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How Virtual Reality Impacts the Landscape Architecture Design Process at Various Scales

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HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE

DESIGN PROCESS AT VARIOUS SCALES

by

Drew M. Hill

A thesis submitted in partial fulfillment
of the requirements for the degree

of

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ABSTRACT

How Virtual Reality Impacts the Landscape Architecture Design Process at Various Scales

by

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Utah State University, 2019

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In the field of landscape architecture, virtual reality (VR) is increasingly being adopted as a tool for visualization and presentation in the late stages of the design process. Many of the benefits that make VR valuable in the later stages of the design process suggest that VR may be equally valuable when used in earlier stages such as analysis and concept development. However, the present body of research does not provide a detailed study of truly immersive design within VR during those early stages. Recent developments in virtual environments, and the availability of high bandwidth networks, have the potential to bring significant changes in the way that design-related professionals collaborate and design. While VR tools for designing and planning are increasingly becoming adopted, there is insufficient research addressing the precise benefits of VR, what unique capabilities VR provides, what are the limitations in its use, and at what project scales should it be used.

This study utilizes a case study approach of two student design projects to test the impacts of VR when used in the analysis and concept development stages of the design process at both a large master planning scale and a smaller site-design scale. A series of surveys and focus groups were used to gather feedback from participants over several data collection rounds in each project. Participants reported various affordances and limitations of utilizing VR in the design process, and the data suggests that the immersive nature of VR improved their ability to understand complex issues and relationships and gave them an improved spatial understanding and awareness of the three-dimensional character of their designs. However, verbal team collaboration proved to be hindered by using VR. The results of this research demonstrate the value and benefits of VR as a tool for analysis and concept development while also highlighting weaknesses and areas for improvement. This study suggests a positive outlook for the use of VR as a design tool and demonstrates that it can enhance and effectively be integrated into the early phases of the landscape architecture design process on both large and small project scales.

(99 pages)

PUBLIC ABSTRACT

How Virtual Reality Impacts the Landscape Architecture Design Process at Various Scales

Drew M. Hill

In the field of landscape architecture, the use of virtual reality (VR) is increasing as a tool for visualization and presentation in the late stages of the design process. Many of the benefits that make VR valuable in the later stages of the design process suggest that VR may also be valuable when used in earlier stages such as analysis and concept development. However, existing research does not provide a detailed study of design within VR during those early stages. Recent advancements in technology allow the potential to bring significant changes in the way that design-related professionals collaborate and design. While the use of VR in design professions is increasing, researching is lacking in addressing the benefits of VR such as what unique capabilities VR provides, what are the limitations in its use, and at what project scales should it be used.

This study examines two student design projects to test the impacts of VR when used in the analysis and concept development stages of the design process at both a large master planning scale and a smaller site-design scale. A series of surveys and focus groups were used to gather feedback from participants over several data collection rounds in each project. Participants reported various advantages and disadvantages of utilizing VR in the design process, and the data suggests that VR improved their ability to

understand complex issues and relationships and gave them an improved spatial understanding and awareness of the three-dimensional nature of their designs. However, verbal team collaboration proved to be negatively affected by using VR. The results of this research demonstrate the value and benefits of VR as a tool for analysis and concept development while also highlighting weaknesses and areas for improvement. This study suggests a positive outlook for the use of VR as a design tool and demonstrates that it can enhance and effectively be integrated into the early phases of the landscape architecture design process on both large and small project scales.

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INTRODUCTION

Background

Virtual reality (VR) is defined as a computer-generated environment that, to the person experiencing it, closely resembles reality. It is an immersive three-dimensional space where the user can interact with surrounding objects. Virtual reality is not a new technology and was developed in the 1970s, but advances in the last decade have allowed the technology to become more accessible and useful to a broader audience. The technology is currently used in a variety of markets such as gaming, education, and design; the latter being what will be explored in this research.

In the field of landscape architecture, VR adoption is increasing as a tool for visualization and presentation in the late stages of the design process (George & Summerlin, 2018). Design firms utilizing the technology have been able to import their designs into VR and share what the design will look like with clients and stakeholders. While it has been utilized in the late stages of the design process, integrating VR into earlier stages of design is still largely unexplored (George, Sleipness, & Quebbeman, 2017).

Although the design process varies by firm, a general landscape architecture design process consists primarily of using two dimensional techniques to convey ideas and information in the beginning phases. This starts with site analysis, where existing conditions, site opportunities, and design constraints are explored. This is followed by

concept development, where loose ideas are sketched, on paper or digitally, and refined through a series of iterations. While much of this phase is two-dimensional, three-dimensional study models are sometimes used. The sketches developed in these early phases often portray three-dimensional ideas, but they are constrained to the two-dimensional surface of a sheet of paper or computer screen, thus restricting the designer and client's immersion within the space. 3D study models overcome some of these challenges, but because they are a scaled model, they are not able to be experienced at a human scale. As the design progresses, digital production begins on outputs such as 3D modeling, perspective and section renderings, and construction documents. It is usually not until these later phases that the details and three-dimensional proportions of a design are fully understood, enabling a typical designer to clearly visualize what their design will look like when built. The spatial nature and scalability of virtual reality may provide landscape architects with a way to design immersively in three dimensions from the initial phases of design at a human scale and become a useful tool to be integrated throughout the design process.

Literature Review

Virtual reality is a tool for spatial visualization and communication (de Freitas & Ruschel, 2013). Tufte (1990) describes visualization as a medium for clarifying certain complex data through a way that has substantial advantages over the written word or voice alone. The visual sense is by far the dominant component of human sensory perception (Bruce, Green, & Georgeson, 1996; Rose, 2016), and the scholarly work on

visualization suggests expanding the visual sense and incorporating all types of representations across different fields and disciplines (Hansen & Machin, 2013; Valiela, 2009; Ware, 2013). Along with having a dominant visual sensory perception, the human brain is wired for spatial thinking (Gersmehl & Gersmehl, 2007). For landscape planners and architects, spatial thinking and communication of designs in space is an essential skill, and Chamberlain (2015) suggests that to get people thinking about landscape scale and complex problems, spatial thinking is critical.

Virtual reality facilitates the understanding of spatial conception (Portman, Natapov, & Fisher-Gewirtzman, 2015), and recent developments in virtual environments and the availability of high-bandwidth networks have the potential to bring significant changes in the way that design related professionals collaborate and design (de Freitas & Ruschel. 2013). De Freitas and Ruschel also suggest that survey data shows possible benefits of these technologies when applied in the design process to understand and communicate ideas. However, VR and AR have not yet been fully incorporated in the landscape architecture design process. Chamberlain (2015) suggests that tools which aid the understanding of spatial landscape planning concepts will improve the capacity of planners and landscape architects to derive solutions in tandem with stakeholder engagement. Design tools and technologies which help improve the human decision-making process will also help us become more effective stewards of our planet (Goodchild, 2010).

As available bandwidth increases, and new virtual environments are developed to support collaborative design, designers are provided with a broader range of choices in

how they communicate and collaborate at various stages of the design process (Gül & Maher, 2006). In the past, powerful visualization tools that provided the end user with the means to generate, explore, analyze and share prospective plans were uncommon, expensive, and the time and resources required to generate images made them impractical (Portman et al., 2015). Advancements in recent years have overcome these limitations, and virtual reality has become a financially feasible and time effective option that is accessible to many designers. The widespread adoption of the use of digital simulation software in landscape planning practices has increased over time and can be seen as a precursor to the application of VR based on how the profession adopted 3D simulation (Lange, 2011). During the last few decades, digital landscape representations using VR have advanced from simplistic, static representations (Pittman, 1992) to extremely realistic visualizations that allow exploration with real time movement and experience at multiple scales (Ghadirian & Bishop, 2008).

Virtual reality can contribute to the creation of new designs or guidelines and is an immersive virtual environment where designers tend to work interactively and three dimensionally with their media (Portman et al., 2015). Every creation is a place experienced directly through movement and interaction parallel to real world familiarity (Schnabel, Wang, & Kvan, 2008). While benefits have been noticed, many challenges for the use of VR for landscape architecture pointed out over a decade ago remain. While VR tools for landscape architecture are increasingly being adopted, there is a lack of research addressing exactly what is to be gained by VR, what can be done by VR that cannot be done otherwise, and what are the cautions necessary for its use? (Orland, Budthimedhee,

& Uusitalo, 2001; Portman et al., 2015)

The majority of VR adoption has occurred in the late stages of the design process, and the present body of research does not provide an example of truly immersive design within VR in the early stages. However, the research demonstrates the value of immersion and interaction in VR (George et al., 2017). This presents the opportunity to incorporate virtual reality into a workflow and test the impacts it may have on the design process.

Questions and Objectives

To better understand the impacts of VR in the design process, the research question for this thesis is: can VR be used as an effective design tool to supplement traditional design methods in the analysis and concept development phases of the landscape architecture design process at a variety of scales, and what affordances and constraints can VR offer at each scale? Working at a variety of scales is important in the field of landscape architecture, and the study will help quantify VR's effectiveness at a large master planning scale as well as a smaller site-design scale. The master planning scale is defined in this research as a large-scale project involving elements of both planning and detailed design. This involves creating a cohesive plan for an entire area usually consisting of many project sites, while also designing specific elements that are a part of that plan. The site-design scale is defined in this research as a smaller scale project usually consisting of one site. This scale is typically more focused on the detailed design and the intricacies of what the finished design of a site will look like.

The affordances and constraints of the analysis and concept development phases of design are the focus of the research, and this involves initial site observations and research, the creation and development of a design from basic forms, through an iterative process of revisions, and finally to a more refined design outcome. Testing an entire VR workflow is not an objective of this research, rather it is focused on testing the impacts of using both VR and traditional methods in an integrated workflow.

Methodology

A case study approach was used to collect data from each of the project scales. In order to quantify the effects of using VR in the design process, data from the case studies was collected using surveys and focus groups. These surveys and focus groups asked participants a series of questions comparing their VR design process experience to their past experiences without VR. Participants in the case studies consisted of a cross section of student volunteers from Freshmen to Graduate Students in the Department of Landscape Architecture and Environmental Planning at Utah State University. Throughout each project, participants were given surveys that asked various questions about their experiences, and they were asked to rate benefits and/or challenges using a Likert scale (see Appendix A). After each project, a focus group was conducted to gather additional data about participants' overall experiences. Comments from throughout the projects were then coded and analyzed to discover patterns that suggest affordances and challenges of each project scale. The codes that emerged from the comments can be seen in Appendix B.

The large-scale master planning project was conducted during the design of the Powder Mountain Ski Resort Village in Weber County, Utah. The project was conducted from January to May 2018, and was part of the LAEP Charette and Senior Capstone. Participants consisted of five females and five males. The class distribution of the design team was two graduate students, two seniors, one junior, three sophomores, and two freshmen. The project focused on designing a village and innovation district on top of a mountain at 9,000 feet. The project involved designing the overall layout and functions of the village, creating a pedestrian oriented experience, programming spaces, developing a vision for future site-specific designs, and integrating the site harmoniously into the surrounding landscape.

Throughout the large-scale master planning project, students tested a workflow that integrated both VR and traditional landscape architecture design process methods into the analysis and concept development process phases. The workflow was as follows.

1. Create a detailed 3D terrain model with drone surveys and photogrammetry
2. Create a regional 3D terrain model by importing Google Earth terrain into 3D modeling software
3. Import the 3D terrain models into Tilt Brush to view in VR
4. Use VR and traditional methods such as trace paper/digital sketches and GIS to generate a site analysis
5. Use Tilt Brush and trace paper/digital sketching to explore design possibilities
6. Use Tilt Brush and trace paper/digital sketching to generate loose design concepts of the site
7. Use Tilt Brush and trace paper/digital sketching to refine the design concepts of the site
8. Iterative loop. Repeat steps 5-7 until the client and design team are satisfied

with a refined outcome

9. Progress into later stages of the design process (beyond the scope of this research)

The small-scale site-design project began in the fall of 2018 and involved designing an innovative landscape and outdoor play environment for the Center for Creativity, Innovation, and Discovery (CCID) charter school in Providence, Utah. The project consisted of a voluntary six student design team with four females and two males, and a class distribution of three juniors and three sophomores. The project produced ideas and detailed designs of an inclusive play and learning environment surrounding the charter school.

The integrated VR and traditional methods workflow of this project is the same as the master planning scale workflow except for the first step. Due to the small size and more detailed nature of the CCID project, a drone survey of the site provided sufficient context and detail of the site and surrounding area, and a regional 3D model from Google Earth was not needed. The integrated workflow that was tested on the small-scale site-design CCID project is as follows.

1. Create a detailed 3D terrain model with drone surveys and photogrammetry
2. Import the 3D terrain models into Tilt Brush to view in VR
3. Use VR and traditional methods such as trace paper/digital sketches and GIS to generate a site analysis
4. Use Tilt Brush and trace paper/digital sketching to explore design possibilities
5. Use Tilt Brush and trace paper/digital sketching to generate loose design concepts of the site
6. Use Tilt Brush and trace paper/digital sketching to refine the design concepts of the site

7. Iterative loop. Repeat steps 4-6 until the client and design team are satisfied with a refined outcome

8. Progress into later stages of the design process (beyond the scope of this research)

The design process for each of these projects integrates all the tools and phases of design as the traditional design process, while also integrating VR as an additional tool. Participants were not forced to use one tool over another, and they were free to utilize all tools available to them in whatever way they chose. Each design team used one HTC Vive head mounted display that was set up in a team workspace next to tables where others could collaborate, observe, and develop ideas through traditional methods such as trace paper sketches. A large screen was also provided that allowed team members outside VR to see what the designer was seeing inside. Tilt Brush was the VR design software selected for this study and was used in both case studies. This program was selected due to its simple and intuitive nature and also its large artistic toolset. It is primarily developed for artists but has tools that can be applied in various design professions. Other VR programs exist that have broader toolsets more conducive to architectural surface creation, but many of these have steep learning curves and expensive licenses. This contributed to why Tilt Brush was chosen, but it is expected that advances with Tilt Brush or other programs will provide more tools and accessibility in the future.

After the master planning scale project was conducted, the department received the resources to create mixed reality environments by adding a green screen behind the VR workspace. This enables team members outside of VR to see a third person view of the designer interacting with the elements they are creating. This technology was

anticipated to be used in the site-scale CCID project and a green piece of fabric was draped from a pole behind the VR setup. As discussed further in this research, this technology presented several technology problems that were not able to be overcome during the design sessions of the site-scale project. Once the technology issues were resolved, this technology was used after the project to create 2D imagery to illustrate the designers experience within VR. As a result of the technology issues, there was no difference between the two projects in the setup and tools that participants had available to them.

Outputs

This research examines the two case studies individually in chapters two and three, which are stand-alone articles that were submitted to journals. The results of each case study are examined and discussed separately within those chapters and the conclusion chapter examines both case studies comparatively. The overall benefits and challenges of incorporating virtual reality into the landscape architecture design process are then discussed. Due to the nature of comparing these two similar projects and writing them to be stand-alone articles, some repetition exists.

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CHAPTER 2

HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS DURING THE PHASES OF ANALYSIS AND CONCEPT DEVELOPMENT AT THE MASTER PLANNING SCALE[1]

Abstract

Virtual reality (VR) can offer many benefits for designers. In the field of landscape architecture, the technology is primarily being used as a tool for design review in the late stages of the design process, yet many of the benefits that make VR valuable in the later stages of the design process suggest that VR may be equally valuable when used in earlier stages such as analysis and concept development. This research examined incorporating VR into the design phases of analysis and concept development, and integrated its use with traditional landscape architecture methods to measure its impacts on a large-scale master planning project. This research explores the affordances and limitations of VR and suggests a positive outlook for VR as a design tool.

Introduction

Virtual reality (VR) provides visual and spatial affordances that potentially make it a powerful tool for designers, who can have an improved understanding of their design decisions in a visual setting that more closely represents the spatial reality of a site than is

[1] Chapter 2 was co-authored by Drew Hill and Benjamin George for submission to *Digital Landscape Architecture*.

possible through traditional hand and digital methods of representation. While significant research has been conducted into the use of VR as a visualization tool, research into the efficacy of applying VR to early stages of the landscape architecture design process is still emergent. This study contributes to the understanding of the impact of VR on the design creation process through an analysis of a student project in the research lab at the author's institution to develop a master plan and town center design for a mountain resort community. VR was a primary design tool used from the earliest stages of design through the development of a final conceptual plan.

Literature Review

Virtual reality is a visualization tool with the potential to significantly alter the way that designers and clients create and experience design solutions. Tufte, Goeler, and Benson (1990) describes visualization as a visual medium for clarifying complex data in a way that has substantial advantages over the written word or voice alone. The visual sense is the dominant component of human sensory perception (Bruce, Green, & Georgeson, 1996; Rose, 2012), and work on visualization supports expanding the visual sense and incorporating all types of representations across different fields and disciplines (Hansen & Machin, 2013; Valiela, 2009; Ware, 2013). Along with having a dominant visual sensory perception, the human brain is wired for spatial thinking (Gersmehl & Gersmehl, 2007). For landscape planners and architects, spatial thinking and the communication of design concepts in a spatial context is an essential skill. VR would appear to be ideally suited to assist designers by providing a mechanism that is highly

visual and creates an inherently spatial environment.

VR is a digital environment that convinces the mind of the user, through visual and other sensory inputs, that they have entered an artificial world (Castronovo, Nikolic, Liu, & Messner, 2013). This type of visualization is valuable to researchers and designers by providing a mechanism to more closely represent and understand the complexities of the landscape (Horne & Thompson, 2008). In this study, we examine the use of immersive VR, which is a device that completely immerses the user visually, and sometimes via additional sensory inputs (Slater & Usoh, 1993). Immersive VR is an active experience, and the user is able to manipulate the virtual environment (Grau, 2003).

VR has been used in design education for several decades, most notably as semi-immersive VR theatres (frequently referred to as CAVE systems), but the majority of VR-adoption in the design fields has occurred in the late stages of the design process as a review mechanism (George & Summerlin 2018). Consequently, the majority of research has described the use of VR as a largely passive viewing platform to visualize, rather than create. Portman, Natapov, and Fisher-Gewirtzman (2015) analyzed the current VR research and found the majority of research focused on passive visualization. Wang, Wu, Wang, Chi, and Wang (2018) analyzed conference presentations that discussed VR in the field of engineering construction and found that nearly 50% used it solely to visualize design proposals. In a similar analysis, de Freitas and Ruschel (2013) determined that nearly all use of VR in design was as a visual evaluation mechanism.

Despite VR being largely limited to use late in the design process, researchers

have identified several benefits. Immersion is a primary benefit of VR. Immersion is particularly effective for evaluating designs because the wide field of view provides a more realistic viewing experience (Castronovo et al., 2013). Design creation becomes a process experienced through movement and interaction that parallels real world familiarity (Dunston, Arns, Mcglothlin, Lasker, & Kushner 2011). However, there has also been criticism that VR separates the designer from the physical site. This separation, combined with the immersive nature of VR may lead the viewer to make incorrect conclusions about the site (Lange, 2011).

Improved spatial awareness is another identified benefit (Castronovo et al., 2013; Portman et al., 2015; Rahimian & Ibrahmi, 2011). In a study using 360 video and immersive VR, students had sufficient spatial understanding of a site from a VR experience to create an accurate site inventory and rudimentary analysis (George, 2016). However, George found that small details were sometimes missed, which supports the conclusion of Bullinger, Bauer, Wenzel, and Blach (2010) that the spatial experience provided by VR may be insufficient in itself to provide for detailed evaluations.

Gu, Kim, and Maher (2011) demonstrated that VR could be effectively used to collaborate and de Freitas and Ruschel (2013) identified increased understanding and communication in collaboration. However, research by George, Sleipness, and Quebbeman (2017) found that students had difficulty collaborating in VR because students outside of VR experienced the design differently.

Advancements in recent years have begun to overcome some of the limitations. As VR has become a financially feasible option, adoption has grown, and a 2018 ASLA

survey reported that 82% of firms have adopted or intend to adopt VR in the near future (George & Summerlin, 2018). During the last few decades, digital landscape representations using VR have advanced from simplistic, static representations (Pittman, 1992), to extremely realistic visualizations that allow exploration with real time movement and multiple spatial and temporal scales (Ghadirian & Bishop, 2008).

Recent research has begun to explore the use of VR as a design creation tool, and initial findings suggests the medium holds promise (George et al., 2017; Lombardo, 2018). Chamberlain (2015) utilized a gaming engine to create hypothetical urban landscapes to help students understand design principles. George et al. demonstrated that VR can be an effective means for developing design concepts on a small site. Sleipness and George (2017) found that students could rapidly prototype designs in VR more effectively than using computer-modeling software and that they were particularly aware of the spatial impacts of their decisions. Based on the demonstrated value that VR can provide we believe that VR can be successfully used to carry out more robust design activities on larger sites.

Methods

The research was conducted with a student design team consisting of ten participants, five females and five males. The class distribution of the design team was two graduate students, two seniors, one junior, three sophomores, and two freshmen. The project was part of a department-wide charrette; a 4-day department-wide project. The charrette involved planning a new village community at a ski resort, and various teams

covered different aspects of the ski resort and the impact on surrounding communities. The master planning team was tasked with developing the village's concept plan and town center using a combination of VR and traditional design methods to analyze the site and develop design concepts to test the impacts of integrating VR into the landscape architecture design process.

Several preparatory steps were required to facilitate the analysis and design in the study. Accurate three-dimensional site models were needed to serve as basemaps within VR. This enabled students to virtually visit, interact with, and design on the site as if they were there, as well as understand the regional context in 3D. Two 3D models were created. The first was a regional model that included a 20-mile radius of 3D terrain. This was created using Google Earth to import terrain data from the focus area into SketchUp (see Figure 1). This model had comparatively low resolution but provided valuable regional elevation

The second model was a detailed 3D terrain model of the project site and surrounding mountain terrain. This model was created using a DJI Mavic Pro drone and Pix4D photogrammetry software. For each mission, the drone flew a grid pattern 250 feet above the ground taking pictures along the nadir line, with an image overlap of 75%. Twenty drone flights, and approximately 8,000 images were collected to cover the site. These images were then processed in Pix4D to create a point cloud and 3D mesh. This resulted in a detailed 3D terrain and vegetation model of 900 acres of montane landscape (see Figure 2). This preparation process took several days to complete, but yielded a detailed site model and contour data valuable both in and out of VR.

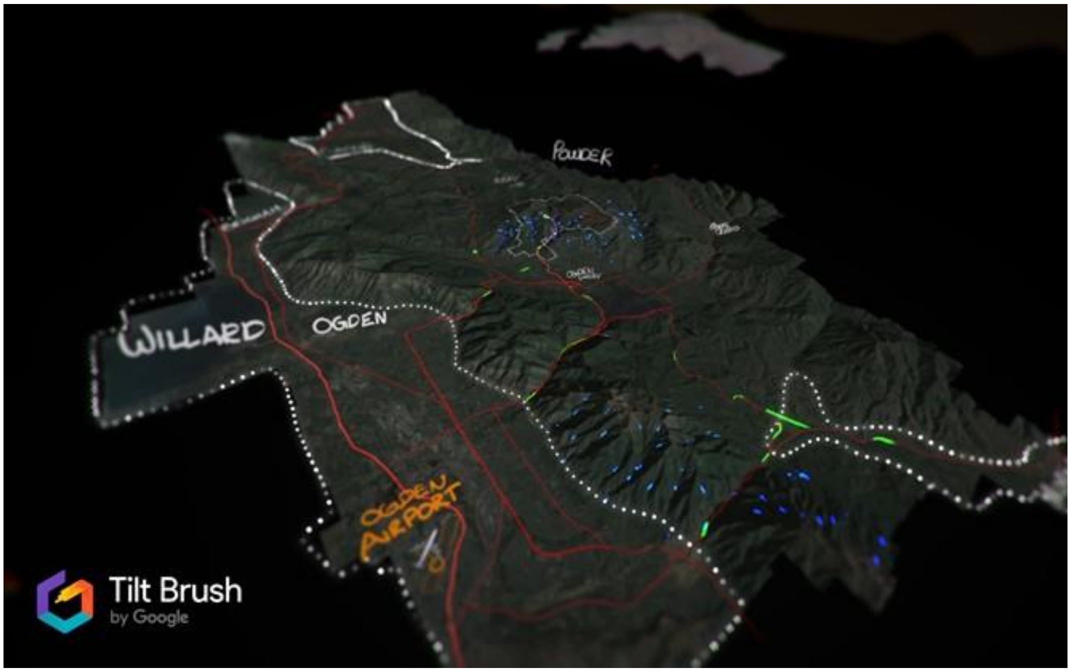

Figure 1. The regional 3D terrain model made from Google Earth data and Sketchup. Context to understand the relationship of the site to the surrounding mountains and valleys.

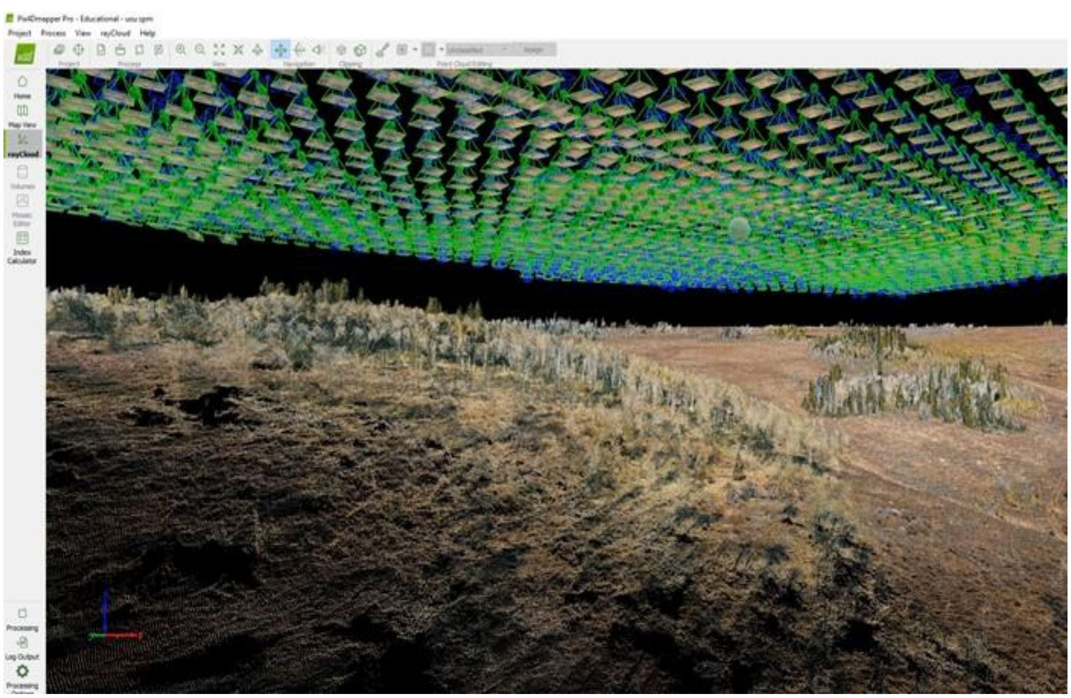

Figure 2. The detailed 3D terrain model from drone imagery and photogrammetry for the Large-Scale Master Planning Project.

Apart from those already listed, the hardware and software used for this project consisted of a Puget Systems PC with high-performance CPUs and GPUs, an HTC Vive VR platform, and Google Tilt Brush VR software. The 3D terrain models from Sketchup and Pix4D were imported into Tilt Brush, to be used as backdrop elements the team could design on. The design team then used VR and traditional methods to conduct the site analysis and develop design concepts. Representations of loose analyses and design concepts that students produced inside VR can be seen in Figures 3, 4, and 5. A large television (43”) was mounted on the wall so that students outside the VR headset were able to see what the designer in VR was creating (see Figure 6). All the students on the team worked interchangeably between the two methods for four consecutive days. Refined design concepts can be seen in Figures 7, 8, and 9.

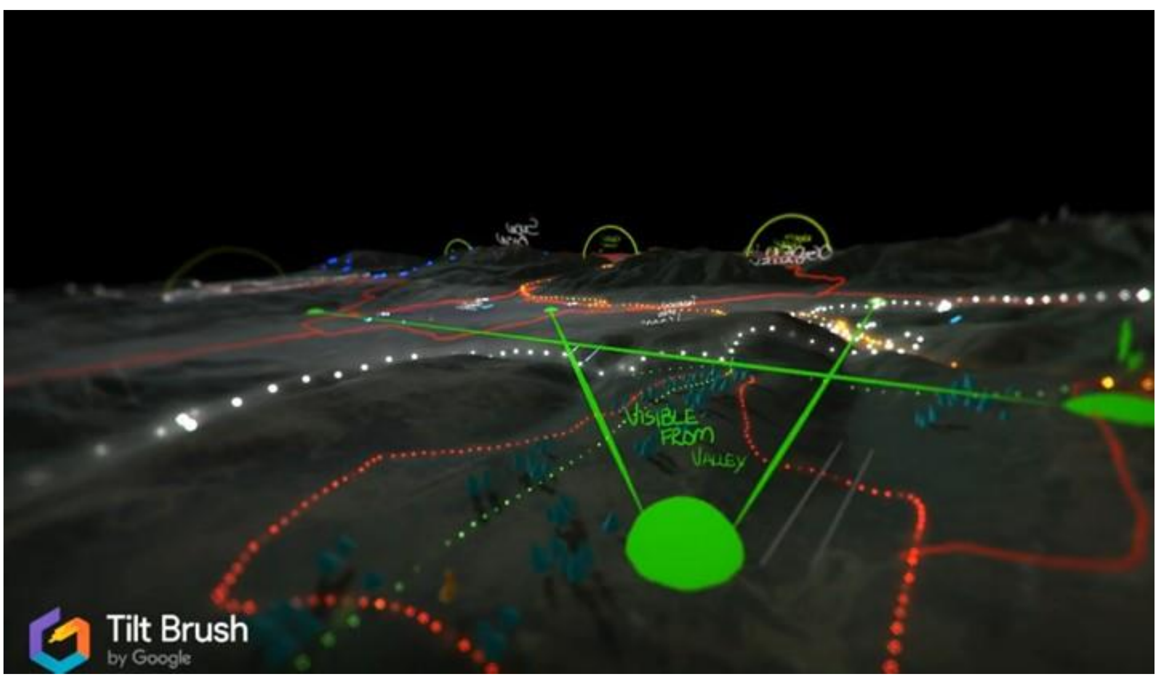

Figure 3. A participant’s analysis developed in VR on the regional terrain model.

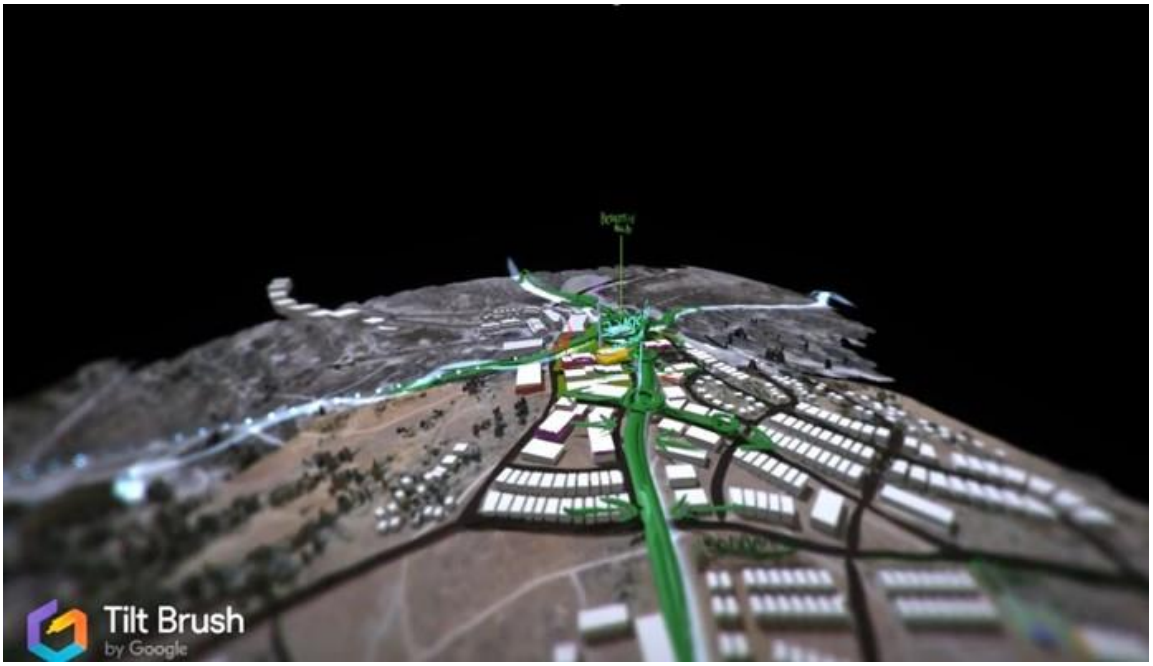

Figure 4. A participant’s conceptual design developed in VR on the detailed terrain model.

Figure 5. A participant’s conceptual village design developed in VR on the detailed terrain model.

Figure 6. A student developing a concept of the village and collaborating with the group.

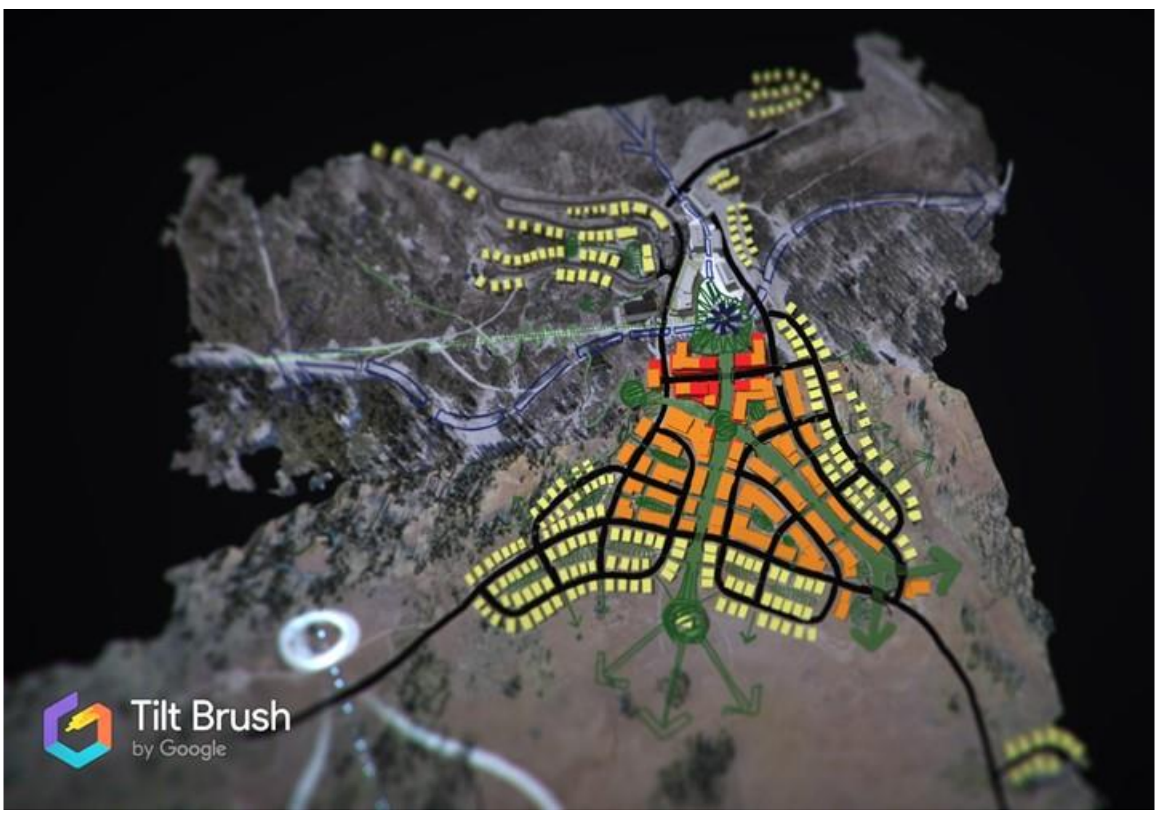

Figure 7. A conceptual massing model of the village development designed in VR.

Figure 8. A mixed reality image showing what the user experience is like in the village development.

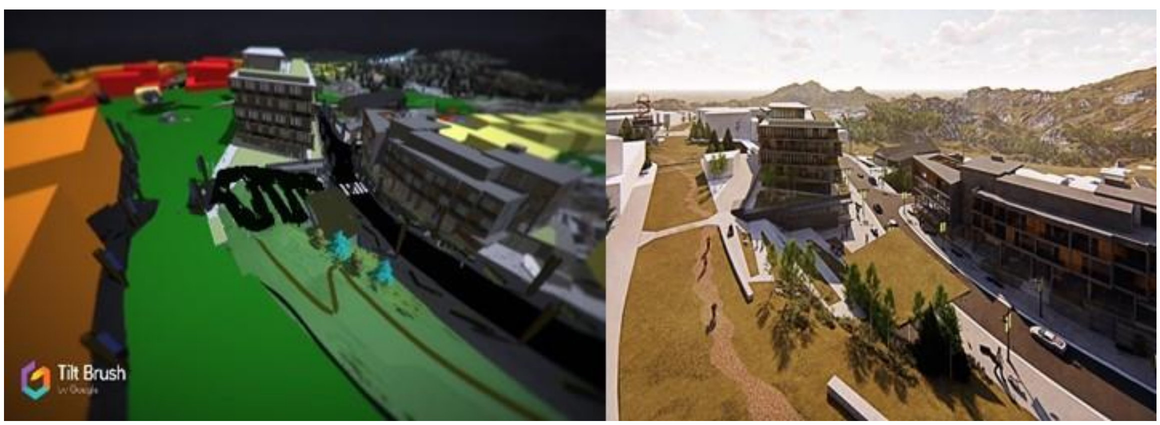

Figure 9. A virtual sketch on the left and finished rendering on the right.

Four data collection rounds were used. In rounds 1 and 2, surveys were sent to the participants at the end of the first and second day of the project to collect preliminary user feedback data. These surveys consisted of five questions and covered topics such as how much time they spent inside VR, what were the benefits that they experienced using VR, and what were the challenges that they experienced using VR. Round 3 data collection

occurred at the end of day four and included additional survey questions about students' experience using VR through both open-ended response and rating-scale questions. Round 4 data were collected during a focus group held several days after the last day of the project, to provide students time to reflect upon their experience, and consisted of open-ended question prompts which were discussed by the group. Examples of questions that were asked in the focus group included, how long did it take you to feel comfortable using VR, how effective was communicating designs ideas in VR, and what about collaboration worked and did not work in VR.

Results

In Round 1, 6 of the 10 participants responded to the survey of quantitative and qualitative questions. In Round 2, 3 participants responded, which was lower than anticipated and is a limitation of this research. All 10 participants responded in Round 3. Finally, in Round 4, 9 of the 10 participants were present for the focus group. In total, 171 open-ended responses were received. The mean of the rating-scale responses was calculated and the open response questions were coded, identifying 14 codes (see Figure 10 for coded comments and Figures 11 and 12 for the Likert rating scales). This process produced 214 coded comments. As an example of the coding process, in response to the question "do you feel that VR allowed you to effectively communicate your ideas?" a participant responded: "It was great for saying things graphically instead of with words, which is often hard for me." This comment was coded as *improved self-expression* and *improved communication of ideas*.

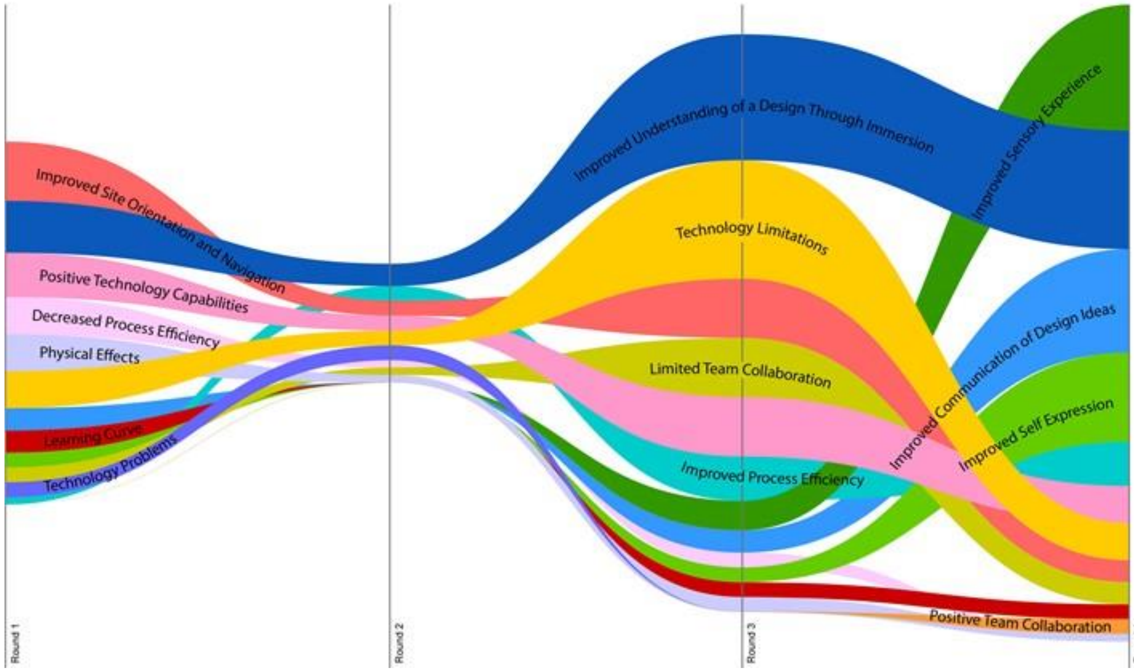

Figure 10. Occurrence of 14 coded comments throughout four data collection rounds. The total amount of responses is represented by the thickness of all codes in a round, and the thickness of each ribbon represents the number of occurrences per code.

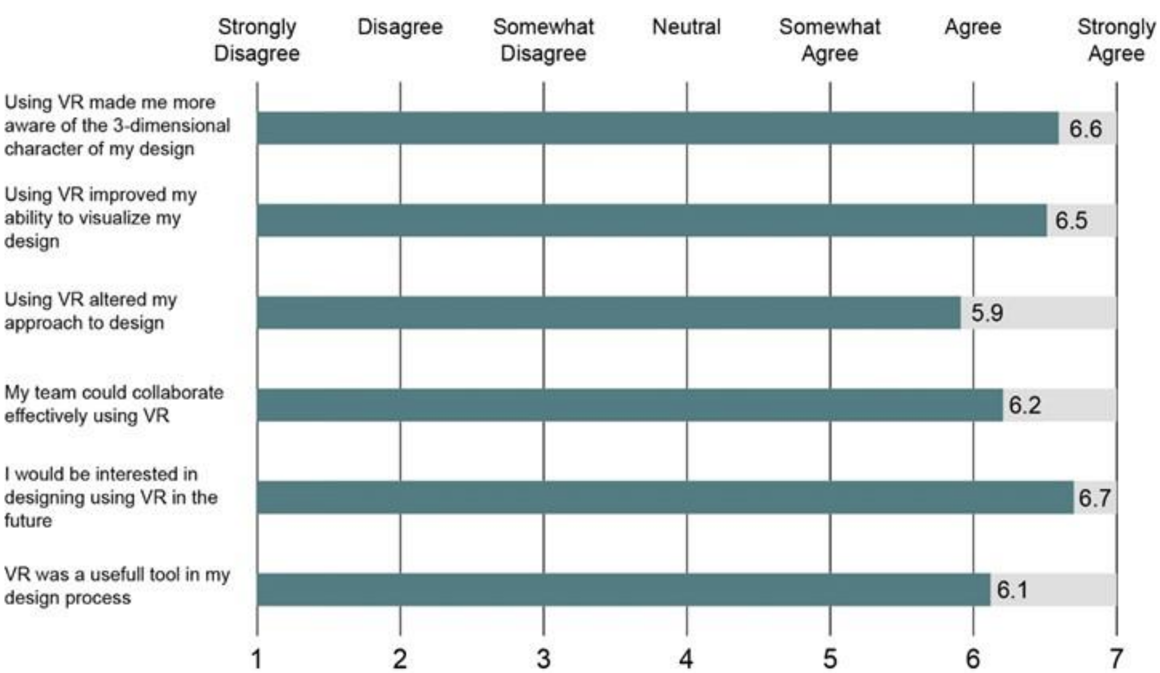

Figure 11. Likert-scale survey results from the master planning project.

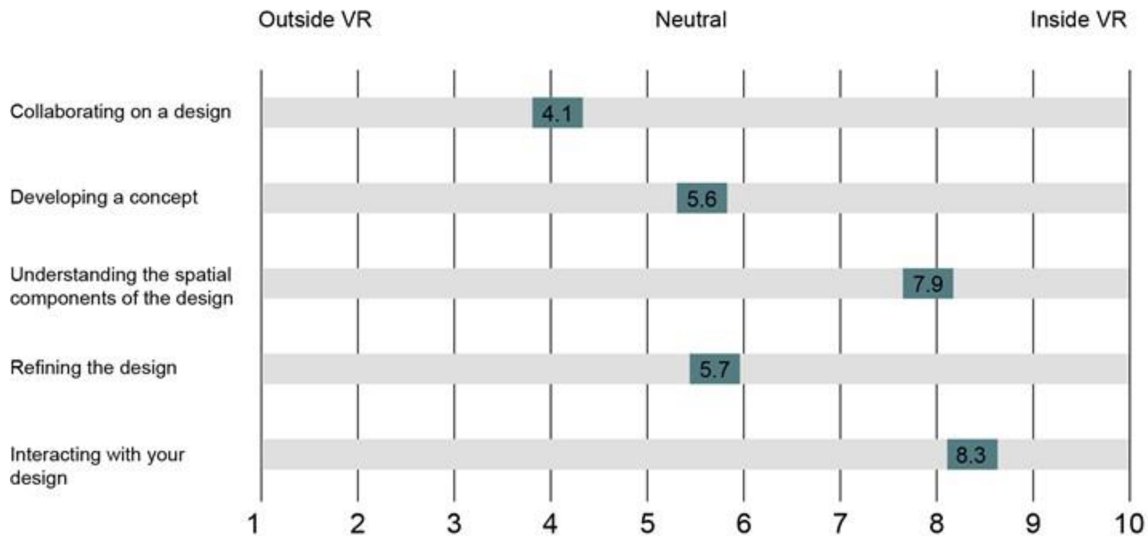

Figure 12. Likert-scale preference of tool choice for a given task on the master planning project.

The code most mentioned by participants was improved understanding of a design through immersion in VR. Students reported that at first it was challenging to think and design in VR because it was different than their usual process, but after a brief learning curve they reported they had a better understanding of the spaces that they were creating. Verbal team collaboration was found to be more difficult with one designer in VR while the rest of the team is not. However, visual communication and sharing of ideas with a team was found to be very effective. Working in VR impacted the students' design process in several ways. Students reported that they were more aware of the three-dimensional nature of their designs. They also noted that they were better able to express their design ideas and share those concepts with other students. Overall, students responded positively to using VR in the design process and would use it again in the future.

Discussion

The results of the codes from Figure 10 suggest an overall positive outlook for the use VR as an analysis and design tool in landscape architecture, however limitations were also apparent. Several codes discussed frequently in the initial rounds tapered off in the following rounds, notably *physical effects* and *technology problems*. Several students experienced dizziness in the first round, but that seemed to not persist in the following rounds as their bodies adjusted. One of the 10 students reported nausea and limited time in VR for the remainder of the project as a result. Some confusion with the technology occurred at the beginning, but decreased later. *Learning curve* also showed overall decreasing trends but with a correlation that is slightly less clear. This might be explained by a student's comment who stated, "The basic controls were easy to learn and intuitive, but I am still not completely comfortable with the more advanced controls". This suggests a low bar to entry in using VR, but that it will take more time to become fully competent.

Decreased process efficiency also declined in frequency over the course of the project. Many of these comments talked about how sketching in VR was taking them slightly longer than in 2D. This might be tied to the learning curve limiting speed, but more research is needed to compare the efficiency of VR and 2D workflows, and the quality of their outcomes. While this code was mentioned several times, increased process efficiency was mentioned substantially more than decreased process efficiency. Many of the student's comments in this code expressed thoughts about the fast and efficient communication of designs, such as one student who commented that VR "made

it quicker to understand and design." This suggests an overall increase in the efficiency of the design process through integrating VR.

The *positive* and *limited technology capabilities* of VR provide an interesting comparison, and these codes appeared in similar numbers throughout all the rounds. Student comments suggest that there were many positive capabilities, such as allowing them to experience the site as if they were there and could interact with their design. Regarding limited capabilities, some students expressed that while Tilt Brush was useful for basic form giving, they felt limited in further refining their concepts and wanted specific tools unavailable in Tilt Brush. Specific tools and abilities that they felt limited without were precision measuring instruments and more detailed surface creation tools. This is important to note because Tilt Brush is primarily designed for artists, and while other programs exist that offer more technical tools, they also come with a steeper learning curve and larger price tag. This contributed to why Tilt Brush was chosen for this research as there was not a VR program at the time that provided an interface and toolset that would support the design approach and scale needed for the project. Such programs may be available in the near future, but for now it must be acknowledged that technology limitations exist for landscape architects using VR.

Collaboration is another set of codes that had both positive and negative responses. Unlike the technology capabilities, this set of codes was heavily skewed towards the negative, and students' responses show that it could be challenging at times to work as a group to make modifications to a design. This could result in students becoming frustrated as they tried to verbally describe what their intent was. This proved

to be a limitation throughout the project and confirms the findings of George et al. (2017). However, on the rating-scale responses to the question “My team could collaborate effectively using VR”, the mean response was 6.2 out of 7 (7 being ‘strongly agree’ and 1 being ‘strongly disagree’). That the coded comments and scale responses seemingly disagree with each other might be explained by looking at a related code.

Improved communication of ideas is a similar code to collaboration, but responses in this category specifically reference visually showing others an idea and their ability to quickly understand it. This code was high during the last two rounds and many of the students talked about how they were able to more quickly and easily share their design. One student commented, “It was great for saying things graphically instead of with words, which is often hard for me.” The word ‘visual’ is also present in many of the comments in this category. This highlights the difference between verbal and visual communication and collaboration. These results suggest that verbal communication and collaboration is hindered in VR, while visual is improved.

The remainder of the codes were the categories of *improved site orientation and navigation*, *improved understanding of a design through immersion*, *improved self-expression*, and *improved sensory experiences*. These four codes all scored highly overall and suggest important affordances that VR can bring to the design process and the findings supported the conclusions of Castronovo et al. (2013) and others. The rating scales in Figure 11 show that VR made students more aware of the three-dimensional character of their designs, improved their ability to visualize their designs, and altered their approach to design. Figure 11 also suggests that students better understood spatial

components of their designs and were able to interact with their designs better in VR than traditional methods. Students also marginally favored VR for developing a concept and refining a design over traditional methods (see Figure 12). Related student comments include, “it took less mental effort,” “it helps you remember what is on site and you see things that trigger your memory of what you saw and experienced when you were at the site,” and “you can understand the energy of a design and how it feels.”

Conclusions

This study examined how students successfully integrated VR into a workflow that utilized both traditional and VR methods to analyze and develop design concepts on a large-scale master planning project. Overall, considering the affordances and limitations, this research shows a positive outlook for the use of VR as a tool for design creation. Using VR for analysis and concept development on a master planning project improved students’ understanding of their designs and allowed them to better express their ideas. However, limitations were observed in verbal collaboration, technology limitations, and the possibility of adverse physical effects. The affordances of the immersive design experience, combined with the rapid technological advancements and decreases in cost, suggests that VR can be successfully incorporated into the landscape architecture design process as a supplement to existing methods. This research also highlights the need for future research on the use of VR as a tool for design creation and how VR impacts final design outcomes. Also, additional research will be needed to assess the effectiveness of collaboration with a team inside VR, as this technology will

become more accessible in the near future.

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CHAPTER 3

HOW VIRTUAL REALITY IMPACTS THE LANDSCAPE ARCHITECTURE DESIGN PROCESS AT THE SITE-SCALE DURING THE PHASES OF ANALYSIS AND CONCEPT DEVELOPMENT[2]

Abstract

Virtual reality (VR) offers many benefits for spatial awareness. In the field of landscape architecture, the technology is primarily being used as a tool for design review in the late stages of the design process. Many of the benefits that make VR valuable in the later stages of the design process suggest that VR may be equally valuable when used in earlier stages such as analysis and concept development. However, the present body of research does not provide a detailed study of truly immersive design within VR in the early stages of the process. This research tested incorporating VR in the design process phases of analysis and concept development and integrated its use with traditional landscape architecture methods to measure the impacts on a small-scale site design project. This research suggests a positive outlook for VR as a creation tool for small scale design and explores its affordances and limitations.

Introduction

Virtual reality (VR) is an important emergent technology that offers the promise of significant benefits to landscape architects through improving a designer's ability to

[2] Chapter 3 was coauthored by Drew Hill and Benjamin George for submission to *Landscape Research Record*.

understand the spatial nature of design decisions. Unlike traditional design tools, which invariably include forcing the designer to work through a series of perception filters such as dimension and scale, VR has the ability to situate the designer in a virtual re-creation of a site that closely imitates physical reality. While research has been conducted on the power of VR in late-stage evaluation of design concepts, research exploring the use of VR as a design generation tool is limited. This study presents a case study analyzing the use of VR in a collaborative design project, where the tool was used from the earliest stages of the design process in order to assess the value of VR in supporting design creation. The design team relied on VR as the primary design mechanism in developing their concepts and supplemented their work with other traditional design tools. It is theorized that VR will enhance students' design thinking and enable them to produce a more thoughtful and rational design

Literature Review

Noted data visualization expert Edward Tufte describes the value of visualization as bringing clarity to complex data through graphical means. The visual representation of data has several advantages over non-visual representations, such as written text or verbal description (Tufte, Goeler, & Benson, 1990). This is because the human mind is wired to prioritize the visual sense, and the brain has evolved to be able to rapidly and intuitively process complex visual information (Bruce, Green, & Georgeson, 1996; Rose, 2012). Research has demonstrated that visualization is effective for conveying information regardless of field or discipline (Hansen & Machin, 2013; Valiela, 2009; Ware, 2013). In

addition to having dominant visual senses, the human brain is adept at processing spatial information and tasks, and the awareness of space is an integral component of the awareness of self (Gersmehl & Gersmehl, 2007). Logically, the understanding and expression of spatial concepts is a critical skill for landscape planners and architects, both for designing and for communicating ideas with clients. Because of this, tools which provide landscape architects and planners with improved spatial awareness should expand the capacity of designers to more effectively engage with clients and stakeholders to develop appropriate design solutions (Chamberlain, 2015). For these reasons, VR should benefit designers in their work by enabling the designer to natively work in a highly spatial and visual environment.

Visual and spatial power of VR stems from its use of multiple sensory inputs to convince the user that they are present in an artificial world (Castronovo, Nikolic, Liu, & Messner, 2013). VR can be divided into two categories: semi-immersive and immersive. A semi-immersive VR environment is when the user is only partially immersed in the virtual world or where the user is unable to interact with the digital environment. In a semi-immersive VR environment, the user is aware that they are participating in a visualization. A common example of a semi-immersive environment is a VR theater, where imagery is projected onto surfaces surrounding the viewer on multiple sides (commonly referred to as CAVE system). In contrast, immersive VR is a digital environment that fully surrounds the user in a multi-sensory experience to convince the user that they are in a virtual world (Slater & Usoh, 1993). To be truly immersive, the virtual environment must be interactive and respond to the user’s actions (Grau, 2003).

Having the ability to craft and enter a digital world that is an accurate representation of the real world empowers designers and researchers to explore complex spatial issues in a more realistic manner (Horne & Thompson, 2008). This type of visualization technology is valuable to researchers and designers by providing a mechanism to more closely represent and understand the complexities of the landscape (Horne & Thompson, 2008). Despite these benefits, most use of VR in landscape architecture has been limited to visualizing design concepts prepared outside of VR as a form of design review and presentation. This has led to VR being used as a passive tool that provides powerful visual feedback, but is not informing the design as much as may be possible. Several studies documenting the use of VR in design and construction fields reveals the large majority of research was evaluated using VR to passively view design (de Freitas & Ruschel, 2013; Portman, Natapov, & Fisher-Gewirtzman, 2015; Wang, Wu, Wang, Chi, & Wang, 2018).

This research has demonstrated the clear value of VR in this role and has also strengthened the case to experiment with the use of VR in earlier design phases. Identified benefits of VR that would support conceptual design activities include immersions and increased spatial awareness. Immersive VR has been attractive as a late-stage evaluation tool because the wide field of view creates a realistic viewing experience for the user (Castronovo et al., 2013). Beyond visual immersion, VR also provides the user the opportunity to interact with design elements, which further heightens the sense of immersion and provides the user with a more realistic experience (Dunston, Arns, McGlothlin, Lasker, & Kushner, 2011). This high level of immersion has also produced

some concerns in the research, as it has been suggested that the user may draw flawed conclusions because they accept at face value the environment that they are immersed in (Lange, 2011).

An ancillary benefit of immersion is that the user also has improved spatial awareness while in VR (Castronovo et al., 2013; Portman et al., 2015; Rahimian & Ibrahmi, 2011). This increased spatial awareness allows users to intuitively respond to a site and design. George (2016) had students utilize VR to conduct a site analysis of a residential site, and found that students were able to successfully conduct an analysis that accurately responded to the site conditions. However, caution should be exercised to not rely exclusively on VR when making design decisions, as the current level of detail supported by VR may constrict the ability to make some decisions (Bullinger, Bauer, Wenzel, & Blach, 2010; Gill, Lange, Morgan, & Romano, 2013)

There have been mixed results on the effects that VR has on collaboration. In their review of VR research, de Freitas and Ruschel (2015) conclude that VR has been demonstrated to improve communication and comprehension. In example, Gu, Kim, and Maher (2011) used semi-immersive VR to enable students to collaborate on simple design exercises. However, when George, Sleipness, and Quebbeman (2017) tasked students with collaborating on designing a micro park in immersive VR, students found it difficult to work together to collaboratively create a design concept because the experience between those in and out of VR was markedly different.

Despite some limitations, VR is being steadily adopted in the design fields and a recent ASLA survey found that 82% of firms in the U.S. either have or intend to adopt

VR into their workflow (George & Summerlin, 2018). This follows the broader trend of practitioners quickly adopting new digital simulation and visualization technologies over the preceding decade (Lange, 2011). As technology continues to improve, it is expected that VR will be integrated into more and more aspects of the design process.

Despite the increased adoption of VR, there has been relatively little research into expanding the use of VR beyond visualization applications, but what research has been done has been encouraging for the use of VR to facilitate design creation (George, Sleipness, & Quebbeman, 2017; George et al., 2018; Lombardo, 2018). Chamberlain's (2015) work combining video game engines and VR has shown that VR can be used to teach design principles. George et al. (2017) found that students could successfully use VR to design and that the students responded to the affordances provided by VR to adapt their design concepts. Rapid prototyping of loose conceptual designs has also been found to be successful in VR (Sleipness & George, 2017). These successful precedents warrant continued experimentation with VR in the design process using sites and projects that have a greater degree of complexity.

Methods

This research is a case study of a project worked on by a six-student team consisting of four females and two males, and a class distribution of three juniors and three sophomores. The project was part of the Community Design Team (CDT) program, which is a program of the student ASLA chapter wherein students volunteer to work on real world extracurricular design projects in the community. This project focused on the

site-design of an inclusive play environment, preservation and enhancement of a wetland, and a waterwise garden at an innovative charter school in Providence, Utah. The team used a combination of VR and traditional methods to analyze the site and develop design concepts to test the impacts of integrating virtual reality into the landscape architecture design process.

Several preparatory steps were taken to facilitate the virtual reality analysis and design in this study. A three-dimensional site model was needed to serve as a basemap in VR. This enabled students to understand the surrounding context in 3D, and virtually visit, interact with, and design on the site as if they were there. A DJI Mavic Pro drone and Pix4D photogrammetry software were used to create the model. The drone was used to fly a single 20-minute drone mission, during which the drone flew 100 feet above the site in a predetermined grid pattern controlled by the Pix4D mobile application. During the flight, the drone took pictures of the ground below, with each image overlapping by seventy five percent. Approximately 300 images were collected from the flight, which were then put into the Pix4D photogrammetry software and processed to create a point cloud and 3D model. This resulted in a detailed 3D terrain and vegetation model of the 5-acre site and the additional surrounding landscape (see Figure 13). The photogrammetry model included the school building, but this was replaced with a model of the building created in Rhinoceros to increase detail and render quality. The building model was then inserted onto the terrain generated from the photogrammetry process in Rhinoceros. The preparation process took several hours to complete, including computer processing, but yielded a detailed site survey with contour data optimized for use in VR.

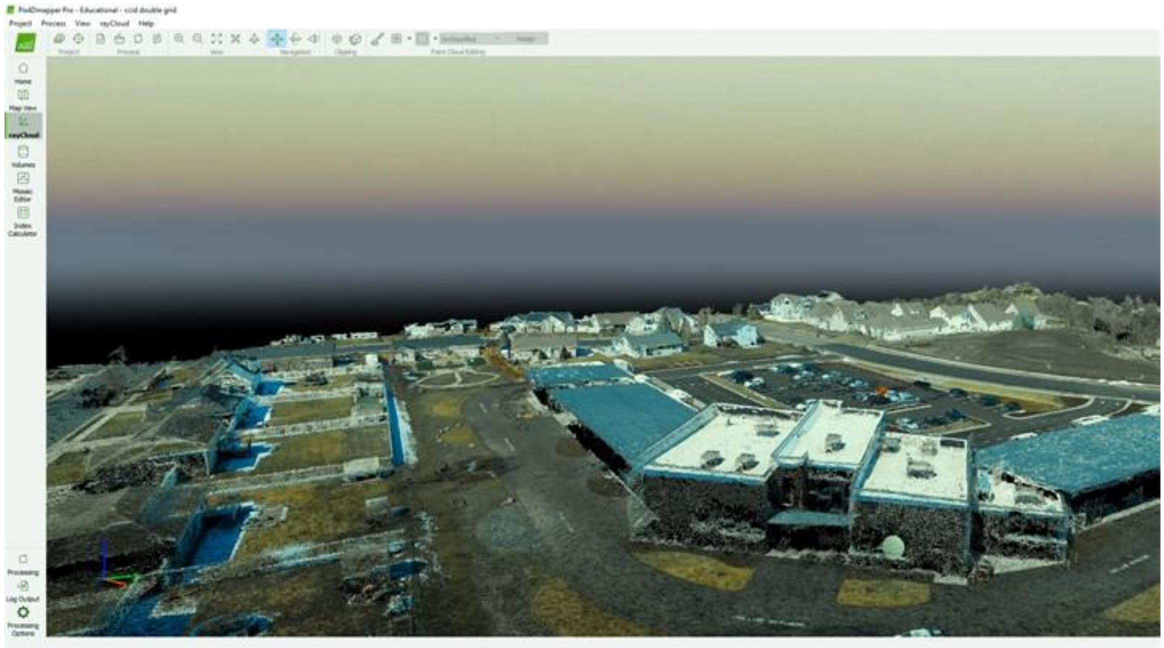

Figure 13. The detailed 3D terrain model from drone imagery and photogrammetry for the Site-Scale Project.

Apart from those previously listed, the hardware and software used for this project consisted of a Puget Systems PC with a high-performance CPU and GPU, HTC Vive VR platform, and Google Tilt Brush software. The 3D terrain model with the new building was exported out of Rhinoceros and imported into Tilt Brush in VR, where it was ready to be used by the design team. The project was conducted in a studio space with a projector and large screen (180”), on which a feed of what the designer was seeing inside VR was projected. This allowed students outside of VR to be able to have improved contextual understanding of what the designer in VR was seeing and doing, with the limitation of it being seen on a 2D screen (see Figure 14). In addition to VR, the students also utilized traditional design process methods such as 2D basemaps and trace paper to assist in conducting site analysis and developing design concepts. Students worked interchangeably between the two methods for three sessions, each 1 week apart,

Figure 14. A student developing a concept of a playground and collaborating with the group.

and data was collected after each session. Loose examples of what was designed inside VR can be seen in Figures 15,16, 17, and 18, while a refined design is shown in Figure 19.

Four data collection rounds were used. Rounds 1 and 2 consisted of surveys distributed directly after the design session concluded to collect preliminary data. These surveys consisted of five questions and covered topics such as time spent inside VR, the benefits they experienced using VR, and the challenges they experienced using VR. Round 3 data collection was a survey that was distributed after the third design session. This was a more comprehensive survey that consisted of seven open response questions and nine questions to be rated on Likert-scales. Round 4 data collection was a focus group held several days after the last design session and consisted of nine open response questions. Examples of questions that were asked in the focus group are, how long did it

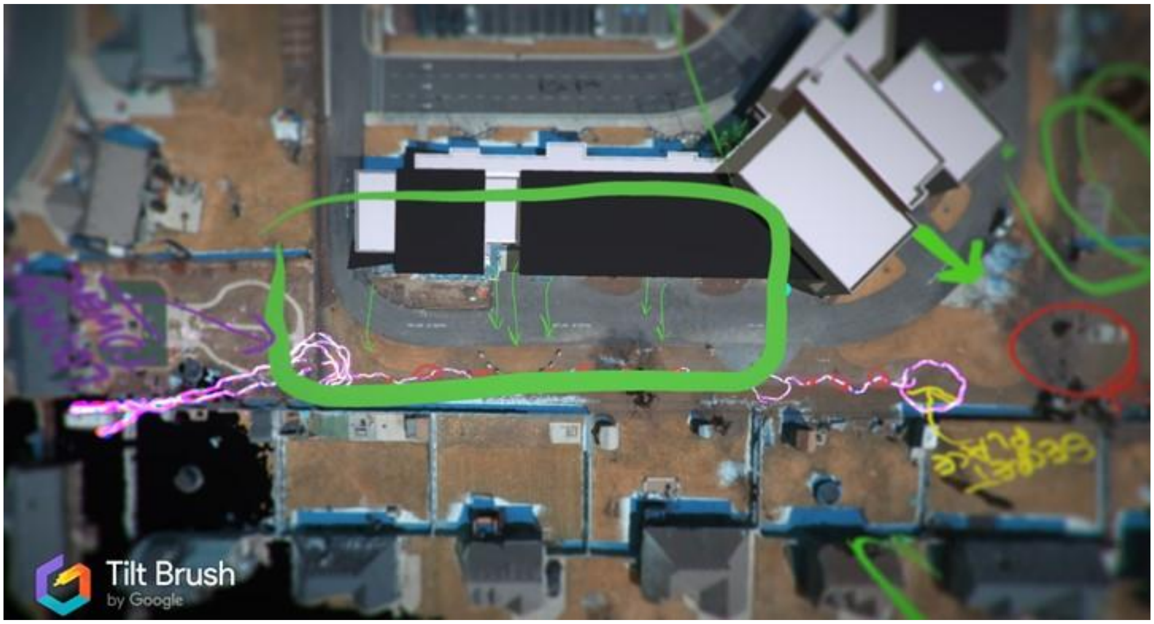

Figure 15. A participant's analysis of the Site-Scale Project developed in VR.

Figure 16. A participant's conceptual design of an outdoor classroom and educational garden developed in VR.

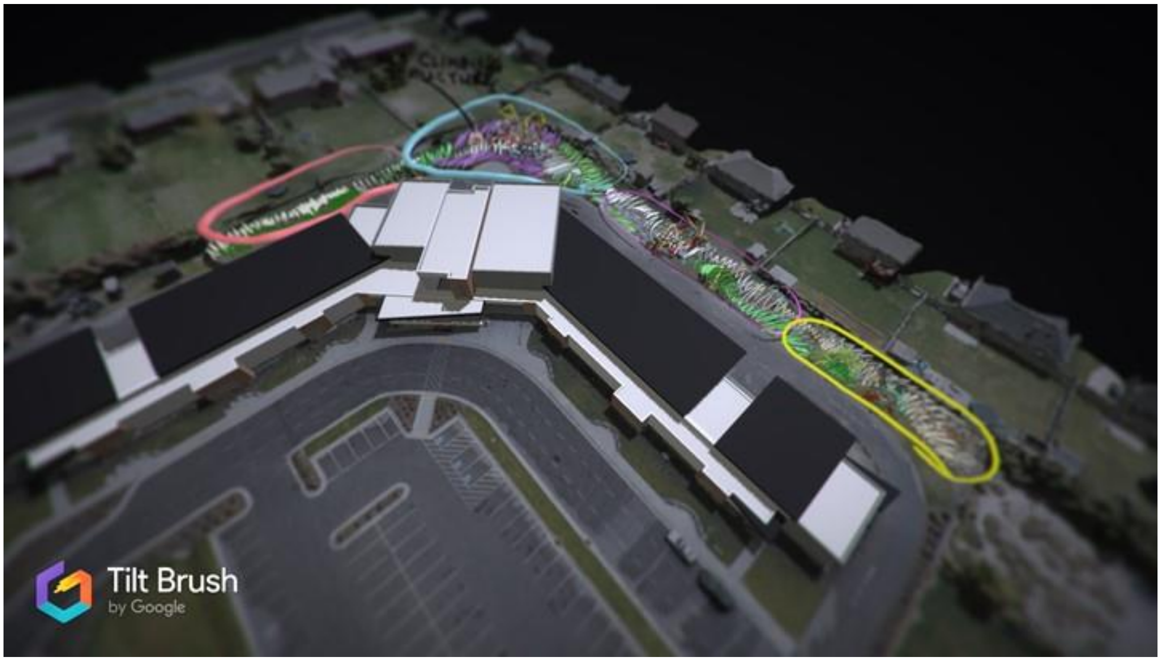

Figure 17. A participant’s conceptual design of playground zones developed in VR

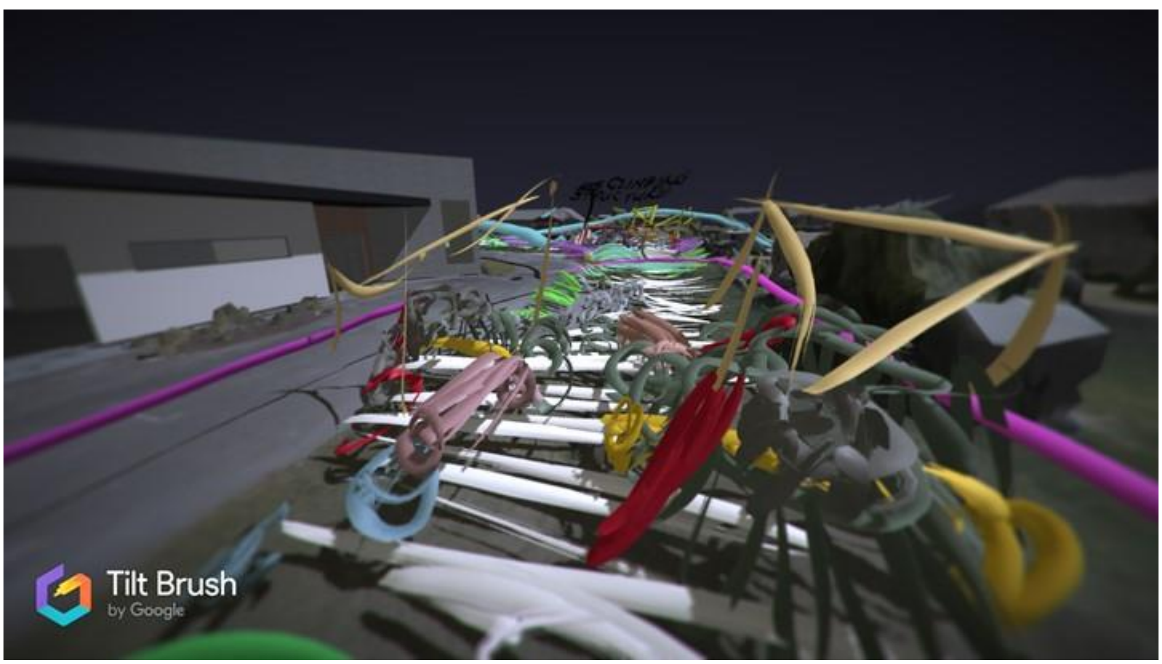

Figure 18. A participant’s conceptual design of play equipment developed in VR.

Figure 19. A first-person view of a student designing in VR.

take you to feel comfortable using VR, how effective was communicating designs ideas in VR, and what about collaboration worked and did not work in VR.

In Round 1, five participants responded to the survey; in Round 2, four participants responded. In Round 3, the longest and most comprehensive survey, all six participants responded. Finally, in Round 4, all six participants were present for the focus group. Data collection resulted in 148 open answer responses and 66 Likert-scale rankings. The open response questions were then coded and produced 13 different codes (see Figure 20). This resulted in 193 combined coded comments, considering that some responses include multiple codes. For example, in response to the question “What part of analyzing the site was easier in VR?” a participant responded that “You could get an understanding of the site and design quickly.” This comment was then coded as improved

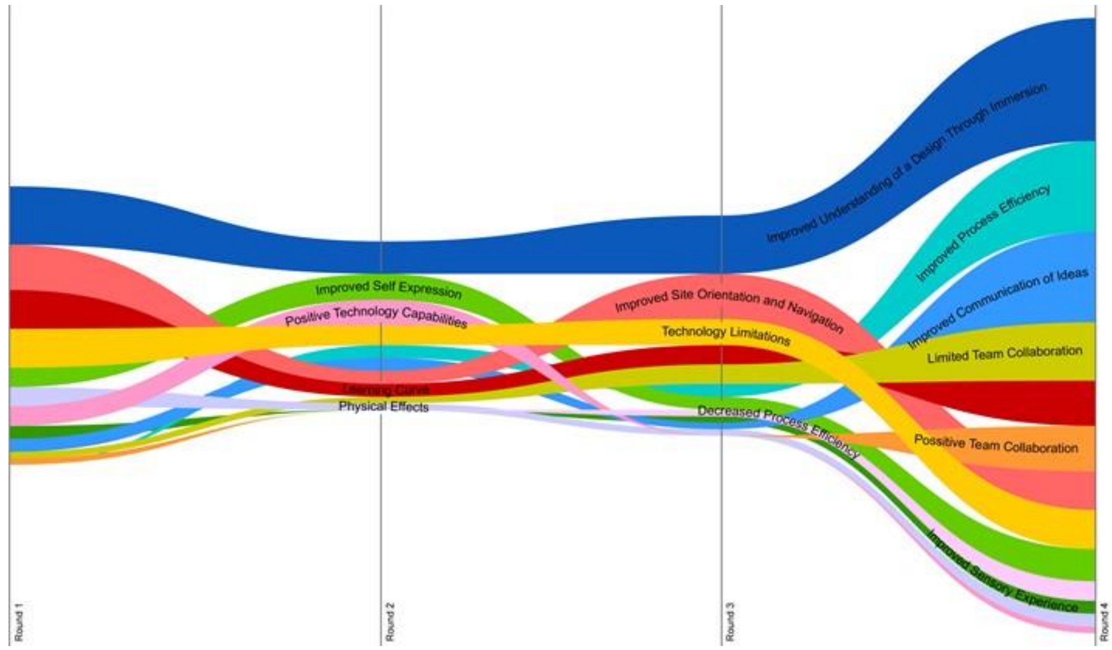

Figure 20. Occurrence of 13 coded comments throughout four data collection rounds. The total amount of responses is represented by the thickness of all codes in a round, and the thickness of each ribbon represents the number of occurrences per code.

understanding of a design through immersion, and improved site orientation and navigation. The mean of Likert-scale responses was calculated (see Figures 21 and 22).

Results

Several important findings resulted from this study. Over the course of all four rounds the code most mentioned by participants was *improved understanding of a design through immersion in VR*. This code was talked about 42 times over the four rounds and is more than double the number of the next highest code. Other codes with significant mentions included *improved site orientation and navigation* (22), *improved communication of ideas* (19), *limited technology capabilities* (19), *learning curve* (18), *improved process efficiency* (18), and *improved self-expression* (14). A complete

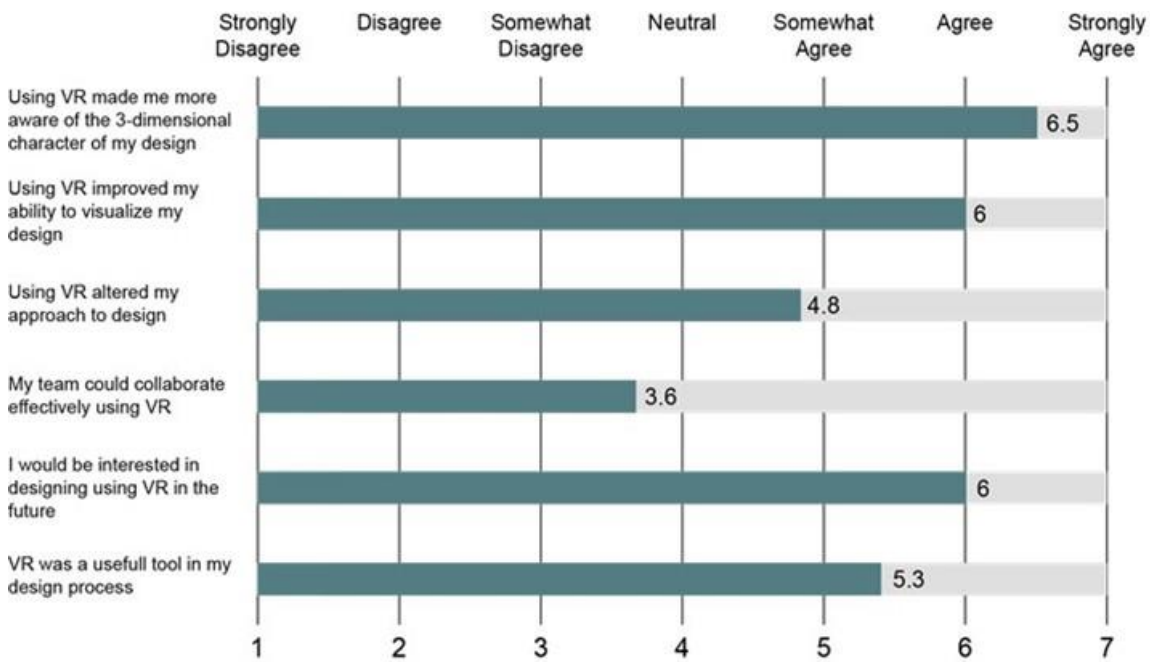

Figure 21. Likert-scale participant results from surveys from the Site-Scale Project.

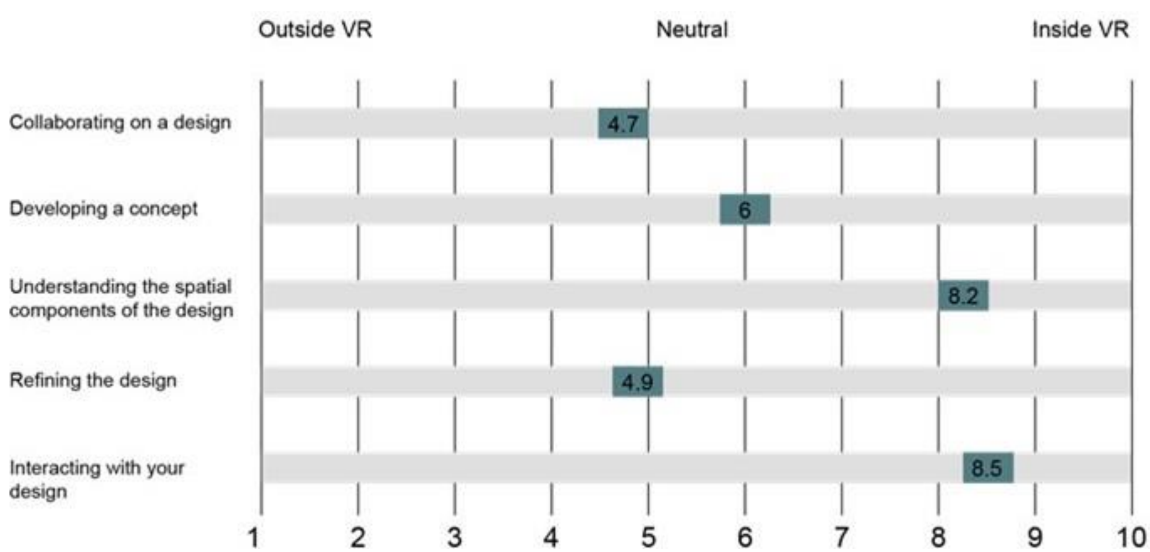

Figure 22. Likert-scale preference of tool choice for a given task on the Site-Scale Project.

representation of the codes illustrating their changing nature in each round is show in Figure 18. Students reported that VR presented several new challenges, such as always thinking and designing in three dimensions and a software learning curve. This is further illustrated by a student's comment which states, "Developing concepts in 3D was challenging because it is new. It made me think about how to design in 3D." However, once they got over the learning curve and became accustomed to thinking in 3D, they reported that they had a better understanding of the spaces that they were creating. Another important finding is that verbal team collaboration was found to be less efficient than the traditional design process with the current limitation of only one designer in virtual reality at a time, while the rest of the team observes. However, visual communication and sharing of spatial ideas with a team was found to be very effective.

Working in VR affected and improved the students' design process in multiple ways. Students responded that they were more aware of the three-dimensional character of their designs. They also commented that they experienced an improved ability to express their design ideas and get their points across to other students quickly. Students also stated that using VR improved the quality of design critiques from other students because of their improved ability to understand designs and communicate ideas visually. Overall, students were very positive in their assessment of VR as a design tool and would want to use it on future projects.

The quantitative data revealed that, overall, students had a positive experience using VR to design. Student ratings were high for issues related to visualization, immersion, value, and desire to use again. However, students disagreed that VR was a

valuable collaboration tool (see Figure 21). When asked to rate which tasks are easier in or out of VR, students preferred using VR to develop, visualize, and interact with a concept, but preferred to be outside of VR to refine the design and collaborate (see Figure 22).

Discussion

Results of the codes from Figure 20 and Likert-scale results from Figures 21 and 22 suggest a positive outlook for VR as a tool for analysis and design in landscape architecture. However, limitations were also documented. Codes that suggest affordances of VR include *positive technology capabilities*, *positive team collaboration*, *improved site orientation and navigation*, *improved understanding of a design through immersion*, *improved self-expression*, *increased process efficiency*, *improved sensory experience,* and *improved communication of design ideas*. Codes that suggest limitations consist of *physical effects*, *limited technology capabilities*, *limited team collaboration*, *learning curve*, and *decreased process efficiency*.

The largest, and perhaps most significant, cluster of codes was related to spatial experiences, and included *improved understanding of a design through immersion*, *improved site orientation and navigation*, *improved self-expression*, and *improved sensory experiences*. *Improved site orientation and navigation* and *improved understanding of a design through immersion* were the two highest codes in the project, these two correspond with 64 of the 198 coded comments, or roughly one third of the total. *Improved self-expression* also scored relatively highly with 14 coded instances, and

an *improved sensory experience* received the lowest of this cluster with 5 instances. These codes suggest important affordances that VR brings to the design process. The Likert-scales in Figures 21 and 22 show that VR made students more aware of the three-dimensional character of their designs, improved their ability to visualize their designs, and altered their approach to design. Students understood spatial components of their designs and were able to interact with their designs much better in VR than via traditional methods, and they showed a slight preference for using VR to design a concept. However, students slightly favored traditional methods for collaborating and refining a design.

The spatial benefits of VR are especially beneficial to landscape architects, who benefit from the ability to visually and spatially communicate their ideas. This benefit is clearly visible in several student comments, such as “seeing 3D is quicker to understand,” “understanding spatial relationships of the site and architecture was made easier in VR,” and “I was able to make better informed decisions.” Viewing the site in VR made it easier for students to understand and respond to complex concepts such as landform, as one student describes “understanding topography was easier in VR, and was helpful for laying out paths and trails.” Just as digital drafting and modeling software accelerated and made possible more complexity in design, it is possible that VR will eventually lead to similar leaps forward as the tool becomes more refined. Ultimately, VR appears to improve the ability of the designer to understand and interact with their design by immersing them in it (see Figure 23), and this provides the designer with the opportunity to engage in a reflective conversation with their own design decisions (Schön, 1984).

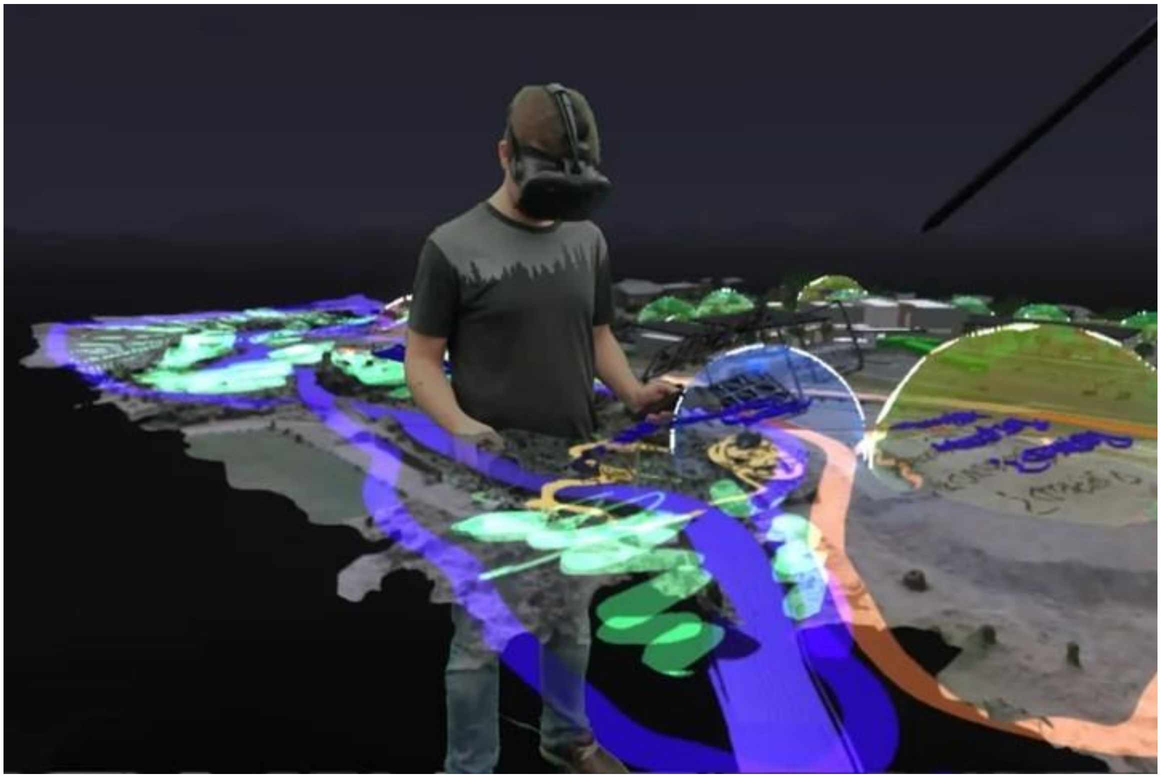

Figure 23. A mixed reality image showing what the user experience is like in the Site-Scale Project.

Physical effects were mentioned frequently during the start of the project and decreased in the subsequent rounds. A couple students experienced dizziness or felt disorientated in the first round, but that seemed to not be present as the project progressed and they became accustomed to working in VR. One of the six students reported nausea in Round 1 and did not use VR for the remainder of the project, but continued physical effects that were most reported were annoyance factors from using the headset such as hat hair and temporary marks left on the skin from the straps. *Learning curve* also showed decreasing frequency between rounds 1 and 3. During the focus group in Round 4, students reinforced that there was a learning curve present that they had to overcome, and some expressed that they still were not fully comfortable with it. This suggests that

the basics of the technology are intuitive, but advanced usage, as with other skills, can take time and effort to become highly proficient. This might be best illustrated by a student's comment who stated in the focus group, "I understood the basics quickly, it was just challenging to get comfortable with the controls for designing detailed and precise ideas."

Decreased process efficiency was mentioned by several students throughout the project. Comments in this category included, "Drawing in 3D took me a little longer," and "It was hard to get a lot done." A majority of the comments received that fit this code seemed to be referencing negative impacts of the learning curve to proficiently use the software, and these comments were also coded under *learning curve*. While there were several comments in this category, there were substantially more comments that gave feedback about how their design process was improved. In total, four comments were about decreased process efficiency and 18 talk about an *increase in process efficiency*. Many of the student's comments about improved process efficiency expressed thoughts about fast and efficient communication of ideas, and one student commented, "I was quickly able to mock up my ideas and show them to the team." This suggests an overall increase in efficiency of the design process through integrating VR once a designer is comfortable with the software.

The *positive* and *limited technology capabilities* of VR showed clear results and the limited capabilities outscored the positive capabilities by a score of 19 to 8. Regarding limited capabilities, many students expressed that they wanted the ability to use more precise measurement and design tools. This is a constraint of Tilt Brush which,

while useful for basic gestures, left students feeling limited in further refining their concepts because they wanted specific tools regularly found in design software that have not yet been developed for Tilt Brush. Tilt Brush is primarily designed for artists and, while other programs exist that offer more technical tools, they also come with a steeper learning curve and larger price tag. Many of these programs do not support the scale of site needed for landscape architectural design, and this contributed to why Tilt Brush was chosen for this research. Unfortunately, there is not a VR design program available at this time that provides an interface, toolset, and scaling capacity equivalent to what is commonly available in landscape architecture design software. Such programs may be available in the future.

However, it is possible that students' comments about being limited by software may be more closely associated with a lack of experience with the software and not knowing the capabilities of what is possible to create. There are many different tools in Tilt Brush that can be used in a variety of ways to closely imitate features of common design software such as SketchUp. There are also many examples built into Tilt Brush that showcase the capabilities of the software, many of which show intricately detailed scenes. However, this requires a greater amount of experience and comfort with both VR and Tilt Brush than the students were able to achieve during this project. Overall this data suggests that there are both positive and limited capabilities of the technology depending on the tasks being performed. In this project the limitations outweighed the capabilities, and more research is needed in order to better understand how these limitations might be overcome and how they affect design outcomes.

Collaboration is another set of codes that had both positive and negative responses, and like the technology capabilities, this set of codes revealed substantially negative results. Limited team collaboration was mentioned much more that positive team collaboration, and students' responses show that it was a challenge working as a group to make modifications to a design. Student comments described how there were times when they experienced confusion or frustration because those outside VR could not completely understand what the person inside was verbally describing or vice versa. This proved to be a limitation throughout the project and confirms the findings of George, Sleipness, and Quebbeman (2017). The Likert scale responses to the question "My team could collaborate effectively using VR" also showed limitations in this category and the mean response was 3.6 out of 7 (7 being 'strongly agree' and 1 being 'strongly disagree'). Although collaboration was identified as being limited in several ways, the majority of the time that students reference collaboration they are referring to verbal communication, and it is important to note that collaboration can happen in more than one way. This is further highlighted in the related code *improved communication of ideas*. Responses in this category specifically reference visually sharing ideas and concepts. This code was especially high during the final round and many of the students mentioned that they were able to easily mock-up ideas to share with their peers, and that their teammates were able to quickly see and understand their design intent, which in turn enabled them to get their points across quickly and improved the design conversation. One student commented,

> When one of us had a good idea but had a hard time telling others about it or showing it in 2D, they just drew it in VR and the group was able to understand.

> This seemed like it reduced team compromises because we understood everyone's ideas and were able to make decisions quicker.

The word "visual" was brought up many times in this category. This highlights the difference between verbal and visual communication in collaboration. These results suggest that while verbal communication and collaboration is hindered in VR, visual collaboration and communication is greatly improved. The hinderance is likely due to the designer being visually separated from the team and as virtual team environments become more accessible, more research is needed to assess team collaboration in the same VR space. Because of this, a recommended workflow for collaborating in VR would need to include frequent sharing of the VR design space so that the entire team is tapping into the visual communication benefits of VR, which in turn should help to alleviate some of the difficulties with verbal communication.

Overall, considering the identified affordances and limitations, this research suggests that there is a positive outlook for the use of VR as a tool for design creation in small-scale site design applications, and the benefits observed validate the efforts used to collect additional materials to facilitate VR design that is not required in traditional methods. While VR is still an emerging technology, the expansion of available software and capabilities has expanded substantially over the last 2 years, and ongoing investment in the technology will further drive technical innovation. While some software already exists that is tailored towards design professionals, such as IrisVR, it can be expected that in the near future more programs will be developed for specialized fields such as landscape architecture. This will create many opportunities for future research and exploration into improvements that are expected to be, made such as team collaboration.

Conclusions

This study examined the use of VR during the analysis and concept development phases of the design process on a small-scale site design project. Instead of using VR in the late stages of the design process as a tool for design review, students successfully integrated VR into a workflow that utilized both traditional and VR methods to analyze a site and develop and design a series of concepts. The results yielded that using VR for analysis and concept development on a small-scale project improved students' understanding of their designs, allowed them to better express their ideas, and make better informed design decisions. However, limitations were also observed, such as difficulties with verbal team collaboration, technology issues, the possibility of adverse physical effects, and a learning curve to proficiently use the software. However, with virtual reality technology rapidly improving and adoption expanding, future research will be needed to quantify the impacts of VR on design decisions and monitor how technological advances impact current limitations, such as team collaboration and the effect of VR on the design process. Overall, this research suggests that VR can be effectively incorporated into the analysis and concept development phases of the design process, and while it offers both benefits and limitations, this study concludes that the benefits outweigh the limitations.

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CHAPTER 4

CONCLUSIONS

Discussion

There are 14 codes for the master planning scale case study and 13 codes for the site-design scale case study. This is a result of *technology problems* being mentioned during the master planning scale, while not being mentioned at all in the site-scale. This most likely occurred because the master planning project occurred before the site-design scale project, and experience was gained with setting up the VR equipment in a way that better supports a team environment, thus avoiding problems.

First, the most frequent code in each study was *improved understanding of a design through immersion.* This code corresponded to 43 of the 226 codes on the master planning scale case study (19%), and 42 of the 193 codes on the site-design scale case study (21.8%). The occurrences of each code can be seen in Table 1. Another trend that was discovered was three of the top five codes in each study are the same, as well as three of the lowest five codes. This suggests relative consistency within the design experiences on both large and small-scale projects. The three codes that appeared in the top five of both studies included *improved understanding of a design through immersion, technology limitations,* and *improved site orientation and navigation.* These three were particularly significant and were present in 175 of the 424 coded responses from both projects (41.2%). *improved understanding of a design through immersion* accounted for 20% of the combined total, *technology limitations* totaled 11.1%, and *improved site*

Table 1

Codes from Each Project Ranked by Number of Occurrences

Large-scale case study			Site-scale case study		
Rank	Code	%	Rank	Code	%
1.	Improved understanding of a design through immersion	19.0	1.	Improved understanding of a design through immersion	21.8
2.	Technology limitations	12.4	2.	Improved site orientation and navigation	11.4
3.	(Tie 3rd) Improved site orientation and navigation	9.3	3.	(Tie 3rd) Improved communication of ideas	9.8
4.	(Tie 3rd) Improved sensory experience	9.3	4.	(Tie 3rd) Technology limitations	8.8
5.	(Tie 3rd) Positive technology capabilities	9.3	5.	(Tie 5th) Learning curve	9.3
6.	Improved communication of ideas	8.8	6.	(Tie 5th) Improved process efficiency	9.3
7.	Improved self-expression	7.1	7.	(Tie 7th) Improved self-expression	7.3
8.	Improved process efficiency	6.6	8.	(Tie 7th) Limited team collaboration	7.3
9.	Limited team collaboration	6.2	9.	(Tie 9th) Positive technology capabilities	4.1
10.	Physical effects	4.0	10.	(Tie 9th) Positive team collaboration	4.1
11.	Learning curve	3.1	11.	Physical effects	3.6
12.	Decreased process efficiency	2.2	12.	Improved sensory experience	2.6
13.	Technology problems	1.8	13.	Decreased process efficiency	2.1
14.	Positive team collaboration				

orientation and navigation was 10.1%. This suggests that the conditions that these codes represent are the most prominent affordances and constraints of incorporating design process at various scales. Two of the three top codes are spatial affordances, while one is related to a need for more technical development. These spatial affordances are especially beneficial to landscape architects, and the results suggest that VR provides an effective immersive environment where designers can better understand their project site and the designs that they propose.

The three that appeared in the bottom five of both studies consisted of *decreased process efficiency, positive team collaboration*, and *physical effects*. These three

combined were only present in 35 of the 424 codes (8.3%), which suggests that the effects or conditions that these codes represent are minimal for the design team inside and outside of VR on both master planning and site-design projects.

Figure 24 compares average results of each code at both project scales. The codes are listed from highest to lowest based on the combined average of the two scales. These results show the above stated findings regarding the top and bottom five codes, as well as the remainder. Data show relative consistency between the averages of each code at both the master planning and site-design scale, and the averages of ten of the fourteen codes are within three percent of each other. Four of the 14 are within 1%, six of the 14 are within 2%, and only four of the 14 have averages greater than 3% away from the other. As shown in Figure 24, the codes with similar averages within 3% include *improved understanding of a design through immersion, technology limitations, improved site orientation and navigation, improved communication of ideas, improved process efficiency, improved self- expression, limited team collaboration, physical effects, and decreased process efficiency.* This shows further consistency between the two scales and supports the idea that a large portion of overall benefits and challenges of using VR in the landscape architecture design process are the same regardless of project scale. However, codes with dissimilar averages suggest that while there are similarities, it is possible that these scales may have some substantial differences. The codes with dissimilar averages are *positive technology capabilities*, *improved sensory experience*, *learning curve*, and *positive team collaboration*.

While many of the codes had overall similar averages, it was important to

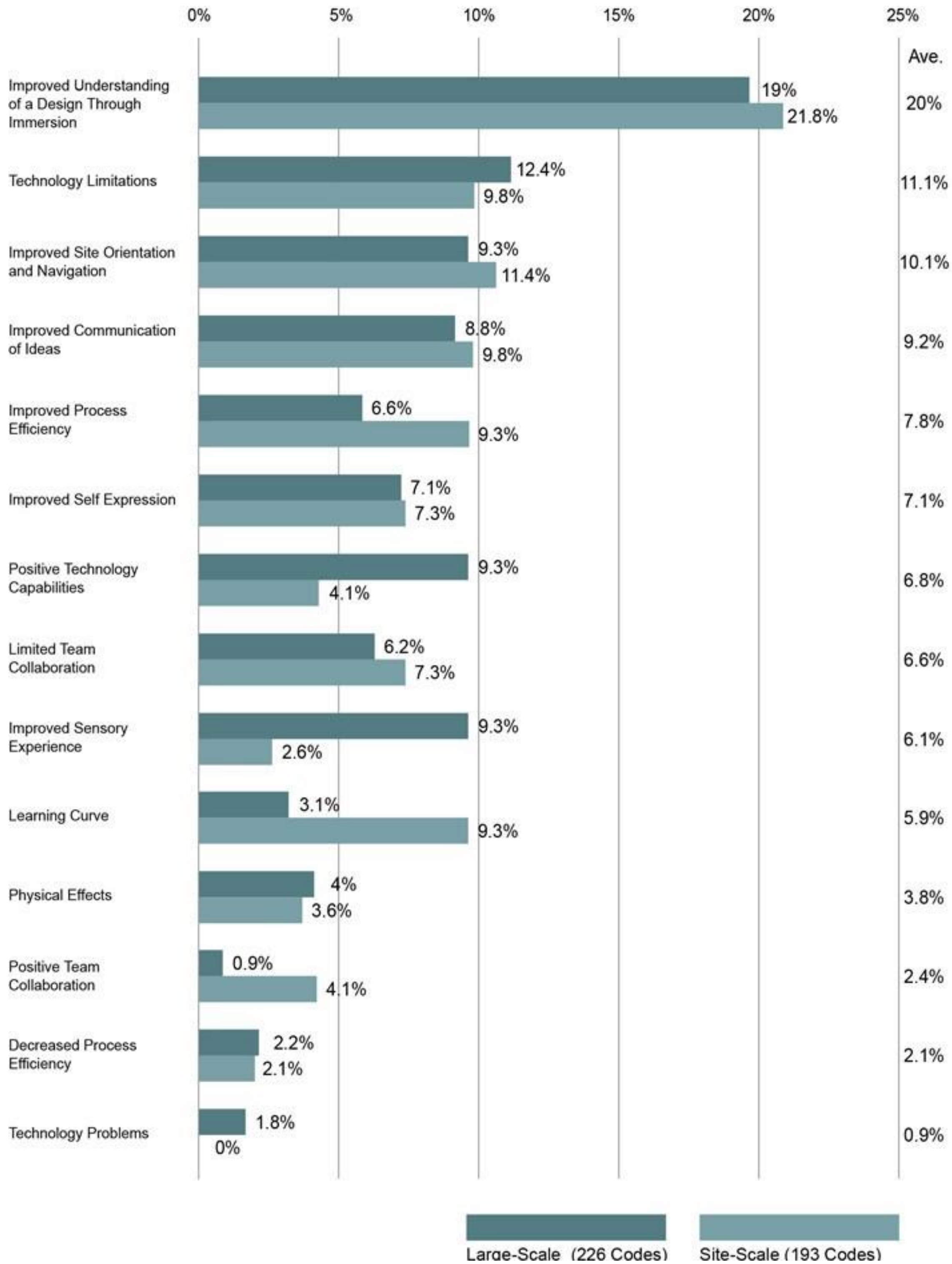

Figure 24. Occurrences of coded comments in both project scales.

examine the outcomes of each round throughout both projects. Additional trends were discovered, and observations were made that are not visible through looking at the combined totals of each project. A comparison of all rounds in each project is shown in Figures 25 and 26. This diagram shows that many of the codes with similar averages were distributed through the rounds differently. *Improved understanding of a design through immersion,* was the highest code throughout all rounds of the site-scale CCID project, and while it was also very high in the master planning scale Powder Mountain project, there were others that were higher in the first and fourth rounds. This supports the conclusions of Castronovo, Nikolic, Liu, and Messner (2013), who claims that immersion can be a particularly effective tool for evaluating designs. This study suggests that it is also particularly effective for design creation. *Improved site orientation and*

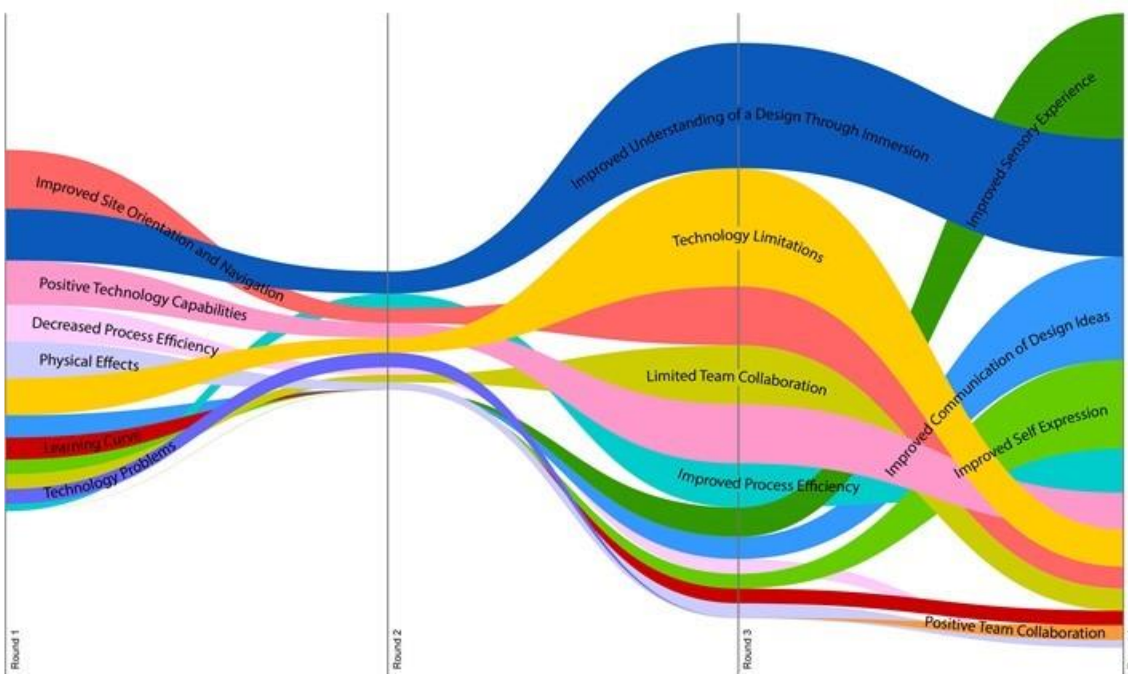

Figure 25. Distribution of coded comments for the master planning scale project. The total amount of responses is represented by the thickness of all codes in a round, and the thickness of each ribbon represents the number of occurrences per code.

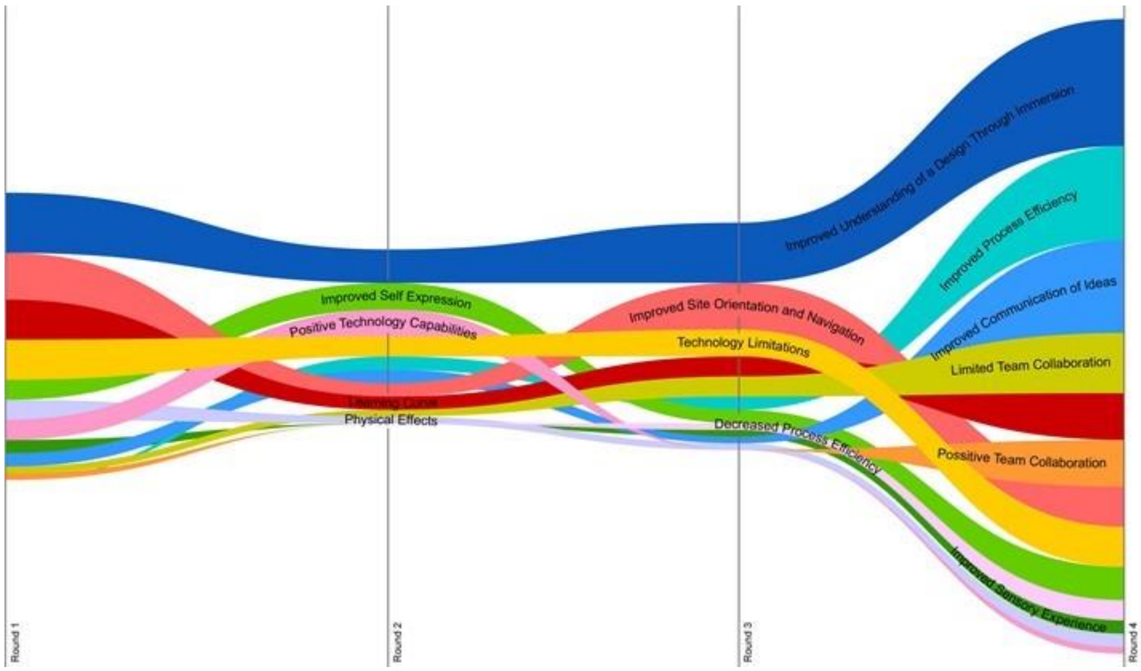

Figure 26. Distribution of coded comments for the site-design scale project. The total amount of responses is represented by the thickness of all codes in a round, and the thickness of each ribbon represents the number of occurrences per code.

navigation seemed to have a consistent pattern of being higher in the early rounds and lower in the final round of both projects. This might be because participants became more familiar with the site and their designs as each project progressed and therefore did not require as much effort to orient themselves in later rounds. The results showed that *improved site orientation and navigation* and *improved understanding of a design through immersion* are benefits of spatial awareness, and this is consistent with the findings of Castronovo et al.; Portman, Natapov, and Fisher-Gewirtzman (2015); and Rahimian and Ibrahmi (2011).

Technology limitations was consistently in the middle of the first three rounds of the site-scale project and lower in the final round. However, in the master planning scale

project, its occurrence seemed to steadily increase over the first three rounds and then decrease in the forth. This could be due to the level of detail that was experienced in each project. The master planning scale project started with very loose drawing gestures and progressed towards more detailed conceptual designs, while the site-design scale project allowed for detailed design throughout all rounds. This might indicate that as the level of detail becomes more refined, technology limitations become more apparent. Many students commented that they wanted more precise tools, functionalities, and controls. Tilt Brush is a program developed for artists and has many capabilities for drawing loose forms. It is not specifically developed as a detailed drafting program, and although tools exist for detailed surface creation, it lacks advanced precision, integrated scale, and layers that traditional design programs have such as Photoshop and Rhinoceros 3D. Participants experience with technology limitations may be in part tied to not being fully aware of what they can create with the existing tools, but many participants mentioned specific tools and capabilities that they wanted to use that are not currently available in Tilt Brush. As stated previously, there are other VR programs with broader toolsets, but they have steeper learning curves and more expensive licenses. This contributed to why Tilt Brush was chosen for this research. In order for VR design applications to be more efficient and valuable for landscape architects, Tilt Brush and other programs will need to develop additional tools for detailed design creation such as units and scale, layers, precise geometric shape creation and manipulation tools, and shape extrusion capabilities.

While Tilt Brush proved to have limited capabilities as a drafting tool, it has many dynamic and interactive tools that students gravitated toward. Some of these include

painting tools for drawing rainbows, fire, and bubbles. These capabilities were initially a distraction to the students and the first few minutes of a VR design session usually consisted of participants writing their names in rainbows and fire. This may have negatively impacted productivity, but it is possible that there are positive effects as well. Drawing and creating in this way seemed to excite students and provoke them to explore and be creative in a loose and informal way.

The findings of *technology limitations* also support the code *positive technology capabilities*. It is likely that the participants of the master planning scale project rated *positive technology capabilities* higher because the majority of the project consisted of creating loose forms and designs, while the end product of the site-design scale project was more focused on detail and precision. This assessment is supported by the results of *learning curve* as well, which also showed a large overall difference across scales. *Learning curve* was reported to be much higher in the site-scale project, while it was much lower at the master planning scale for developing concepts that were more loose. Students commented that they were able to understand the tools for basic form giving relatively quickly, but more detailed drawings and advanced controls took longer to learn. This was in part because most of the students had not used Tilt Brush before and were not aware of many of its capabilities. However, many did comment on the program's intuitiveness. It is expected that designers with moderate familiarity with the software would be able to develop detailed designs relatively quickly and easily.

Improved communication of ideas was very similar at both scales. It was a middle ranking code throughout the first three rounds and then increased in the final round. This

could be because it was perceived by the participants to some degree throughout the entire project but was especially appreciated in hindsight after the project. *Improved process efficiency* is a middle ranking code throughout both scales but gets slightly higher in the fourth round of the site-scale project. *improved process efficiency* was relatively consistent in the middle of the codes in both projects, although it increased in round four of the site-design scale project. It scored convincingly higher *than decreased process efficiency* in both projects, and while using both VR and traditional methods can potentially take more time than traditional methods, this suggests that the result of the process provides the designer with a better outcome overall. However, more research is needed to confirm this relationship. It is probable that the improved process comes as a result of the other reported affordances such as *increased site orientation and navigation* and *improved understanding of a design through immersion*. While *decreased process efficiency* had a similar overall average, it is interesting that in the master planning scale project the occurrences were higher initially and decreased over time, while in the site-design scale project the occurrences were nonexistent in the first two rounds and increased slightly in rounds three and four. This does not show a clear pattern but may be tied to the level of detail in each project and also the difference between gross and fine motor control compared to traditional methods. VR presents more opportunities for large motions of gross motor control while drawing on paper or digitally involves smaller movements of fine motor control, which could be tied to why some participants reported that drawing took them longer. More research is needed to assess process efficiency, but the overall data suggests that the design process can be improved by incorporating VR

into the design process at both large and small scales.

Improved self-expression had an extremely similar overall average, but its occurrences are distributed slightly different throughout the projects. While there are not extreme differences, this code occurred more in the early stages of the site-design scale project and later in the master planning scale project. The level of detail in each project may contribute to this, and more detailed design scenarios may facilitate the ability of a designer to express their ideas. *Physical effects* had a very similar pattern at both scales and started out as a mild occurrence and decreased over each round until it was minimal or non-existent. This shows that while a small percentage of VR users experience physical effects such as headache or nausea, many of them dissipate over time as the user's body adjusts.

Limited team collaboration seemed to be consistent in both projects and was consistently ranked near the middle of the codes. This finding suggests an important limitation with the ability to collaborate using VR. Teamwork and collaboration are critical to landscape architects and many participants commented that the visual barrier of the headset and the inability to see their team members outside VR proved to be a hinderance. This finding is inconsistent the conclusions of Gu, Kim, and Maher (2011), and de Freitas and Ruschel (2015), and supports the findings of George, Sleipness, and Quebbeman (2017), who also observed verbal communication barriers resulting from the use of a head mounted display. However, as mentioned in the previous chapters, the data shows that there is not only one form of communication and collaboration. Other codes like *improved communication of ideas* and *improved self-expression* suggest that there

can be a separation of the term collaboration into verbal and visual forms. In the site-scale project, the results clearly convey a message of verbal limitations due to visual separation of space. This is evident in the variation in the coded comments of both projects and the results of the Likert scale questions. The results of this topic on the master planning scale project are not as clear, and the coded comments and Likert-scale responses do not completely agree with each other. This may be a result of confusion surrounding the definition of collaboration and it is possible that some students are referring to visual communication and collaboration, while other are referring to verbal only. Based on the number of comments that specifically mentioned the difficulties in verbal communication and also the high number of positive comments on the ability to communicate and express ideas, it can be inferred that verbal communication between team members is currently a limitation at both scales while using VR, while visual communication and collaboration have several affordances.

The remaining codes did not have similar overall averages. *Improved sensory experience* was very different in each project and while it scored the highest in round four of the master planning project, it was very low in the first three rounds at that scale and was consistently low throughout the entire site-design scale project. The fact that students did not report substantial numbers during the three design phases of master planning project suggests that this affordance was not present in the minds of the designers as they were in VR but was recognized in hindsight during the focus group. The setting of the project may be a factor in why this was reported in the master planning scale project and not the site-design scale. The master planning scale project was an expansive mountain

landscape and users experienced views into meadows and dense vegetation, while the setting of the site-design scale project was in a residential neighborhood, and thus potentially provided less sensory stimuli. It may also be a result of participants not being able to fully experience the large master planning scale site in person due to its size, and VR enabled them to more fully experience it. In contrast, the smaller site-design scale project allowed them to experience the entire site in person. However, these results remain unclear and more research is needed to fully assess the sensory experiences of design in VR.

The Likert-scale responses also reveal interesting data, many of which provide support to the coded comments. For example, in Figure 27 the question "Using VR made me more aware of the 3-dimensional character of my design" corresponds with the code *improved understanding of a design through immersion.* This question received high scores from both projects and had the highest combined average of 6.55 out of 7. Figures 27-28 have different rating systems because they communicate, and the first focuses on level of agreement, while the second focuses on preference of use. While they examine different aspects of the design process, the results of both scales are very similar and consistent. All but two of the ratings are within one point of each other, and the ratings with inconsistencies greater than one point are My team could collaborate effectively using VR and Using VR altered my approach to design. This supports the previous findings that collaboration has mixed results and that there may have been confusion on expressing which type of collaboration participants experienced. It also supports the findings of VR potentially altering and improving the efficiency of the design process,

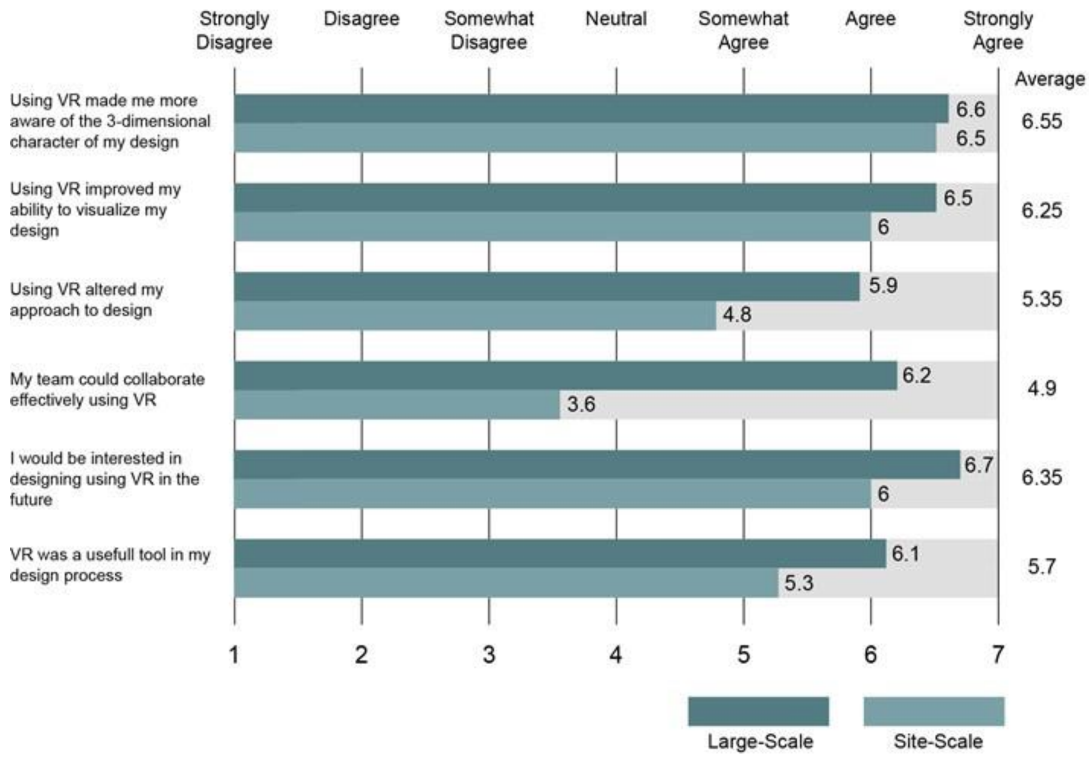

Figure 27. Combined preference rating of VR utilization.

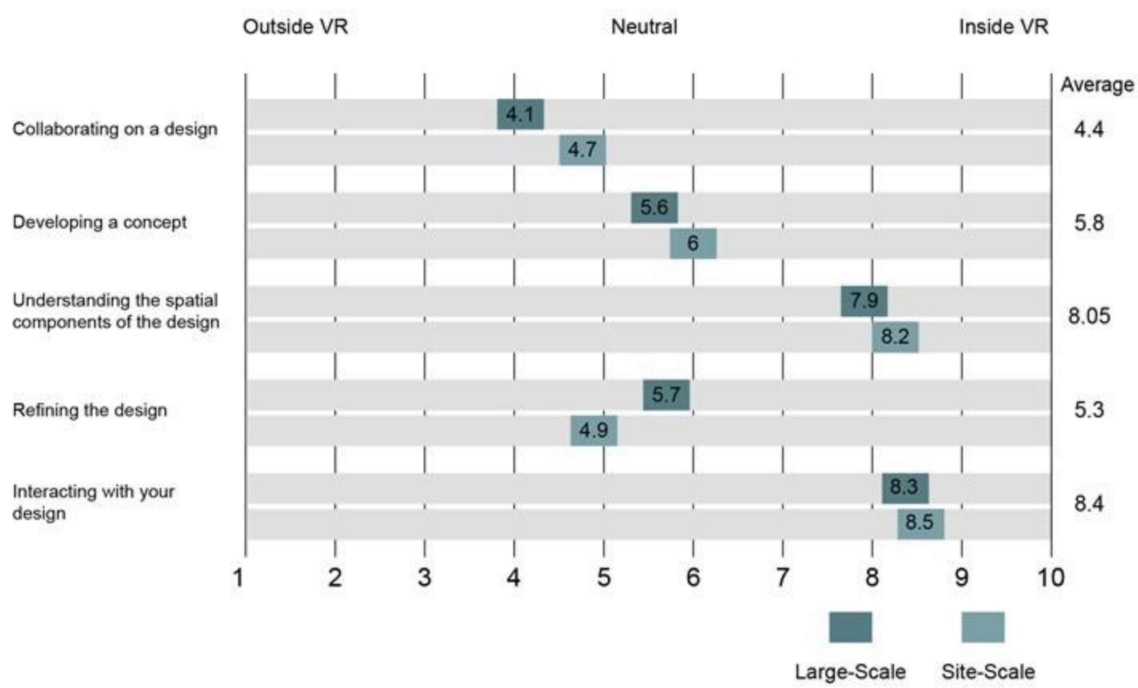

Figure 28. Combined preference rating of completing a task within or outside VR.

although more research is needed to fully evaluate the quality of the overall outcomes of the process. Overall, the data suggests an overall consistent design experience in VR at both large and small scales, except for the few topics that were just discussed.

As a result of the relative consistencies between scales, the results of each round were combined in Figure 29 to illustrate the average affordances and constraints of integrating VR into the design process at both scales. This, combined with Figure 24, illustrates the potential benefits and limitations that a team might expect on average if they were to use VR at a variety of project scales. While there are several limitations and areas that require more research to understand, it is evident that there are many benefits that can be achieved through the incorporation of VR into the early stages of the landscape architecture design process. This supports the findings Sleipness and George,

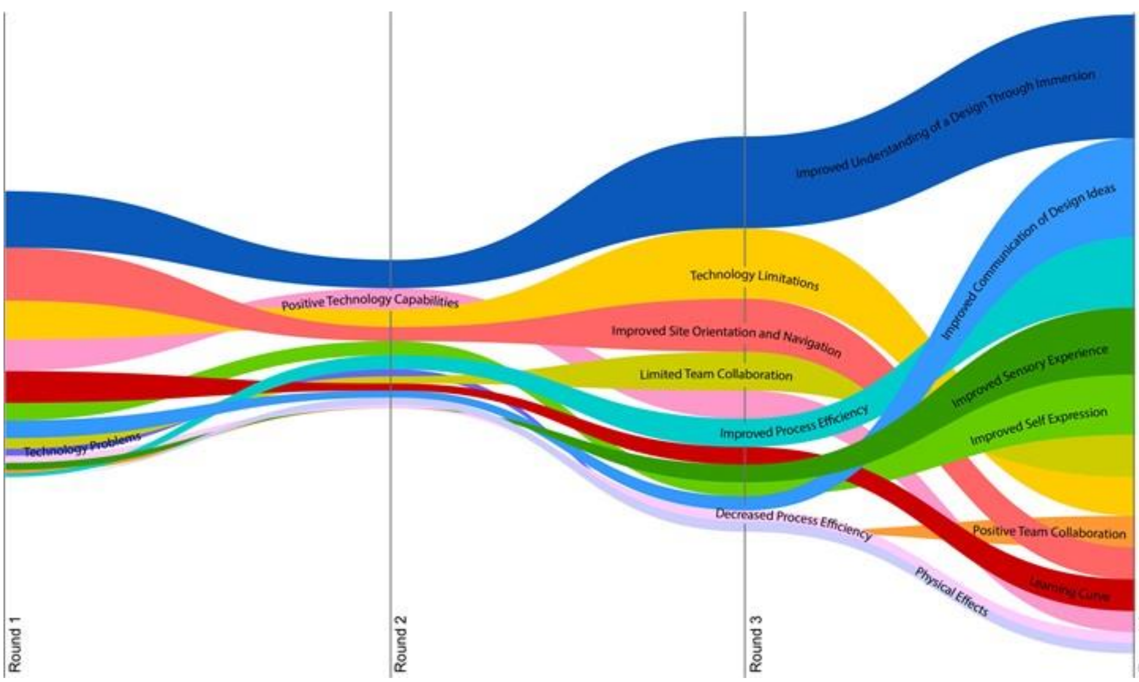

Figure 29. Distribution of coded comments for both projects over four rounds. The total amount of responses is represented by the thickness of all codes in a round, and the thickness of each ribbon represents the number of occurrences per code.

(2017), who found that students could rapidly create designs and understand their spatial impacts more effectively in VR than in computer-modeling software. It is also evident that the codes that imply affordances are trending upward as designers progress through a project and become more experienced with the programs.

Figures 30 and 31 illustrate the room configurations for the design teams in each case study. Due to space and scheduling constraints, the projects were not able to be conducted in the same space. Each room setup was similar and consisted of a large central table for the team to gather around to collaborate and draw. A large VR workspace was immediately next to the table to allow team members to quickly transition in and out of VR. Large screens were provided in both setups to allow the team members outside of VR to see what the designer was seeing. However, there was one minor

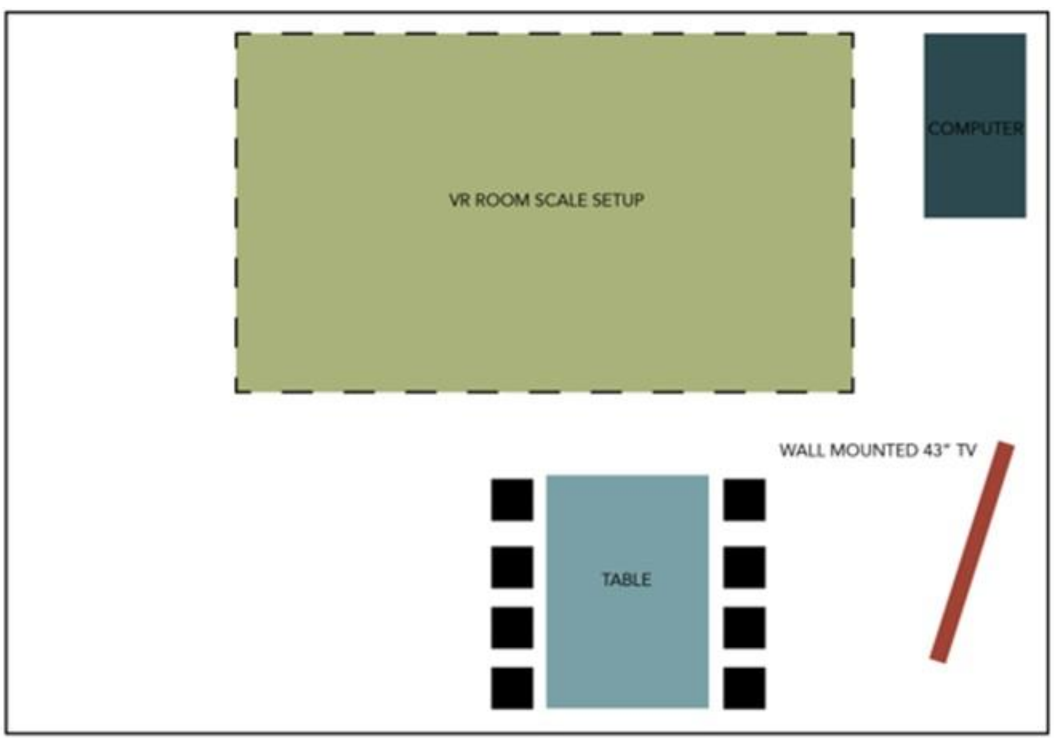

Figure 30. Room setup for the master planning scale Powder Mountain project.

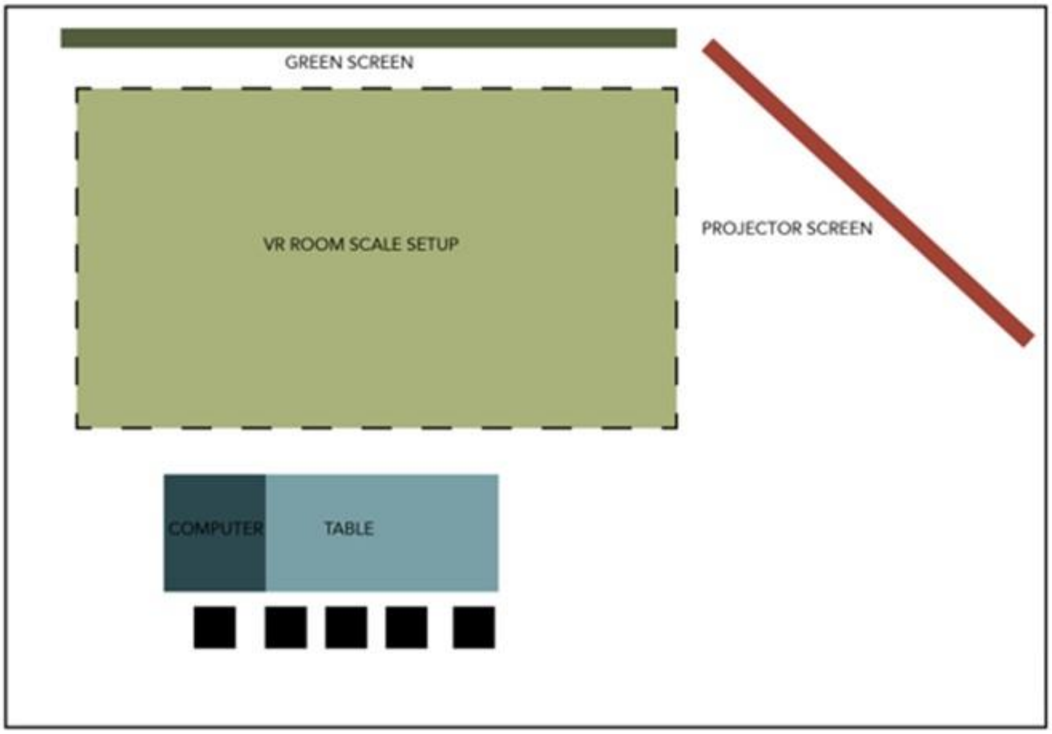

Figure 31. Room setup for the site-design scale CCID project.

difference in the setup of the spaces. As mentioned in Chapter 1, a green screen was used in the smaller site-design scale project in order to experiment with creating mixed reality and test its impact on team collaboration. This setup consisted of a green piece of fabric draped from a pole and placed behind the VR setup as indicated in Figure 31. A camera was then placed in front of the VR setup that captured a third person mixed reality view. However, due to technology issues, this method was not able to be used as the team designed and was only used afterwards to create 2D imagery that illustrates what the designer sees in VR. This method would enable team members outside of VR to experience both first person and third person views of what the designer is experiencing inside VR in real time. Further research could test this technology and the effects that it has on team collaboration.

Limitations

Several limitations exist in this study. First is that the two case studies of design teams are each of a small sample size. Landscape architecture design teams are typically small in size and compiling large teams would have created an unrealistic team environment. In order to increase the sample size, several separate teams would have been needed on each project. Due to limited space, technology resources, and access to participants, this obstacle was not able to be overcome in this study. Another limitation that exists is the varying academic classes and experience levels of the student participants in each case study. Participants range from first year undergraduates to graduate students. Although variation in experience level exists in landscape architecture practice, the level of familiarity with design may be more significant in this study due to some of the students being new to the profession. Variation was also present in the number of participants who responded in each round. Round two of the master planning scale case study was particularly low and only several students responded to the survey after designing.

This study examines a large-scale master planning project and small-scale site-design project. It does not examine other scales that exist in the industry. It also does not address the various types of projects that exist at different scales and how they might affect the design process. For example, an urban design project in comparison to an environmental restoration project. More research is needed to assess these different areas. Lastly, the projects were conducted with a slightly different room setup, which may have unknowingly presented opportunities or limitations for one team that were not available

for the other.

Conclusion

From assessing two case studies of a master planning project and site-design project, it is apparent that both benefits and challenges exist in the integration of virtual reality into the landscape architecture design process. The two project scales were found to provide a consistent experience of benefits and challenges and the top three codes in each case study consist of benefits of spatial understanding as well as limitations in current software development. While many affordances exist with its use, there are also limitations that must be overcome in order to better facilitate industry needs such as team collaboration and programs with a toolset and features more catered towards landscape architects.

Technology developments need to better enable entire design teams to work inside VR on the same project and enable seamless verbal and visual communication that eliminates lag and confusion from one team member to another. Other technology developments need to occur within VR programs such as Tilt Brush and other design applications. Loose and conceptual sketches proved to be of value, but difficulties arose when more precise and detailed designs were attempted. Tools and features such as units and scale, layers, precise geometric shape creation and manipulation tools, and shape extrusion capabilities need to be developed in order for landscape architects to more effectively design within VR.

While the results suggest many similarities between both the master planning and

site-design scales, there is also significant data that suggests several differences. It was found that the programs used in this study are more efficient on large-scale master planning projects where the level of detail is less detailed than a site design. This is illustrated by the lower occurrences of Technology Limitations and Learning Curve codes. Designing detailed spaces in Tilt Brush is possible but required more familiarity with design tools. However, master planning scale projects involve a more complex workflow to assemble the required terrain model assets in order to design on a site and requires many drone flights and increased processing time. Site-scale design requires significantly less time to create the needed assets.

In summary, there are benefits and challenges in the use of VR at both project scales described in this study. The data collected in this research suggests that the biggest impacts to the design process are benefits, which illustrates the value of VR. The large amount of reported benefits suggest that the increased efficiencies brought about by VR overcome the challenges encountered and additional resources needed. Overall, the data conveys a positive outlook for the use of virtual reality and suggests that it can be used as an effective design tool to supplement traditional design methods in the analysis and concept development phases of the landscape architecture design process at a variety of scales.

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APPENDICES

Appendix A

Surveys Distributed to Participants

Rounds 1 and 2 Survey Questions

Name

Approximately how much time did you spend in VR today?

What was the biggest benefit you experienced with VR today?

What was the biggest challenge you experienced with VR today?

What was the most enjoyable thing about using VR today?

What was the least enjoyable thing about using VR today?

Round 3 Survey Questions

What is your name?

About how much time do you think you spent in VR during the charrette?

About how much time do you think you spent outside of VR, but collaborating with someone who was in VR at the time?

For the following questions, please indicate how much you agree or disagree with the following statements:

	Strongly disagree	Disagree	Somewhat disagree	Neither agree nor disagree	Somewhat agree	Agree	Strongly agree
Using VR made me more aware of the 3-dimensional character of my design.	O	O	O	O	O	O	O
Using VR improved my ability to visualize my design.	O	O	O	O	O	O	O
Using VR altered my approach to design.	O	O	O	O	O	O	O
My team could collaborate effectively using VR	O	O	O	O	O	O	O
I would be interested in designing using VR in the future.	O	O	O	O	O	O	O

Round 3 Survey Questions Continued

On a scale of 1-10 (1 being outside VR,10 being inside VR), please indicate which of the following design tasks would be easier to complete using VR or using a traditional design method outside of VR.

	Outside VR 1	2	3	4	5	6	6	7	8	9	Inside VR 10
Collaborating on a design	O	O	O	O	O	O	O	O	O	O	O
Developing a concept	O	O	O	O	O	O	O	O	O	O	O
Understanding the spatial components of the design	O	O	O	O	O	O	O	O	O	O	O
Refining the design	O	O	O	O	O	O	O	O	O	O	O
Interacting with your design	O	O	O	O	O	O	O	O	O	O	O

What would improve the design experience within VR?

What do you think was made easier by designing in VR?

What do you think was made more difficult by designing in VR?

What aspects of the design process changed for you by designing using VR?

If you were asked to use VR on future studio project, how useful do you think it would be?

	Extremely useless	Moderately useless	Slightly useless	Neither useful nor useless	Slightly useful	Moderately useful	Extremely useful
Future use of VR?	O	O	O	O	O	O	O

Round 4 Focus Group Questions

1. How long did it take you to feel comfortable using VR?
2. What strategies could we use to train people to use VR?
3. Do you feel that VR helped you to communicate your ideas better? If so, how?
4. What about collaboration worked in VR? What didn't work?
5. Was analyzing the site made easier using VR? If so, did that change your approach to analyzing and designing the site?
6. Do you think that VR changed the concepts that you developed? How?
7. What were some benefits? What were limitations?
8. If you chose to use VR in your design process, what stages would you use it in?
9. What scale do you believe this would be best suited for?

Appendix B

Codes from Survey Responses

Codes from Survey Responses

Code Color

Learning curve ……………………………………………

Improved site orientation and navigation ……………………

Positive team collaboration ………………………………

Technology Limitations ……………………………………..

Limited team collaboration …………………………………

Improved self-expression ……………………………………

Improved sensory experience ………………………………..

Improved process efficiency …………………………………

Improved communication of design ideas …………………..

Improved understanding of a design through immersion ……

Technology problems ………………………………………..

Physical effects ………………………………………………

Decreased process efficiency ………………………………..

Positive technology capabilities ……………………………..