and a stream to the area. 3. Include a basketball court. 4. Develop a section for residential or commercial purposes. 5. Implement underground storage for water management. 6. Create a walkable area with stores and sidewalks. 7. Utilize concrete structures for water storage and management.
b21	<ol style="list-style-type: none"> 1. Remove unused structures and keep the basketball courts as a recreational area. 2. Plant trees all around the border of the area to help with stormwater management and groundwater replenishment. 3. Utilize half of the concrete area for leisure businesses, such as restaurants and malls. 4. Divide the remaining area into four sections, with trees planted along the paths. 5. Establish a stormwater treatment plant and storage facility in a vertical design to save space. 6. Create a community space with chairs and trees for leisure and relaxation. 7. Designate an area for storage needs, surrounded by trees. 8. Add vegetation, grass, and flowers to the area for aesthetic and environmental benefits. 9. Consider installing underground storage tanks for groundwater management if needed.
b22	<ol style="list-style-type: none"> 1. Replace soil in the area to allow for better infiltration and runoff drainage. 2. Build a pseudo dam to redirect or slow down water flow during heavy rain activity.

	<ol style="list-style-type: none"> 3. Reroute the pipe in favor of water basins to slow down water flow and provide better control during heavy rainfall. 4. Recondition abandoned homes into usable spaces, possibly for businesses with parking. 5. Create an artificial grade or a dish to redirect water and prevent flooding in the streets.
h23	<ol style="list-style-type: none"> 1. Demolish existing structures in the park area to create a more vibrant and walkable green space. 2. Add sidewalks and through paths for better connectivity within the neighborhood. 3. Demolish and rebuild vacant or deteriorating houses around the park. 4. Remove the trailer park and parking lot to reduce stormwater runoff. 5. Improve crosswalks and pedestrian safety. 6. Place infrastructure elements like storage tanks and water treatment facilities underground when possible. 7. Plant more trees and vegetation to enhance the area's aesthetics and stormwater management. 8. Widen existing pipes and add new tanks to prevent stormwater overflow into the wastewater system.
c24	<ol style="list-style-type: none"> 1. Develop a community space with commercial sites in the underused area. 2. Create walkable green space in the middle of the community space. 3. Attract people to the area with commercial spaces. 4. Demolish structurally unsound buildings and rebuild in a more sustainable fashion. 5. Implement bioretention features like swales in the green space. 6. Channel the green space towards the existing pipe system. 7. Consider incorporating storage options for stormwater management.
h25	<ol style="list-style-type: none"> 1. Create a pond that brings the community together and serves as a stormwater drainage system. 2. Preserve and plant new trees around the pond to maintain a natural environment. 3. Construct paths around the pond for residents to enjoy walks and outdoor activities. 4. Design the pond and surrounding area to be visually appealing, attracting new homeowners and increasing property values. 5. Ensure proper overflow management for the pond to prevent stagnant water. 6. Replace any existing grey infrastructure, such as parking lots or asphalt, with green spaces and trails. 7. Utilize the soil's natural ability to absorb water to help manage overflow and rainwater.
h26	<ol style="list-style-type: none"> 1. Recreational area: Basketball court, tennis court, or open field for activities. 2. Ponds and streams: A network of small ponds connected by streams, with the main pond in the center. 3. Sidewalk waterway: A stream alongside the sidewalk, disappearing and reappearing at intersections. 4. Floral decor starting point: A small triangle area with trees, bushes, and flowers as an introduction to the garden area. 5. Garden area: A path through the foliage, leading to the main pond and other ponds. 6. Educational signs: Information about native plants and the water cycle throughout the park. 7. Eco-friendly environment: Emphasis on water reuse and native plants. 8. Walking paths: A network of paths connecting different areas of the park, including sitting areas and outposts.

	<p>9. Center of attention: A "peace of mind" spot with the most attractive native plants and flowers.</p> <p>10. Open area of foliage: A large area for people to explore and enjoy the natural environment.</p>
b27	<ol style="list-style-type: none"> 1. Preserve and enhance the existing green space on the left side. 2. Investigate soil type and incorporate plants that absorb water or improve soil quality. 3. Transform the area into a community park for residents to use and enjoy. 4. Add a water retention pond to support biodiversity and water management. 5. Remove the tractor-trailer area and convert it into additional green space. 6. Create a designated area for vendors to support local economic activity.
c28	<ol style="list-style-type: none"> 1. Expand the existing Parks and Recreation area into the nearby lot and add more trees, shrubs, and bushes to create a more natural and communal park space. 2. Increase the number of trees to help absorb water and reduce stormwater runoff. 3. Make the surrounding asphalt and streets more porous to absorb water and prevent it from entering the stormwater system. 4. Add a communal basketball court or similar recreational facility to attract more community members. 5. Introduce food trucks or other local businesses to provide jobs and additional amenities for the community.
b29	<ol style="list-style-type: none"> 1. Create a park to address water flooding issues and provide a habitat for birds. 2. Design the park to be more natural and inviting for people to visit. 3. Make the soil permeable to slow down water flow and help feed the trees. 4. Utilize the water to support life and growth in the area. 5. Consider adding a gravel pathway, benches, and a fountain. 6. Explore the possibility of an underground system for the fountain. 7. If possible, expand the park by demolishing unused buildings to create a larger natural habitat.
b30	<ol style="list-style-type: none"> 1. Roadway and traffic configuration 2. Underground work for infrastructure 3. Garden with vegetation for land treatment and aesthetics 4. Walkway patterns leading to the river 5. Basketball courts 6. Permanent stage for concerts and events 7. Park area 8. Rock walkways throughout the area
c31	<ol style="list-style-type: none"> 1. Create a park in the vacant area. 2. Separate park and storage for sanitation purposes. 3. Implement cost-effective design solutions. 4. Incorporate green infrastructure, such as planted areas and storm drains. 5. Ensure the park is not affected by underground infrastructure, such as deep storm drains. 6. Design the underground infrastructure to be at least 10 feet deep to avoid interference with the park.
b32	<ol style="list-style-type: none"> 1. Redevelop the green space with more vegetation to improve its appearance and functionality. 2. Expand the park area and add a basketball court on the far left of the map. 3. Create a track around the park to attract more visitors and encourage outdoor activities. 4. Demolish abandoned buildings and redevelop them into small shops and coffee

	<p>shops to boost the local economy.</p> <ol style="list-style-type: none"> 5. Focus on stormwater management by adding more trees and vegetation. 6. Incorporate flower gardens to make the area more attractive and encourage people to spend time and money there. 7. Update the outdated underground stormwater system to handle overflow more effectively.
c33	<ol style="list-style-type: none"> 1. Install underground sewers along the main road, with four on each side. 2. Connect the sewers with pipes that flow outwards from the roads and towards the land. 3. Connect four to six sewer pipes to one underground storage tank to prevent overflow. 4. Provide access to the tanks through a central building and pathways for maintenance purposes. 5. Remove some roads and old buildings to focus on soil and capturing groundwater naturally. 6. Create a balance between the underground sewer system (grey infrastructure) and the soil on the outside for groundwater (green infrastructure).
h34	<ol style="list-style-type: none"> 1. Add stormwater management features, such as ponds, in the area near the trailer park or commercial storage. 2. Surround the pond with shrubs, grass, and riparian zones to help filter out water and stabilize the area. 3. Plant trees to further stabilize the area and provide additional environmental benefits. 4. Restructure the park to ensure the soil is permeable and allows for rainwater to drain through. 5. Separate stormwater and sewage systems to alleviate stress during rainfall and reduce the need for overflow into the river. 6. Tear up and regrade the area to accommodate the stormwater pond and other design elements. 7. Integrate the stormwater pond with the park, creating a visually appealing space for residents to enjoy, including benches and walking paths.
c35	<ol style="list-style-type: none"> 1. Channel stormwater underground to avoid it being above ground. 2. Maintain the surface as it is, with minimal changes. 3. Increase vegetation in the area to help treat stormwater. 4. Keep the park in its current location. 5. Add more vegetation, trees, and plants in the commercial area. 6. Use underground pipes and storage tanks to manage stormwater.
h36	<ol style="list-style-type: none"> 1. Improve the recreational area by adding a lake or pond to hold more water and address overflow issues. 2. Retain the basketball court and baseball field to attract more people to the area. 3. Consider relocating the baseball field to create more space for recreational activities. 4. Transform the unused commercial zone into a mixed-use area with an underground tank holding facility. 5. Construct commercial buildings, such as restaurants and shopping centers, above the underground facility. 6. Use pervious surfaces for the recreational area to promote better water management.
c37	<ol style="list-style-type: none"> 1. Combine existing park with water management features. 2. Utilize storage containers under the park area for excess water. 3. Incorporate more trees and plants in the park to absorb stormwater. 4. Allow stormwater to drain through the ground for plant use, with excess stored away.

	<ol style="list-style-type: none"> 5. Consider options for repurposing stored stormwater during dry spells. 6. Ensure minimal waste in the stormwater management system.
h38	<ol style="list-style-type: none"> 1. Retain the park for recreation purposes. 2. Keep the basketball court. 3. Add more trees and vegetation. 4. Depress the land to create a wetland for water sequestration. 5. Remove the under-utilized baseball field to make room for the wetland. 6. Replace the concrete commercial space with a dirt lot or a multi-level storage facility. 7. Extend the park into the vacant lot. 8. Add businesses or an apartment complex in the remaining space for new residents and affordable housing.
b39	<ol style="list-style-type: none"> 1. Above ground tanks for water storage 2. Retain existing highways 3. Line the area with trees and vegetation 4. Divots for water on sidewalks to feed vegetation 5. Bioswales along the property line 6. Keep existing roads for easier access and less disruption to residents 7. Underground tanks in specific areas 8. Pipes on the ground to build out of the area 9. Separate pipe systems for stormwater and other water sources 10. Create a new set of pipes for stormwater management, following the same path as existing pipes
c40	<ol style="list-style-type: none"> 1. Incorporate nature into the design 2. Add a small river or stream to control water flow 3. Create a small lake for standing water 4. Design a central park with trees surrounding the area 5. Include a stream in the middle of the park to collect water
h41	<ol style="list-style-type: none"> 1. Renovate the existing basketball court to improve its appearance and promote community engagement. 2. Add more greenery, such as bushes and grass, to enhance the park's appearance. 3. Install a water collection and filtration system beneath the park to manage stormwater and promote sustainability. 4. Add a playground with a swing set for children to play. 5. Plant more trees throughout the park to increase green infrastructure and promote a natural environment. 6. Install a fence around the park's perimeter to provide safety and separation from busy roads. 7. Add street lights to improve visibility and safety during nighttime hours.
h42	<ol style="list-style-type: none"> 1. Relocate tractor trailer area to create open space. 2. Expand sewer systems to improve infrastructure and create jobs. 3. Add water retention banks to help manage water flow and reduce combined sewer overflow. 4. Establish a headquarters for workers, including a place to eat. 5. Implement water diversion points at the bottom of the mountains to direct water away from the sewage system. 6. Create a community park with sports facilities to engage the local community. 7. Install underground water storage for emergency situations.
h43	<ol style="list-style-type: none"> 1. Implement vegetation for stormwater management: Add a variety of plants, trees, and bushes around roads and other busy areas to handle stormwater and provide aesthetic

	<p>appeal.</p> <ol style="list-style-type: none"> Upgrade the existing wastewater treatment plant: Increase its capacity to handle more stormwater and prevent overflow into nearby bodies of water. Construct a new wastewater treatment plant: Utilize the available empty space to build an additional treatment plant to further increase stormwater management capacity. Implement underground storage for stormwater: Create large underground storage areas to handle excess stormwater, providing a short-term solution for overflow prevention.
c44	<ol style="list-style-type: none"> Construct a mixed-use apartment complex with a grocery store (Harris Teeter) and popular fast food restaurants on the ground floor. Build a 16-storey apartment complex above the commercial spaces. Install impervious surfaces on the sidewalks surrounding the apartment complex. Create a park with trees and vegetation adjacent to the apartment complex to help manage stormwater runoff. Design the land to have a slight incline, with the apartment complex and commercial spaces at a higher elevation than the park. Include a playground and basketball court in the park for community use. Aim to improve the socioeconomic conditions and reduce crime rates by fostering a sense of community and attracting more people to the area.
b45	<ol style="list-style-type: none"> Park with a pond on the left side Walkways around the pond and connecting to streets Open field for sports and other activities Trees and greenery to make the area more appealing Waste management center with an underground storage tank Residential buildings and homes Picnic area and playground for children Dog park for pet owners Pervious pavement and soil to promote better water management Benches and seating areas for relaxation and socializing
c46	<ol style="list-style-type: none"> Add more pipes on the ground to manage rainwater and other water resources. Implement surface-level infrastructure for water management. Construct underground tunnels for water management. Develop outdoor infrastructure to help with excess water.
h47	<ol style="list-style-type: none"> Remove the unused basketball court and replace it with a retention/detention facility for stormwater management. Surround the detention facility with greenery to create a green space. Tie the detention facility into the pre-existing underground stormwater system. Add curb inlets and drainage systems to major roads to manage water overflow. Repurpose the building in the middle of the park into a community center to address social issues. Plant trees and add park benches throughout the green spaces. Incorporate artificial water structures to help with stormwater management. Enhance the detention pond area with stones or other aesthetic elements. Utilize the storage lot for a rainwater harvesting facility to create jobs and help with stormwater overflow management. Focus on improving social and community wellbeing aspects through the addition of green spaces and rainwater management systems.
h48	<ol style="list-style-type: none"> Sloping roads to direct water towards the target area. Creating structures on the side of the road for water management.

	<ol style="list-style-type: none"> 3. Implementing an underground detention system beneath the upgraded park. 4. Adjusting the grading of the area to facilitate water flow. 5. Creating a single point of access structure for the detention system. 6. Repaving roads and connecting them to the target area. 7. Treating water in the detention system. 8. Preserving open space in the area. 9. Enhancing the park to improve socioeconomic conditions and attract families. 10. Installing crosswalks and stone paths leading to the park. 11. Adding more vegetation to the area.
c49	<ol style="list-style-type: none"> 1. Remove tractor trailers and junk from the area. 2. Rip up existing pavement and replace with permeable pervious pavement for parking. 3. Expand grass and green space, including trees and shrubbery. 4. Add bio swales near streets for groundwater remediation. 5. Repair and maintain existing pavilion, possibly adding solar panels. 6. Convert tractor trailer storage area into football fields or other green spaces. 7. Line streets with more trees for shading and water remediation. 8. Add more bio swales for water detention and filtration. 9. Include onsite parking with pervious pavement.
c50	<ol style="list-style-type: none"> 1. Water treatment plant: The participant suggests building a water treatment plant near the river to reduce the environmental damage caused by wastewater. 2. Stormwater management: The participant emphasizes the need to reduce stormwater and help with the treatment process. 3. Green infrastructure: The participant proposes replacing hard surfaces with more trees to absorb stormwater and treat wastewater without losing the functionality of the park. 4. Cost-effectiveness: The participant believes that while the water treatment plant may be expensive, it is a long-term investment that will provide value.
h51	<ol style="list-style-type: none"> 1. Preserve and expand grass area. 2. Fence in the area for social purposes. 3. Install light posts along the area. 4. Develop remaining area with proper water management. 5. Create a high point around buildings to direct water flow. 6. Implement a swale or ditch system around the park to manage water runoff. 7. Separate park and other area with a soil barrier to prevent water mixing. 8. Install an underground pipe network for water management and direction.
h52	<ol style="list-style-type: none"> 1. Underground detention for stormwater management. 2. Walkable shops with green roofs for infiltration. 3. Vegetated areas and minimized impervious surfaces. 4. Park area for children. 5. Retention pond for stormwater capture and recreational purposes. 6. Trees for usability and increased infiltration. 7. Green roofs for all surrounding buildings. 8. Underground parking to reduce surface area.
b53	<ol style="list-style-type: none"> 1. Retain the basketball court with entrances on one side. 2. Add a trail through the park with picnic benches. 3. Plant trees along the trail and park. 4. Install sidewalks along the road. 5. Develop commercial spaces like coffee shops and grocery stores on the other side of the road.

	<ol style="list-style-type: none"> 6. Incorporate green roofs on commercial buildings for stormwater management. 7. Extend the trail through the back part of the park. 8. Include a soccer field to maintain green space.
b54	<ol style="list-style-type: none"> 1. Create a basketball court in the existing space. 2. Design a long run through the whole strip with two additional paths jutting out. 3. Improve the existing baseball diamond. 4. Add trees and vegetation around the area, outlining the shape of the space. 5. Make the entire area pervious. 6. Add more trees in the corner near the storage space.
b55	<ol style="list-style-type: none"> 1. Incorporate a park with a pond. 2. Add a bike path and a bridge. 3. Plant trees around the area. 4. Use space with containers for wastewater storage (not treatment). 5. Install underground tanks for wastewater collection. 6. Create a park for people and birds to enjoy. 7. Store wastewater offsite for treatment to avoid unpleasant smells.
c56	<ol style="list-style-type: none"> 1. Scale up the park to use as a water storage area during flood events. 2. Design the park to function as a pond during non-flood periods. 3. Direct water to the park through proper elevation and slope adjustments. 4. Implement groundwater recharge through filtration systems. 5. Assess the park's capacity to store water during flood events and make necessary adjustments. 6. Maintain commercial properties in the area, ensuring proper water management. 7. Consider urban redevelopment to adjust elevations and direct water to the park. 8. Install infiltration systems to clean and direct water to the park. 9. Utilize the park for environmental benefits and to attract more people to the area.
c57	<ol style="list-style-type: none"> 1. Retain the park and improve soil for better drainage into the groundwater. 2. Upgrade the treatment facility in the commercial area for better pollution control. 3. Separate the sanitary sewer from other wastewater systems. 4. Implement an underground sewer system to filter water from the park and surrounding areas more effectively.
b58	<ol style="list-style-type: none"> 1. Re-route the eastern road to create a large open space. 2. Remove side streets and houses to create a central area for people to gather. 3. Divide the area into four quadrants: <ol style="list-style-type: none"> a. Quadrant 1: Community garden with a shed and tools for residents. b. Quadrant 2: Park with a skate park, water storage tanks, basketball court with permeable pavers, walking trail, and separate play areas for younger and older children. c. Quadrant 3: Trails, trees, and a detention pond with wildlife, connecting to the walking trail in Quadrant 2. d. Quadrant 4: Mixed-use development with shops on the bottom and apartments on top, with a permeable paver parking lot and stormwater runoff directed to holding tanks. 4. Incorporate permeable pavers and green infrastructure throughout the design to manage stormwater and create a more sustainable environment. 5. Focus on creating a people-centric space that also supports the needs of animals and the environment.
b59	<ol style="list-style-type: none"> 1. Reduce road lanes to one in each direction for both north and south roads, allowing for street parking and landscaped areas. 2. Make sidewalks narrower to reduce impervious surfaces. 3. Move the park to the center of the block and add more trees for better soil infiltration.

	<ol style="list-style-type: none"> 4. Include a pond in the centralized park area. 5. Add bench-style seating and exercise steps around the pond. 6. Develop mixed-use buildings on the east and west sides of the park, with apartments, stores, and office spaces. 7. Create a ditch in the landscaped areas on either side of the road to slow down water and reduce concentration. 8. Install underground detention for stormwater management. 9. Eliminate parking within the plot of land, relying on street parking instead. 10. Add a safe and well-designed bike lane to the road.
h60	<ol style="list-style-type: none"> 1. Create a livable area with multipurpose residential spaces towards the outskirts. 2. Design a central open space for water to fill. 3. Construct apartment-style buildings on the outside of the central area. 4. Incorporate vegetation for a natural presence. 5. Implement underground infrastructure, including pipes for sewer and stormwater management. 6. Remove the trailer park and replace it with apartment complexes or other purpose buildings. 7. Incorporate the surrounding mountains for natural beauty and connection to nature. 8. Separate sewer and stormwater pipes to prevent overflow during large storms. 9. Establish a treatment point for the pipes near the creek. 10. Add a supplement away from the living area, closer to the creek.
c61	<ol style="list-style-type: none"> 1. Increase vegetation in the area for aesthetic and environmental reasons. 2. Add trees and other vegetation in the commercial area. 3. Convert the open space into a vegetated space. 4. Install an underground water collection basin in the current commercial area. 5. Add more vegetation on top of the water collection basin. 6. Encourage the use of the area by adding lights and other amenities.
h62	<ol style="list-style-type: none"> 1. Remove or modify the main road to allow access to smaller roads and create more space for the design. 2. Rezone the area for industrial use to accommodate a wastewater treatment plant. 3. Install underground storage tanks for water management. 4. Implement deep piping to connect the treatment plant to the water outlet. 5. Utilize the surface area above the underground infrastructure for a community facility or park.
h63	<ol style="list-style-type: none"> 1. Retain the basketball court in the park. 2. Add a large pond for stormwater retention. 3. Create streams throughout the park to collect stormwater. 4. Improve walkability around the streets. 5. Install crosswalk signals for pedestrian safety. 6. Plant trees to reduce stormwater runoff. 7. Maintain the baseball courts. 8. Construct better apartments near the park. 9. Upgrade the sewer system with separate lines.
c64	<ol style="list-style-type: none"> 1. Keep industrial areas close to the water. 2. Convert the outflow pipe into a water treatment plant. 3. Zone the area near the water treatment plant for commercial use. 4. Create a Central Park-like area in the city center. 5. Separate water and sewage lines, directing sewage to the water treatment plant.

	<ol style="list-style-type: none"> 6. Treat and redistribute clean water back to the community. 7. Improve stormwater management and infrastructure.
h65	<ol style="list-style-type: none"> 1. Retain the park in the design. 2. Include a pond or water feature. 3. Implement underground stormwater management. 4. Incorporate mixed-use developments in the area. 5. Add green space in the middle of the construction. 6. Consider multi-story parking options. 7. Focus on stormwater management. 8. Integrate rain gardens along the road.
h66	<ol style="list-style-type: none"> 1. Remove trucks and transform the commercial area into a more usable space. 2. Add residential housing, including densely populated apartments. 3. Implement above-ground stormwater practices, such as swales and retention ponds. 4. Remove underutilized green areas, like the basketball court. 5. Install underground infrastructure, such as piping and tanks, to control water quantity during flooding. 6. Connect the new apartment complexes to the underground infrastructure. 7. Develop commercial buildings on top of the underground stormwater infrastructure. 8. Incorporate green elements, such as trees and bushes, to create more pervious areas.
c67	<ol style="list-style-type: none"> 1. Retain the park and tennis court for social revitalization and common outdoor space. 2. Replace the concrete area with a soccer field and another sporting field. 3. Add sidewalks with ditching on the sides for better accessibility and water control. 4. Create a parking lot near the fields for easy access. 5. Introduce businesses in the surrounding area to support local economy. 6. Implement a stormwater system with inlets, vegetated islands, and underground detention for better water management. 7. Utilize BMP (Best Management Practices) for filtration methods and overall environmental design.
b68	<ol style="list-style-type: none"> 1. Preserve existing commercial frontage along the major road. 2. Expand the park by removing the storage lot. 3. Keep and repurpose the historic building in the park for public restrooms and storage space for grounds crews. 4. Allow for residential or mixed-use development on the south side of the park. 5. Upgrade the baseball diamond and add a turf soccer field or similar sports facility. 6. Add a detention basin or pond in the center of the park for stormwater management. 7. Create paths for circulation throughout the park, connecting major areas. 8. Plant more trees to create a greener environment. 9. Replace the commercial storage zone with stormwater detention or a more permanent water feature. 10. Encourage new residential or mixed-use development, including multifamily housing, around the park. 11. Enhance bus service along larger roads to improve access to downtown.
b69	<ol style="list-style-type: none"> 1. Maintain the existing open grass and basketball court as community space. 2. Add more vegetation, especially trees, along the road. 3. Remove the trailers and convert the space to pervious land. 4. Modify the grid to add a retention pond and underground storage for stormwater management. 5. Increase vegetation along the road all the way around.

	6. Consider adding a swale in the area where the trailers were removed, directing runoff towards the treatment facility.
b70	<ol style="list-style-type: none"> 1. Sports field: A permeable surface area for a soccer field or similar recreational activity. 2. Retention pond: A natural feature to separate the sports field from storage areas, capturing water and providing a buffer. 3. Duck pond area: A deep pond with riparian vegetation to slow down water and provide a pleasant environment for park visitors. 4. Seating areas and gazebo: Benches and a gazebo for community gatherings and fostering a sense of togetherness. 5. Vegetation and fencing: A fence with vegetation to hide the industrial area and create a sense of separation from the surrounding urban environment. 6. Storm drain outlets: Directing water flow towards the pond for better water management. 7. Topographic variety: Shaping the land to direct water flow and possibly elevating or depressing the soccer fields for better water storage during heavy runoff events. 8. Entrance gate: A welcoming entrance for the community to access the park. 9. Natural vegetation: Planting vegetation to slow down and absorb water, providing environmental benefits. 10. Picnic tables and benches: Inexpensive additions for community use and enjoyment. 11. Taller trees: Planting taller trees for added privacy and aesthetic appeal.
c71	<ol style="list-style-type: none"> 1. Install a curved tee elbow pipe to connect to the grass area. 2. Add chemicals to help with stormwater absorption and decomposition by soil and grass. 3. Build an underground tank for emergency water storage. 4. Redesign the grass area with a large tank at the bottom for water and wastewater treatment. 5. Use grass and soil on top of the tank for decomposition purposes.
h72	<ol style="list-style-type: none"> 1. Change the street grade to 5-8%. 2. Connect inlets to an underground storage tank. 3. Maintain the basketball court as an attractive feature. 4. Add a pond in the green space and connect it to the sewer recollection underground. 5. Enhance the green space with benches and trees. 6. Relocate the storage unit area to improve aesthetics. 7. Expand the pond in the undeveloped area. 8. Excavate an area for additional storage tanks in the green land.
c73	<ol style="list-style-type: none"> 1. Enhance and expand the park area for improved aesthetics and community use. 2. Implement source control measures such as adding trees and retention ponds in the park area. 3. Consider rezoning the commercial area to accommodate a storage or conveyance facility. 4. Address the influx of water flow from the nearby hills by incorporating land development strategies and conveyance systems. 5. Improve the socio-economic standing of the area by enhancing the park and surrounding environment.
h74	<ol style="list-style-type: none"> 1. Remove the underutilized storage space in the park area. 2. Install a small-scale wastewater treatment facility in the freed-up space. 3. Add necessary pipes to bring water in and out of the treatment facility.

	<ol style="list-style-type: none"> 4. Maintain the park for community use. 5. Implement drainage basins to manage water runoff from the mountains. 6. Angle the ground to direct water towards the drainage basins. 7. Connect the drainage basins to the wastewater treatment facility for stormwater management.
h75	<ol style="list-style-type: none"> 1. Remove two roads near the park and replace them with a double-sided bike path. 2. Increase green space by adding more trees and vegetation, specifically plants that can retain water. 3. Create a pond in the park for water retention. 4. Add picnic areas and more trees in the park. 5. Remove empty houses and create a residential building. 6. Develop a small downtown area with commercial spaces, vegetation, and pedestrian-friendly walkways. 7. Implement underground parking with green space on top. 8. Create an underground storage facility for trucks. 9. Add more green space with vegetation in place of the removed buildings. 10. Incorporate alternate pipes for stormwater management, directing water to a nearby stormwater facility. 11. Expand the park to create a larger green space for public use.
c76	<ol style="list-style-type: none"> 1. Incorporate a park with greenery to absorb rainwater and groundwater, reducing the load on the wastewater treatment plant. 2. Convert some commercial space into park area, doubling the size of the existing park. 3. Add more trees to the park for shade and to absorb rainwater. 4. Refurbish the softball field to encourage community engagement and reduce violence. 5. Implement source control measures to keep rainwater and groundwater out of the treatment plant, ensuring a more concentrated sanitary water source. 6. Incorporate channels or drains to prevent runoff from entering the water system and surrounding tributaries. 7. Install underground storage tanks to temporarily store excess water. 8. Decrease underutilized commercial space and maintain necessary commercial areas.
b77	<ol style="list-style-type: none"> 1. Remove storage space to make room for stormwater management and vegetation. 2. Add a community center to provide public infrastructure and incentivize housing. 3. Create a permeable playground to help filter water and direct it to underground tanks. 4. Add vegetation to make the space more inviting. 5. Maintain existing basketball court and consider multi-use options for the baseball field. 6. Improve lighting in the park to make it more inviting. 7. Develop trails connecting crosswalks, looping around the park, and leading to the community center. 8. Incorporate underground systems and sloping for effective stormwater management.
b78	<ol style="list-style-type: none"> 1. Retain the existing basketball court and add a football or soccer field with turf to appeal to middle and high school age kids. 2. Remove the trailer storage area and create a creek to collect stormwater, preventing it from being routed directly to the treatment facility. 3. Transform the area around the creek into a park by maintaining it, adding flowerbeds, bridges, and gazebos. 4. Extend paths around the park to connect the fields, bridges, and gazebos.

	<ol style="list-style-type: none"> 5. Implement underwater drainage from the turf fields into the creek before it exits the parcel. 6. Add more features to increase the likelihood of people using the parcel.
c79	<ol style="list-style-type: none"> 1. Transform the area into a park and recreation center for environmental, social, and economic benefits. 2. Plant trees and create a pond for water management and aesthetics. 3. Develop restaurants, souvenir stores, and restrooms to attract visitors and boost the local economy. 4. Incorporate food trucks for additional food options and visitor engagement. 5. Add parking spaces to accommodate visitors. 6. Implement a stormwater management system, combining ponds and underground storage. 7. Design roads to encourage people to pass through the area and make it a desirable stop.
c80	<ol style="list-style-type: none"> 1. Expand the stormwater pipe and treatment system. 2. Separate sanitary and stormwater systems for more efficient treatment. 3. Design the sanitary sewer pipe to be smaller. 4. Implement different treatment processes for sanitary and stormwater systems. 5. Locate the infrastructure under the strip to create more space for water flow.
h81	<ol style="list-style-type: none"> 1. Maintain and expand the existing park. 2. Plant trees to help alleviate runoff. 3. Convert unused trailer area into a treatment plant. 4. Consider a storage tank for emergency purposes. 5. Focus on surface-level solutions to meet community preferences.
c82	<ol style="list-style-type: none"> 1. Add bio-swales along the sides of roads to help with stormwater runoff and improve vegetation. 2. Enhance the park by increasing its size, adding more vegetation, and making it more inviting for people to use. 3. Research and plant vegetation that can absorb more water to help with stormwater management. 4. Create a retention pond to handle excess water and prevent flooding. 5. Consider redesigning the surrounding area to include more green infrastructure and reduce the amount of paved surfaces, which contribute to runoff.
h83	<ol style="list-style-type: none"> 1. Install a Sheetz or WaWa store to benefit the city. 2. Add a pond to manage stormwater and potentially connect it to the sewer system. 3. Remove the basketball courts to make space for the store. 4. Create a park area with tables for people to relax and socialize. 5. Excavate the soil to direct runoff into the pond. 6. Consider testing the connection between the pond and the sewer system.
h84	<ol style="list-style-type: none"> 1. Divide the large area into two sections: park area and industrial storage area. 2. Create a series of retention ponds or one large pond in the park area to collect stormwater. 3. Install piping to transport stormwater from the retention ponds to the second half of the lot. 4. Construct a smaller, auxiliary water treatment plant in the industrial storage area to handle excess stormwater during heavy storms. 5. Connect the outflow from the auxiliary water treatment plant to the main storm sewer system.

c85	<ol style="list-style-type: none"> 1. Expanding the park 2. Adding more trees 3. Removing parking 4. Relocating the storage center 5. Purchasing the commercial area for park development 6. Creating detention basins
b86	<ol style="list-style-type: none"> 1. Maintain and improve the existing park area by: <ol style="list-style-type: none"> a. Adding swales for surface improvements and runoff management. b. Avoiding detention or retention ponds for aesthetic reasons. c. Increasing greenery, such as trees, to enhance infiltration. d. Adding walking paths with pervious surfaces. e. Fencing the area and implementing operating hours for safety. f. Improving the existing basketball court and making its surface more pervious. g. Adding a playground with mulch or other infiltration-friendly materials. h. Installing benches and other amenities to encourage usage. 2. Repurpose the impervious storage area by: <ol style="list-style-type: none"> a. Removing unnecessary impervious surfaces. b. Adding convenience stores, grocery stores, or a community center with green roofs or rain barrels to reduce runoff. c. Separating the underground systems to avoid combined overflows. d. Creating a community garden for skill-building and food production to alleviate poverty and reduce violence in the area.
b87	<ol style="list-style-type: none"> 1. Place the pond further away from the basketball court. 2. Install an underground detention center near the pond with a drain connecting them. 3. Plant trees and flowers in the landscape to slow down water during rainfall. 4. Add more trees around the area, if possible, despite the impervious surface. 5. Increase the size of the pond. 6. Expand the underground area for water storage.
c88	<ol style="list-style-type: none"> 1. Add medians to roads with pervious areas, grass, and trees. 2. Create stormwater retention ponds in the central area with local wildlife to improve permeability. 3. Establish a larger pond at the eastern end. 4. Connect smaller ponds with a channel to prevent overflow and manage sewer capacity. 5. Include inlets in each pond for overflow to enter the sewer system and go underground.
b89	<ol style="list-style-type: none"> 1. Separate the area into two sections with a road. 2. Create a pedestrian-focused development with a row of shops. 3. Design a pedestrian mall in the middle of the development. 4. Include underground storage beneath the walking section. 5. Enhance the park with trees and paths to address urban heat island effects. 6. Minimize impervious surfaces and promote water infiltration in the park area. 7. Implement underground detention for stormwater management in the developed area.
c90	<ol style="list-style-type: none"> 1. Combine stormwater and wastewater systems, similar to the Blacksburg water treatment plant, to regulate water distribution based on population and rainfall predictions. 2. Implement multiple filtration systems to ensure continuous operation of the water

	<p>treatment plant.</p> <ol style="list-style-type: none"> 3. Add more trees and vegetation to the area to increase water absorption and prevent overflow. 4. Implement innovative technologies to control and divert stormwater flow to desired locations. 5. Create job opportunities by expanding the water treatment plant's capabilities and employing more engineers and staff. 6. Improve community health and well-being by reducing pollution and efficiently managing water resources.
h91	<ol style="list-style-type: none"> 1. Separate the sewage sewer system and rainwater pipes to improve the underground infrastructure. 2. Create a lake at the surface level to make the area more presentable and provide a water feature. 3. Add more trees and greenery to the area to enhance the environment. 4. Transform the area into a park to attract residents, tourists, and potential investors. 5. Address the socio-economic problems of the city through the improvement of the area and the addition of new features.
h92	<ol style="list-style-type: none"> 1. Divide the land into two sections, removing the park and storage/commercial unit. 2. Build a stormwater management treatment facility where the park was, using sustainable methods and materials. 3. Consider going underground for the stormwater management system due to the flat topography. 4. Implement a pipe connection system to manage water flow between areas. 5. Install filters in the pipe system to catch trash, debris, and harmful bacteria. 6. Conduct research and testing on site for the effectiveness of the stormwater management system. 7. Address potential traffic volume increase due to new construction and job opportunities. 8. Redirect traffic to nearby highways or interstates, possibly implementing roadblocks or investing in additional road infrastructure.
c93	<ol style="list-style-type: none"> 1. Indoor water park: The participant proposes an indoor water park that uses rainwater, which would be treated and safe for use. This would provide a year-round attraction and create jobs in the area. 2. Parking garage: To optimize space for the water park, a parking garage is suggested, with enough capacity for visitors. 3. Green roofs: To increase permeability and reduce rainwater runoff, the participant suggests adding green roofs to both the water park and the parking garage. 4. Environmental, social, and economic benefits: The design aims to reduce the chances of overflow, provide a fun attraction for families, and create jobs in the area.
h94	<ol style="list-style-type: none"> 1. Separate the combined sewer system into two distinct systems: one for stormwater and another for sanitary sewer. 2. Convert the basketball court into a grassy area with trees planted. 3. Increase the size of the grassy area with trees. 4. Implement a pond at the end of the project area, where trucks and storage are currently located. 5. Surround the pond with vegetation to create a more natural appearance. 6. Add a few benches for people to enjoy the area. 7. Consider introducing ducks or geese to the pond in the future to enhance the natural feel and attract visitors.

b95	<ol style="list-style-type: none"> 1. Remove the storage place to improve the flow of the park. 2. Expand the park area. 3. Create a pond with overflow management, including underground water storage. 4. Improve surrounding houses and incorporate vegetation. 5. Add trees and sidewalks. 6. Improve the sewage system and drainage. 7. Increase green infrastructure, such as trees and vegetation, to utilize water. 8. Create a walking path through the green area. 9. Add a small stream leading into the pond. 10. Upgrade or improve the wastewater management facility.
b96	<ol style="list-style-type: none"> 1. Rezone the area to improve runoff and attract more people. 2. Improve access to parks for families and children. 3. Address traffic issues in the area. 4. Tear down and rebuild structurally unsound residential areas to attract new residents. 5. Consider increasing the capacity of the treatment facility as a stopgap measure. 6. Evaluate the costs of increasing the treatment facility size versus separating sanitary and stormwater systems. 7. Add vegetation, trees, and possibly a retention pond to help with water runoff and reduce the impact on the treatment facility. 8. Separate stormwater from the sanitary system to improve the capacity and efficiency of the treatment facility.
b97	<ol style="list-style-type: none"> 1. Expand the small park area to cover the entire center space of the site, creating a large green space. 2. Relocate commercial storage areas and trailers to a different location off-site. 3. Increase the appeal of the area by adding more green spaces. 4. Install underground storage tanks to collect excess water that can't be managed. 5. Upgrade the water treatment system, if necessary, after testing for dangerous chemicals. 6. Add more trees and plants to increase biodiversity. 7. Create a community feel by adding sitting areas or benches. 8. Focus on stormwater management by building underground storage that doesn't detract from the surface appeal.
b98	<ol style="list-style-type: none"> 1. Create a mixed-use green space to attract people to the neighborhood. 2. Include an entertainment center in the area. 3. Preserve existing green space for a park with a basketball court and softball fields. 4. Consider moving the entertainment center to an adjacent site. 5. Incorporate trees and trails throughout the design. 6. Install an underground detention basin for stormwater management beneath the entertainment building. 7. Add a parking lot across the street. 8. Create a trail around the pond and add trees along the road on the north side. 9. Separate the sidewalk from the busy road with trees. 10. Include a garden in the design. 11. Consider daylighting a natural stream, if it exists, and potentially connecting it to the river. 12. Ensure storage requirements are met with the underground detention basin and pond.
b99	<ol style="list-style-type: none"> 1. Retain the existing park and enhance it with more green features. 2. Add a retention pond or a regular pond for water collection and community gathering.

	<ol style="list-style-type: none"> 3. Keep the ball field and add a basketball court if not already present. 4. Plant trees along the roadway and around the pond for community health and water management. 5. Add shrubs, bushes, and flowers to encourage people to visit the park. 6. Place benches by the pond and other areas for relaxation. 7. Add garbage cans throughout the park. 8. Create a creek that drains into the pond. 9. Build bridges over the creek for easy access and movement. 10. Develop a bike trail with minimal blacktop and line it with trees. 11. Add walking paths and connect them to different park features. 12. Increase the number of trees and bushes throughout the park for a more natural environment.
b100	<ol style="list-style-type: none"> 1. Plant trees in the park to provide better drainage, absorption of stormwater, and create a more appealing space for residents and wildlife. 2. Expand the park into the trailer storage area, which currently serves little purpose and sits dormant. 3. Relocate the trailers to another space, possibly using buildings in the area that need reconstruction or heavy modification. 4. Improve the transition between the park and the storage area to create a more continuous green space. 5. Add drainage areas throughout the park to manage excess water. 6. Upgrade the sewage stormwater drainage system to separate stormwater and sewage, moving away from the old, dated method of combining them.
b101	<ol style="list-style-type: none"> 1. Establish a park with green features such as trees, shrubbery, and a playground. 2. Include outdoor amenities like a basketball court and an outdoor gym. 3. Create pedestrian paths for easy access across the park. 4. Develop residential areas with high-density buildings on the right side of the park. 5. Introduce quiet commercial spaces, such as a drug store, on the other side of the block away from the park. 6. Implement storm drains and graded inlets to manage runoff from the park. 7. Separate sanitary sewer and stormwater lines to prevent overflow and ensure proper treatment of wastewater.
b102	<ol style="list-style-type: none"> 1. Extend the existing park to cover the whole area of interest. 2. Retain the existing basketball court and baseball field. 3. Add more plant life to the park. 4. Provide access to water through water fountains, bird baths, or a manmade stream. 5. Rehabilitate the commercial storage area and possibly add another basketball court or a soccer field. 6. Create a winding path throughout the park, lined with trees. 7. Include a walkway/bike path with a good panoramic view of the park. 8. Design a stream that snakes underneath and around the walkway/bike path. 9. Add water fountains and bird baths throughout the park.

CHAPTER 5: CONCLUSION

The research conducted in this dissertation explored the impact of embodied VR on the human-nature connection and engineering design. The results indicate that embodied VR changes both the human-nature connection and engineering design. Embodying a bird avatar strengthened the human-nature connection and increased the number of nature related design ideas (Chapter 2). The use of embodied VR both as a bird and human avatar shifted how engineers ideated the bird group was more inclusive of nature, which was verified through thematic content analysis (Chapter 3) and using natural language processing techniques (Chapter 4).

Due to the relative nascency of this type of research as outlined by Markowitz et al. (2018) and Spangenberger et al. (2022), various methods of evaluating design ideas were used, such as thematic content analysis (Smith, 2015), an exploration of design space (Gero & Milovanovic, 2022), word-based statistics (Toh & Miller, 2014a), and artificial intelligence through large-language models (Katz, 2023). While each of these methods for analysis were used for different purposes, the results from each technique provided complimentary outcomes that suggested the group embodying a bird formulated different ideas, specifically toward nature-based thinking. The research questions from the previous chapters are presented below in bold, with their findings and additional commentary following.

Research Question 1 - How does the embodiment of nature through virtual reality change human-nature connection in the engineering design process?

Embodying nature positively influences the human-nature connection. Through the Connectedness to Nature Scale (Mayer & Frantz, 2004), both the control group and the self-lens group did not witness any change in human-nature connection, whereas the bird group

experienced an increase in human-nature connection after the VR experience. While previous research presented null findings in a similar space (Spangenberg et al., 2022), a critical difference that led to a significant increase in human-nature connection for the bird group was the incorporation of the activity within the lens of the engineering design process.

Research Question 2 – How does the embodiment of nature impact green vs. gray design concepts?

Based on the results presented in Chapter 2, embodiment influences how designers ideate. More specifically, an increase in nature-based ideas was reflected in the bird group. This research connects green design ideas as an extension of pro-environmental behaviors from embodied VR that Ahn and Bailenson (2012) discuss. In other words, not only are embodied VR participants more likely to behave altruistically toward nature (Ahn & Bailenson, 2012; Ahn et al., 2016), engineering design ideas were also more likely to incorporate elements of nature.

Embodiment also influenced the number of socioeconomic ideas that were mentioned during design. Since the case study was centered around stormwater infrastructure (Project Groundwork, 2020), the inclusion of socioeconomic ideas could be due to the connection between green infrastructure (i. e., nature-based ideas) and various co-benefits to societal improvements (Dhakal & Chevalier, 2017). The socioeconomic ideas that were explored during this research were largely land-based design, including mixed-use development, new restaurants, improvements toward existing housing, and new apartment complexes.

While this research observed an increase in nature-based solutions from embodiment, the research presented in Chapter 2 lumped design ideas into three bins only: green, gray, and socioeconomic. Further exploration into the actual design ideas was done in Chapter 3 using thematic content analysis and natural language processing techniques.

Research Question 3 - How does the embodiment of nature through virtual reality change engineering design?

Through thematic content analysis (Chapter 3), participants who were given the VR experience were more likely to develop concepts matching their bird or human avatar. Beyond green and gray infrastructure ideas, participants within all groups reflected upon an emergent idea surrounding socioeconomic benefits. This emergent finding agrees with previous research on green infrastructure to incorporate societal co-benefits (Bell et al., 2019; Randolph, 2003). The second pass of coding assessed and lumped all the design ideas, which is presented in the Appendix of Chapter 3. The third and final pass presented the generalized themes, which are:

- Theme 1 – The control group identified the plausibility of green design, but gravitated toward gray-thinking to solve problems
- Theme 2 – The bird group focused on socioeconomic benefits to the area of interest, then merged green ideas to facilitate the benefits.
- Theme 3 – The embodied and human groups provided more vivid descriptions of nature-based design than the control group

In general, the VR participants were more likely to ideate toward the subject they embodied. The control group was more likely to stick to the status quo of gray infrastructure design ideas (Rosenbloom, 2018).

Research Question 4 - How do automated natural language processing techniques compare thematic content analysis when evaluating design ideas?

The goal of this research question was to narrow down how embodiment impacts design ideas between groups, which required a generalization of themes. The siloed themes for each group from the LLM used in this research are listed in Table 14.

Table 14 - Comparison of design themes across groups from the LLM

Bird group (Bird)	Self-Lens Group (Human)	Control
1. Stormwater management and environmental sustainability	1. Stormwater management and green infrastructure	1. Integration of nature and green infrastructure
2. Community engagement and recreation	2. Community development and revitalization	2. Utilization of gray infrastructure
3. Greenery and aesthetics	3. Sustainable and eco-friendly solutions	3. Urban redevelopment and community engagement
4. Sustainable urban planning	4. Aesthetic enhancement and community well-being	4. Sustainable design and water management
5. Water treatment and quality control	5. Underground infrastructure and technology	5. Separation and management of sanitary and stormwater systems
6. Accessibility and safety	6. Traffic and road management	6. Balancing environmental, social, and economic impact
7. Collaboration with nature	7. Environmental considerations	7. Incorporation of water treatment plants and filtration systems
8. Innovative design solutions		8. Innovative approaches and long-term planning

Siloed themes from Table 13 were generalized to discover embodiment's impact between groups. Themes had to be cross-checked manually from the LLM's summary of themes based on each group with the list of design ideas, which required ample researcher time. Ultimately, the themes that were manually deduced from the LLM were as follows:

1. The bird group tended to ideate toward the benefit of both nature and the surrounding community, gravitating to a synergistic relationship through minimizing stormwater runoff.
2. The self-lens group was concerned about environmental sustainability, but encouraged more ideas toward community planning and management wins
3. The control group discussed the importance of nature-based design, but commonly called upon gray infrastructure through separating sewer systems and the inclusion of new water treatment plants

The design spaces were quantified for the embodied, self-lens, and control groups. The words used to describe design concepts was significantly larger for the bird group. Based on Kan & Gero (2018) and Gero & Milovanovic (2020), this method of quantifying the design space begins to suggest the bird group was more creative. The use of force graphs to create networks, such as in Sopher et al. (2022) can assist future research with visualizing this data. Further research can expand on the use of word frequency, using more robust n-grams for textual and sentiment analysis (Bernard & Ryan, 1998).

Based on a comparison of the design ideas identified through TCA, the natural language processing techniques serve to supplement but not replace TCA. Large language models such as ChatGPT are tools that can supplement TCA with an initial establishment of design ideas. The research in Chapter 4 illustrated the granularity, organization, and accuracy of results in comparison to the TCA results used in Chapter 3 by using the approach for thematic coding using an LLM developed by Katz (2023). In some instances, these findings from an LLM even surpassed human-based TCA, especially in organization of complex design ideas.

However, small errors were spotted with the LLM. These errors were rooted in an inability to spot and count the first instance of a design idea. For example, participants commonly ideated solutions involving “trees”; while many of these solutions involved tree placement in strategic locations, some of the participants were referring to one particular tree placement multiple times.

On occasion, the LLM would identify the multiple occurrence of the singular idea as multiple solutions.

Design ideas produced by an LLM were similar to design ideas found in Chapter 3's use of thematic content analysis. However, this semi-automated version of thematic content analysis through a LLM is limited by its understanding of the transcripts. In order to even present the above three themes, the previous design ideas had to be referenced and manually compared, similar to thematic content analysis (Smith, 2015). In other words, a LLM is strongest in synthesizing design ideas, but has room to improve for generalizing themes and comparing between groups. The cross-comparison between groups requires substantial familiarity with the data-set, such as by closely evaluating all of the design ideas within and between each groups to find differences.

Automated methods like ChatGPT, Bard, and other LLM tools alongside semantic distance as a proxy for design space serve to supplement TCA. LLMs synthesized and organized design ideas rapidly, which can help to streamline the process and resource-intensive TCA. Semantic similarity as a proxy for the design space analyses can point researchers to possible differences between groups. Through this process, the analysis showed the bird group had used a larger semantically diverse concepts, which may suggest more creative design solutions than the control group. The greater benefit of using design space analyses is toward very large datasets; with vast amounts of data to comb, this automated method of calculating design space can present objective evidence rapidly and could prevent researchers from missing findings that may be overlooked.

Limitations and Opportunities for Future Research

The limitations that are presented from the work of this dissertation provide ripe opportunities for future research thrusts. Limitations are described below, with supporting rationale and the opportunity for future research that exists:

Limitation 1 – Multiple VR environments should be made to illustrate design solutions rather than the existing terrain

Expending resources into creating an immersive VR experience of a site that already exists may not be feasible. Not only is the creation of virtual environments expensive, but they also require a high level of expertise in graphic design and computer science to seamlessly integrate immersive components. However, this research is a testament that virtual environments can influence design and decision-making processes. A highly valuable future research objective should be to document the process of utilizing embodied VR within the stakeholder engagement process. Real cases are encouraged. In the VR environments, opposite ends of the “spectrum” of gray vs. green infrastructure could be presented (Bell et al., 2019), using embodiment as an additional independent variable. The benefit of performing this future research is that the method’s case study is more akin to a real-world example, where the problem is known, seen, and felt, but VR intends to examine the unknown: the designs’ impacts on how stakeholders work and live within the area of interest.

Limitation 2 – Design professionals were not studied

Future research could test the effect of embodiment on design cognition with a sample of professional engineers rather than students. Professional engineers bring a wealth of practical experience and expertise to the design process, which could lead to different outcomes compared to student participants. Follow-up studies could also explore the impact of embodiment on design cognition using small samples of engineering design professionals with a range of field experience. This would allow researchers to examine how the effects of embodiment vary across different levels of expertise and specialization within the engineering profession.

Limitation 3 – How can a researcher be sure that a participant “felt” like an avatar?

Embodiment is an experience that is not easily compared among individuals. The majority of VR research, especially within design, employs scales and questionnaires to track immersion (Coroado, 2015; Emamjomeh et al., 2020). Immersion is a measure of how “there” one feels in the virtual environment, but is traditionally assessed by objective immersive instruments, like the type of VR headset, the use of sounds, and the sharpness of the image. Presence is a psychological metric of how one feels in a virtual space (Grigorovici, 2003), and is not easily measured.

Previous VR research tends to employ immersion as a dependent variable due to the relative nascency of VR in the field of construction. Immersion scales are beneficial for studies using different types of immersive media, e.g., a VR headset vs. watching a movie (Spangenberg et al., 2022). This research utilized presence through a premade scale from iGroup (2016) because of the nature of the subjectivity of empathy. As empathy changes how one feels for another and can impact rational decisions (Cuff et al., 2016), presence (a subjective phenomenon) was selected as a dependent variable to assess differences in presence between both VR groups.

Beyond a questionnaire, semi-structured interviews should be used for presence, similar to Spangenberg et al.’s (2022) inclusion of interviews for immersion. Interview questions should center around personal feelings within the virtual environment, potentially asking questions surrounding empathy for additional data.

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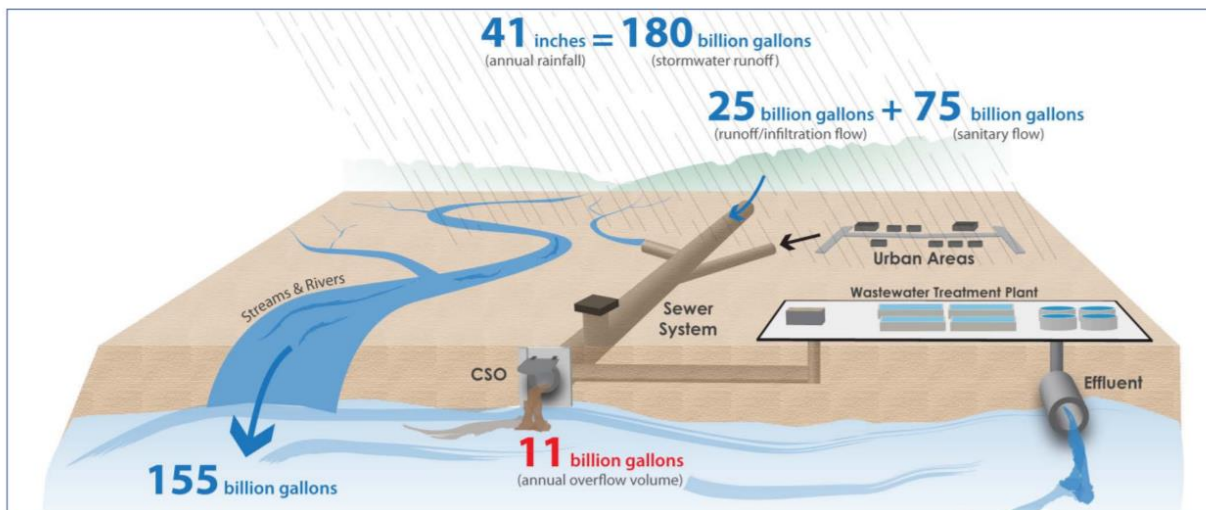
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APPENDIX

South Fairmount Case Study

Cincinnati's stormwater infrastructure requires an update from the Environmental Protection Agency (EPA). The EPA has levied a consent decree, which is a federal mandate, to drastically reduce Cincinnati's 11 billion gallons/year of combined sewer overflow (CSO). Figure 10 depicts the CSS of Cincinnati, which operates by collecting stormwater in underground sewers and transporting the stormwater to a treatment center, which is discharged to the Ohio River. However, during heavy rainfall events, the sewers and treatment system become overburdened, causing the system to overflow through outfall locations, known as CSO.



MSD's sewer system during wet weather based on the typical year rainfall.

Figure 10 - Overview of a combined sewer overflow system

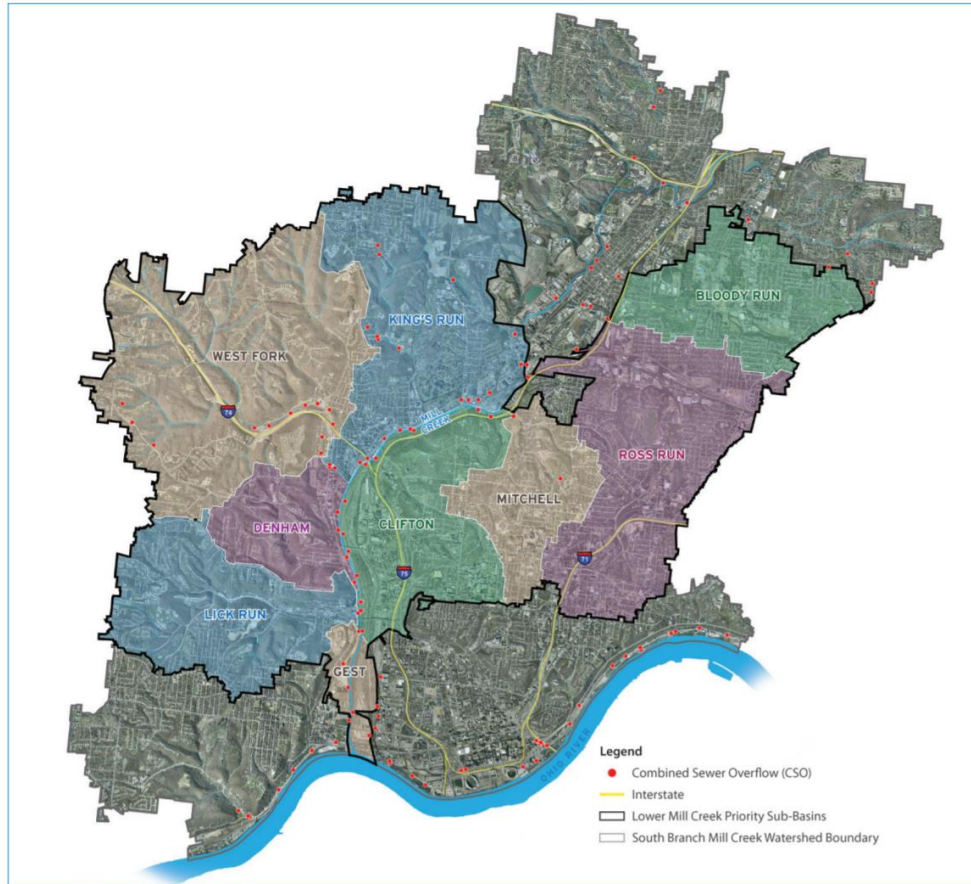
CSO is detrimental to all forms of life, which is why the EPA is requiring its minimization. This raw water holds a host of adversarial bacteria and microscopic life that can cause severe illness and death to most aquatic species, mammals, and humans. Figure 11 illustrates what CSO can look like, which is typically water that is brown and tepid (sediment-heavy). Since CSO is rather

difficult to remove entirely, the EPA has placed a quota for Cincinnati to remove at least 85% of the 11 billion gallons/year.



Figure 11- CSO issues in the Lick Run watershed

In order to do this, Project Groundwork formed a plan to make improvements for each watershed in Cincinnati. This combined watershed, known as the Lower Mill Creek watershed, has many locations for CSO to emerge, seen in Figure 12. The most impactful of these locations are known as “outfalls”, which are 20’ diameter tunnels. The largest emitter of CSO of all of these outfalls is CSO Outfall #005, which is responsible for 500 million gallons of CSO/year.



Lower Mill Creek Watershed

The Lower Mill Creek Watershed covers approximately 40,000 acres (62.5 square miles) in the heart of Hamilton County. It includes nine smaller watersheds, including Lick Run, that drain to the Mill Creek. The watershed includes almost 50 Cincinnati neighborhoods, as well as Elmwood Place, Norwood, St. Bernard and portions of Green Township and Springfield Township.

Figure 12 - The Lick Run watershed

CSO #005 is the central emitter for the Lick Run watershed, and abuts the South Fairmount neighborhood. Figure 13 presents an aerial image of South Fairmount and CSO #005. South Fairmount has become known as a neighborhood within Cincinnati with urban blight, exacerbated by the CSO problem. Various studies performed by MSD and Project Groundwork have discovered that this neighborhood is distressed:

- Economic activity is low compared to other neighborhoods in Cincinnati
- Abandoned properties and vacant lots have become numerous
- Business innovation is markedly low compared to other neighborhoods based on the exodus of old businesses, rather than introduction of new businesses

- Violence rates are high
- Property values are low in comparison to other neighborhoods in Cincinnati
- Traffic studies determine that South Fairmount is a “pass-through” town with relatively few trip ends



Figure 13 - The South Fairmount neighborhood and close-up on CSO #005

To assuage these issues, Project Groundwork’s stakeholders have identified a need to revitalize the critical stormwater infrastructure for South Fairmount. MSD, along with Project Groundwork, identifies their joint vision as the following:

- use innovative technologies
- revitalize communities through creation of jobs and growth opportunities for local businesses
- create solutions that benefit communities on an environmental, social and economic level

Project Groundwork has assembled three modes of thinking to attain these goals, which is visualized in Figure 14. First, source control acts as a method to prevent stormwater from

entering the system entirely. Second, conveyance allows for the better movement of stormwater by making the capacity of the sewer system larger. Third, wastewater systems can be hardened to handle more stormwater during heavy rains.

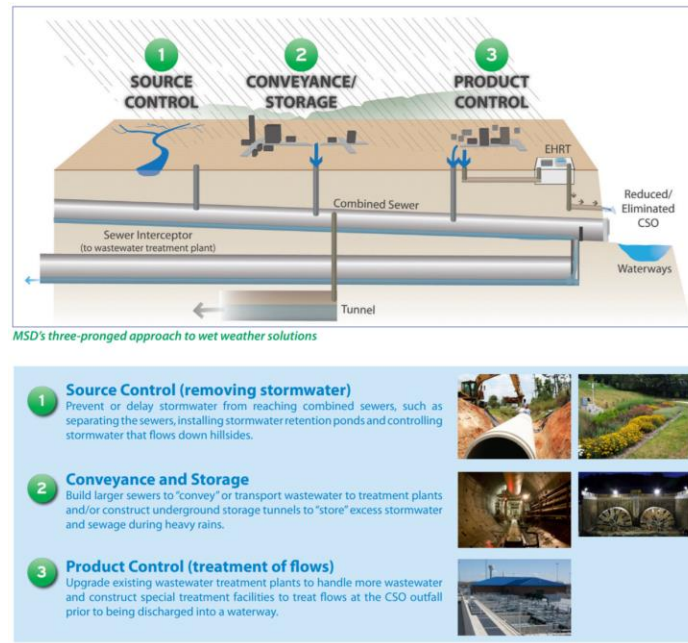


Figure 14 - Schools of thought for stormwater management

Following a few feasibility studies, Project Groundwork discovered that regardless of the project placed forward for South Fairmount, upgrades to the treatment centers must occur. Therefore, the solutions that were left to utilize were either source control or conveyance control. A combination of the two could also be utilized.

Source control projects would require changes to the existing landscape of South Fairmount. Examples that are commonly used range in means and methods, but can include retention ponds, channels, swales, and daylighting projects. These projects are meant to withhold excess water from entering the system, preventing overflows.

Conveyance control projects likely would not require the surface of South Fairmount to change. Common measures are to create new storage tunnels underground or to enlarge the current

system, providing the treatment system with enough time to handle the vast amount of stormwater from a large storm event. These projects are meant to allow the current system to handle more stormwater.

In the next stakeholder engagement event, MSD and Project Groundwork want your input as a local South Fairmount stakeholder. While there are a range of possibilities that they are considering, they want to know if participants value projects with more source control or conveyance control elements. The following exercises are aimed at visualizing these stormwater control examples. While these exercises will not replicate South Fairmount entirely, they are aimed to be visualization techniques to only illustrate the thought process of the type of stormwater control.

In the following two phases of this research experiment, please pretend like you are a resident of South Fairmount. A common phenomenon in research experiments is for participants to not choose or act as they would in the real world given the same decision-making circumstances. Please replicate your decisions as you would in the real-world as this is a real-world issue.

Additional drawings and pictures of South Fairmount

CAGIS Map



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1:9,600
0 0.1 0.2 0.4 mi
0 0.17 0.35 0.7 km

Figure 15 - Small scale map of South Fairmount with the area of interest highlighted

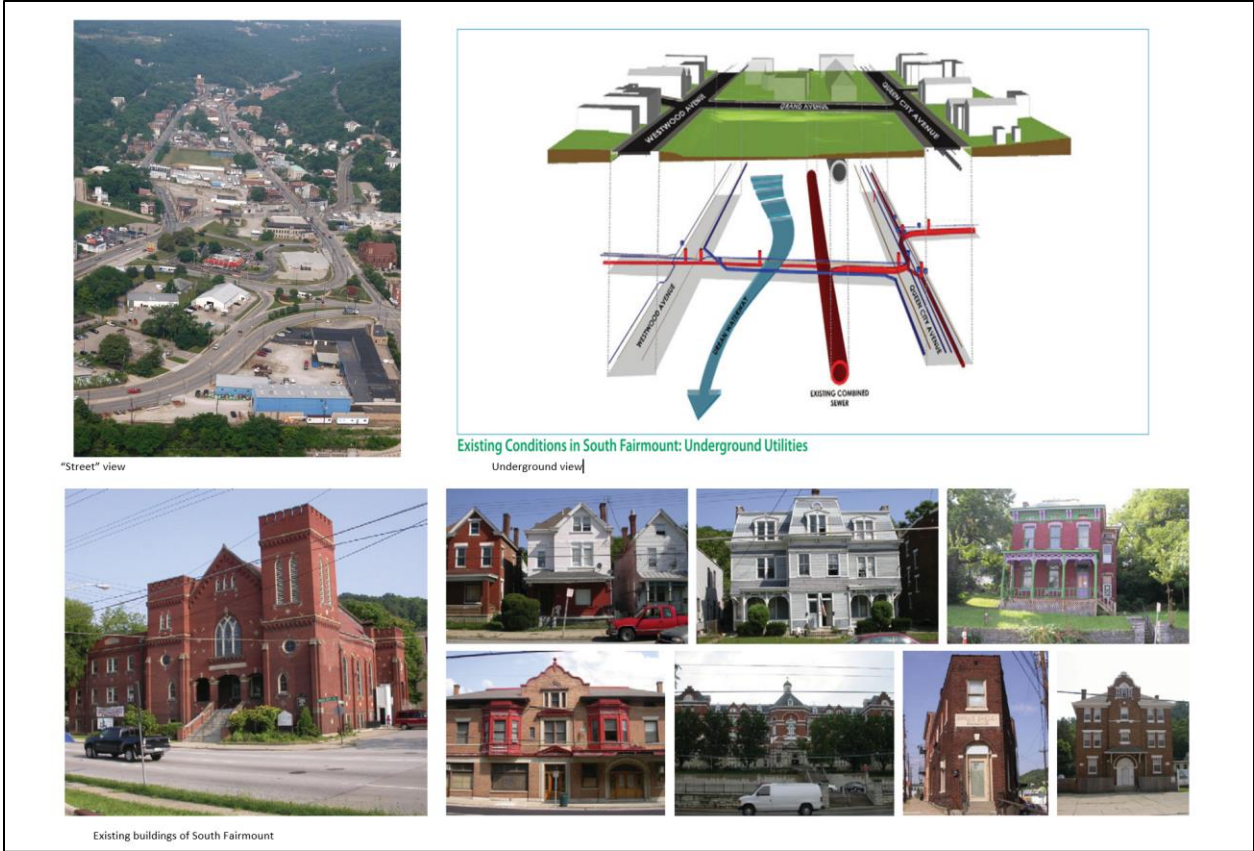
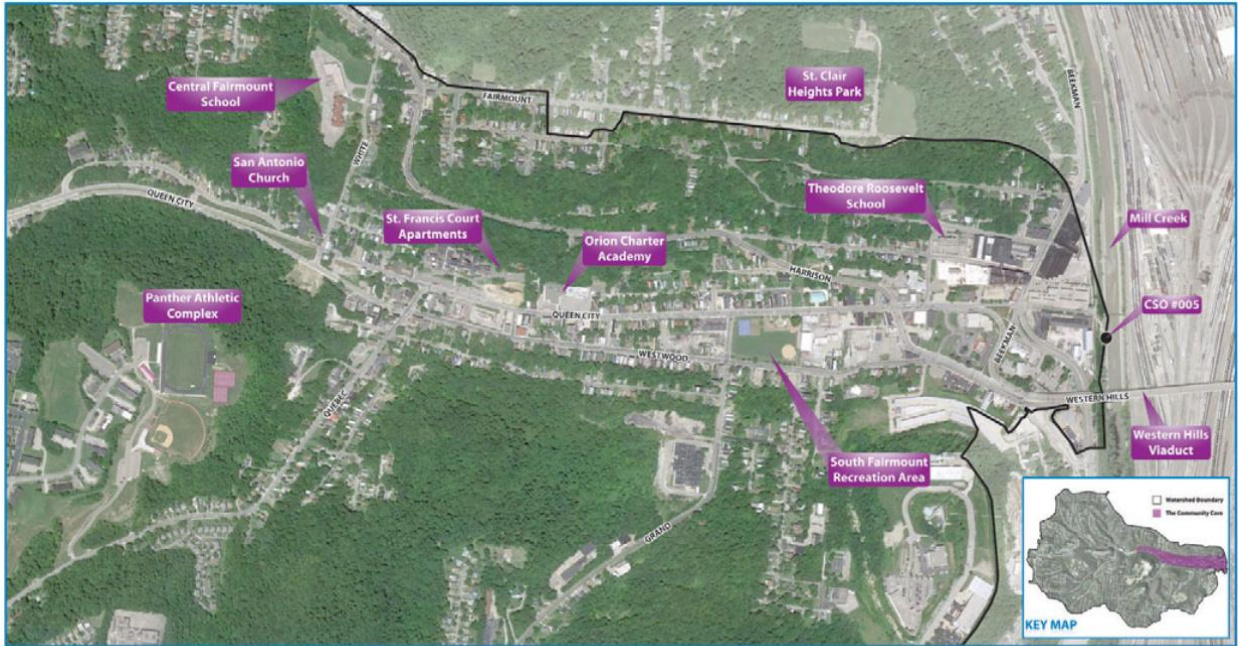


Figure 16 - Street view, underground view, and existing buildings of South Fairmount



South Fairmount - Community Core

Figure 17 - The plan view of the South Fairmount neighborhood with key buildings and locations identified



Figure 18 - The “soundness” of the structural integrity of the buildings in South Fairmount. Green – requires minor repair. Yellow – requires major repair. Red – critical condition

South Fairmount



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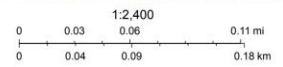
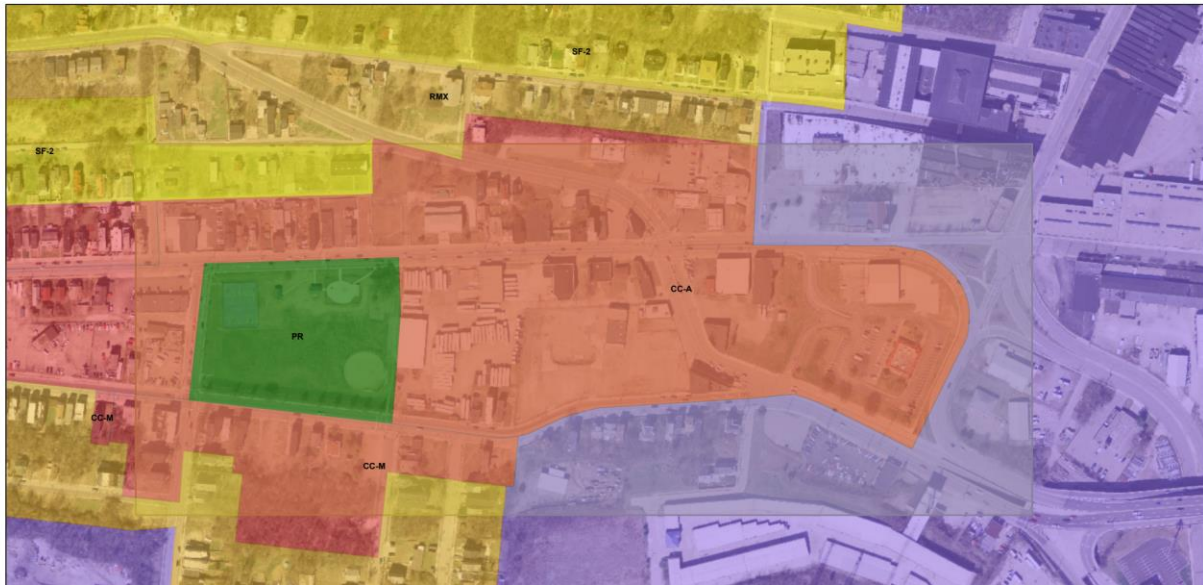


Figure 19 - Close-up of the area of interest for the design charrette

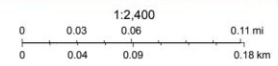
South Fairmount Zoning



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Zoning Designation (Cincinnati Only)

- PR Parks and Recreation
- CC-A Commercial Community - Auto
- CC-M Commercial Community- Mixed
- MG Manufacturing General
- RMX - Residential Mixed
- SF-2 Single-family Residential (2,000 sf)
- SF-4 Single-family Residential (4,000 sf)



CAGIS

Figure 20 - 2011 zoning of the area of interest



Figure 21 - South Fairmount area of interest with highlighted streets, buildings, and identified park space

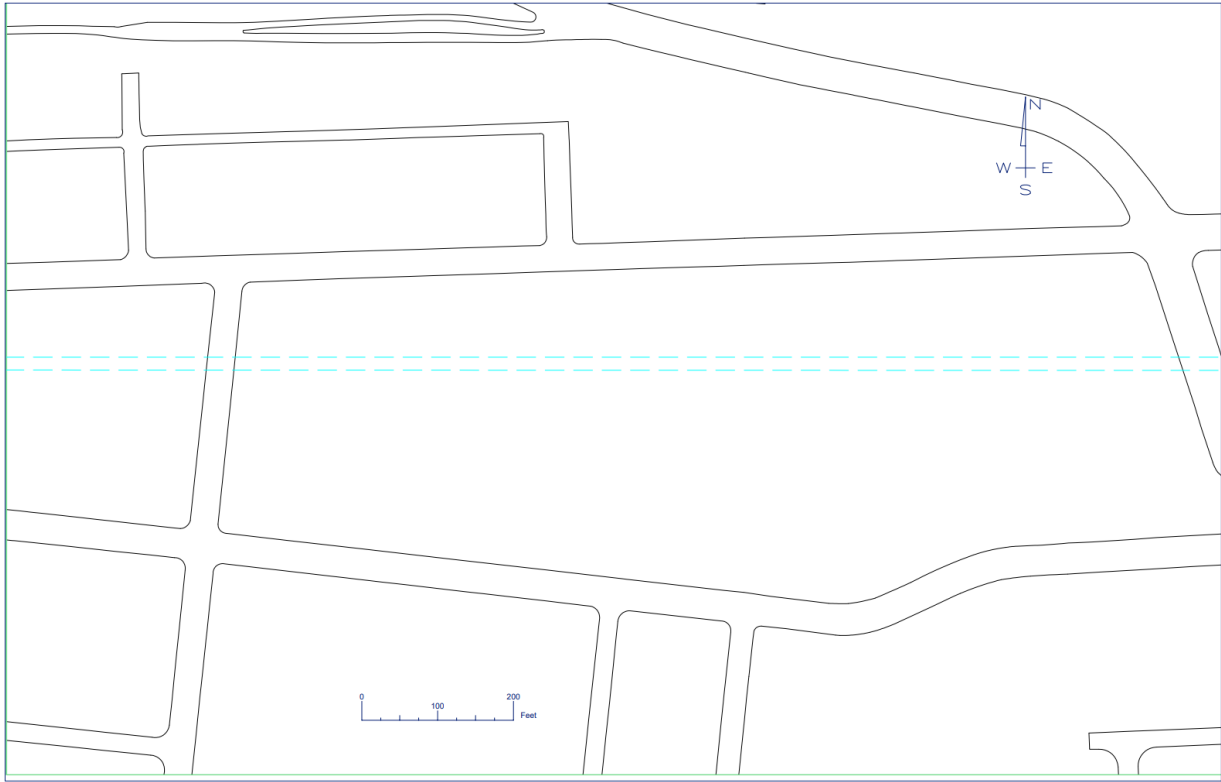


Figure 22 - Location of a proposed sewer upgrade (and the existing outfall location)

IRB Exemption Letter



Division of Scholarly Integrity and
Research Compliance
Institutional Review Board
North End Center, Suite 4120 (MC 0497)
300 Turner Street NW
Blacksburg, Virginia 24061
540/231-3732
irb@vt.edu
<http://www.research.vt.edu/sirc/hrpp>

MEMORANDUM

DATE: August 30, 2022
TO: Tripp Shealy III, Josh Trump
FROM: Virginia Tech Institutional Review Board (FWA00000572)
PROTOCOL TITLE: Influencing Engineering Design Thinking through Perspective-Taking
IRB NUMBER: 22-691

Effective August 30, 2022, the Virginia Tech Human Research Protection Program (HRPP) determined that this protocol meets the criteria for exemption from IRB review under 45 CFR 46.104(d) category (ies) 2(ii).

Ongoing IRB review and approval by this organization is not required. This determination applies only to the activities described in the IRB submission and does not apply should any changes be made. If changes are made and there are questions about whether these activities impact the exempt determination, please submit an amendment to the HRPP for a determination.

This exempt determination does not apply to any collaborating institution(s). The Virginia Tech HRPP and IRB cannot provide an exemption that overrides the jurisdiction of a local IRB or other institutional mechanism for determining exemptions.

All investigators (listed above) are required to comply with the researcher requirements outlined at:

<https://secure.research.vt.edu/external/irb/responsibilities.htm>

(Please review responsibilities before beginning your research.)

PROTOCOL INFORMATION:

Determined As: **Exempt, under 45 CFR 46.104(d) category(ies) 2(ii)**
Protocol Determination Date: **August 30, 2022**

ASSOCIATED FUNDING:

The table on the following page indicates whether grant proposals are related to this protocol, and which of the listed proposals, if any, have been compared to this protocol, if required.

Invent the Future

VIRGINIA POLYTECHNIC INSTITUTE AND STATE UNIVERSITY
An equal opportunity, affirmative action institution

Survey Instruments

Connectedness to Nature Scale - From Mayer & Frantz (2004)

- | 1 | 2 | 3 | 4 | 5 |
|-------------------|---|---------|---|----------------|
| Strongly disagree | | Neutral | | Strongly agree |
| ___ 1. | | | | |
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| ___ 14. | | | | |

Presence Questionnaire – From iGroup (2016)

English IPQ Items

Number	PQI/II Nr. (internal)	IPQ item name	shortcut	loading on ...	English question	English anchors	Copyright (item source)
1	s62	G1	sense of being there	PRES	In the computer generated world I had a sense of "being there"	not at all--very much	Slater & Usoh (1994)
2	s44	SP1	sense of VE behind	SP	Somehow I felt that the virtual world surrounded me.	fully disagree--fully agree	IPQ
3	s30	SP2	only pictures	SP	I felt like I was just perceiving pictures.	fully disagree--fully agree	IPQ
4	s28	SP3	not sense of being in v. space	SP	I did not feel present in the virtual space.	did not feel--felt present	???
5	s31	SP4	sense of acting in VE	SP	I had a sense of acting in the virtual space, rather than operating something from outside.	fully disagree--fully agree	IPQ
6	s33	SP5	sense of being present in VE	SP	I felt present in the virtual space.	fully disagree--fully agree	IPQ
7	s64	INV1	awareness of real env.	INV	How aware were you of the real world surrounding while navigating in the virtual world? (i.e. sounds, room temperature, other people, etc.)?	extremely aware--moderately aware--not aware at all	Witmer & Singer (1994)
8	s37	INV2	not aware of real env.	INV	I was not aware of my real environment.	fully disagree--fully agree	IPQ
9	s40	INV3	no attention to real env.	INV	I still paid attention to the real environment.	fully disagree--fully agree	IPQ
10	s38	INV4	attention captivated by VE	INV	I was completely captivated by the virtual world.	fully disagree--fully agree	IPQ
11	s48	REAL1	VE real (real/not real)	REAL	How real did the virtual world seem to you?	completely real--not real at all	Hendrix (1994)
12	s7	REAL2	experience similar to real env.	REAL	How much did your experience in the virtual environment seem consistent with your real world experience ?	not consistent--moderately consistent--very consistent	Witmer & Singer (1994)
13	s59	REAL3	VE real (imagined/real)	REAL	How real did the virtual world seem to you?	about as real as an imagined world--indistinguishable from the real world	Carlin, Hoffman, & Weghorst (1997)
14	s47	REAL4	VE wirklich	REAL	The virtual world seemed more realistic than the real world.	fully disagree--fully agree	IPQ

REFLECTION

This PhD has brought many highs and lows that were necessary for my growth as a researcher. I chased research question after research question in academic literature, searching for something that I wanted to put my mark on. As many PhD students, I tried to “shoot the moon” with ideas that, as my committee pointed out, were too large in scope. Narrowing down the research to lead to this dissertation took both time and a good understanding of the problem space. Now that I am at the finish line, I have learned and lamented some key takeaways from this PhD process that I hope can resonate with future PhD students, regardless of their interest in VR’s role in engineering design.

Start with what interests you. Going into this dissertation, I knew I was very interested in impacting the use of green infrastructure in large stormwater projects. I took this idea from my Master’s thesis, where I had the chance to interview stakeholders of the Lick Run Greenway. Of note, I was able to talk with the designers of the massive green infrastructure project that was developed, which spurred my interest in the topic. I felt transported after that interview, and I wanted to know more and more about their own process of design, especially with their form of stakeholder engagement. After my thesis, I knew I wanted to learn more and more about green infrastructure, its benefits, and how to get *more* of it.

Incorporate what you want to be “dangerous” in. I knew I wanted to study green infrastructure in the design process. Early in the PhD process, I had these early ideas of how interesting it would be to do something with VR and maybe make a career out of it, whether it be in consulting or academia. I was told that I should take something out of the PhD process that I want to market as a consultant or researcher, or be “dangerous” in. Incorporating VR into my problem and solution spaces of my research not only narrowed down the field, but led to the actual gap in knowledge that I was able to fulfill in this dissertation.

Every PhD is difficult; work smart. Teaching myself how to develop and operate virtual environments seemed insurmountable in difficulty at times. I am neither a programmer nor a graphic designer, so my incoming ability to create a virtual terrain that loosely resembled an area of interest within the South Fairmount neighborhood was a vast undertaking. To get around these obstacles, I had to find ways that I could get an end product that was functional and timely. I learned about the Unity Asset Store, which not only led to a much improved environment, but was also easier to defend in an academic setting since I used something that was pre-existing. Figuring out how to “work smart” within VR taught me the mechanics that I wanted to learn and helped me produce the end product more efficiently.

Write with the intention of great delivery, but the acceptance of revisitation. As many PhD students can empathize with, I procrastinated toward sitting down to get this dissertation written. I was concerned with how I could make something *great*, without accepting that before I could attempt that I first needed to make *something*. I found that once I got some initial writing done, I felt much more encouraged to keep going. It took many, many revisions and I accept that there will be many more before these papers are published.

Remember “why”! Taking on the PhD is a challenge, but it is much more attainable to break it up into smaller chunks for each incoming deliverable. At times, it was difficult to see the light at the end of the tunnel through the mountain of work ahead of me. I wanted the PhD to lead me to a career that excited me and visualizing the future brought me comfort in the times when I was frustrated. I call this visualization of my future my “why” – I want to have an impact toward increasing the sustainability and resilience of engineering design decisions that are made for our nation’s infrastructure. I have made my “why” for the PhD my introduction pitch in professional settings and I found that saying my “why” with conviction provided me with even more encouragement.