Sanctuary: A Virtual-Reality, Immersive-Environment Mobile Application to Promote Mindfulness, Meditation, and Relaxation

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Sanctuary: A Virtual-Reality, Immersive-Environment Mobile Application to Promote Mindfulness, Meditation, and Relaxation

A Thesis
Presented to
the Graduate School of
Clemson University

In Partial Fulfillment
of the Requirements for the Degree
Master of Fine Arts
Digital Production Arts

by
Amanda Caroline Smoak
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Accepted by:
Dr. Eric Patterson, Committee Chair
Dr. Victor Zordan
Professor David Donar
Professor Insun Kwon
Abstract

The World Health Organization calls stress the health epidemic of the twenty-first century [40]. Finding ways to manage stress – not just for our own health, but also for the health of our communities and children – is one of our most significant challenges for wellness. Virtual-reality (VR) therapy is the use of stimulated, interactive, and immersive environments as a tool for physical and psychological healthcare applications [31]. VR therapy and mindfulness practices have both been shown to alleviate stress and anxiety. The mobile application detailed here attempts to aid in stress reduction using virtual-reality therapy by immersing the user in a calming VR environment to encourage mindfulness in nature. It is my hope that the use of this mobile application will provide users with a sacred space from which they can escape from day-to-day stressors.
Artist’s Statement

Since the humble beginnings of humanity, nature has inspired hundreds of artists and philosophers in their work. In fact, those that most inspire me today lived almost two hundred years ago. The transcendentalist philosophers and the Hudson River Valley School artists have influenced my vision and, further, my mission to remind others about the importance of nature and its impact in our lives.

Transcendentalists, like Ralph Waldo Emerson and Henry David Thoreau, believed in individuality, self-reliance, spirituality, intuition, idealism, and the importance of nature. In his most memorable work, *Walden*, Thoreau writes, “I went to the woods because I wished to live deliberately, to front only the essential facts of life, and see if I could not learn what it had to teach, and not, when I came to die, discover that I had not lived [50].” In short, Thoreau and the transcendentalists promoted mindfulness in nature.

Visually, the Hudson River Valley artists like founder Thomas Cole, Asher Brown Durand, William Hart, and Thomas Moran have played an instrumental role in capturing the majesty of nature. Inspired aesthetically by Romanticism, this group of artists painted grand landscapes depicting the Hudson River Valley and some surrounding areas in the Northeast. The paintings reflected themes of discovery and exploration while highlighting the triviality of man. Though the landscapes are often idealized – with grandiose color, lighting, and form – these are still subjects that exist just outside our doors. It is not a scene from a science fiction movie – these are places we can see, smell, and touch.

Like many of the transcendentalists and Hudson River Valley artists, my oasis in nature is in the eastern forests of the United States – specifically the forests of the Blue Ridge Mountains in North and South Carolina. It is there that I have memories floating down icy rivers in inner tubes during the summer and picking apples as the leaves change in the fall. You will see that the forest
environment in *Sanctuary* reflects my personal version of this oasis.

The artistic style of my VR mobile application is unlike anything I have ever created – it is realistic. Like the Hudson River Valley artists, however, I will create an *idealized* version of nature by thoughtfully managing layout, form, color, lighting, and effects. My previous productions have been heavily stylized which has always felt more safe because it is subjective – who can say what is right or wrong? For this project, though, I decided to create a realistic environment not only to broaden my experience, but because that is the style which will most help users feel like they are truly escaping to the outdoors. It is important to me that the user not be so overwhelmed and distracted by the colors and shape of a stylized environment that they could not use the experience for mindfulness, meditation, and relaxation.

The motivation behind *Sanctuary* stems from a simple love of being outdoors. I consider nature’s beauty to be unmatched by anything human-made, and I make any excuse to surround myself by it. When I travel, I hike the mountains or cycle around the city; and when I am at home, I have coffee on my plant-filled porch and take extra-long dog walks through the woods near our house. Breathing fresh air and walking between trees with our feet in the grass is good for the soul – for our mind and body, too.

As I get older, it has become exceedingly easier to convince myself to stay indoors to maximize productivity. In the fields of digital arts and computer science, that means being in front of the computer in my desk chair for hours on end. I hate that. I want to remind people that the sun, trees, and grass exist – something I have too often let myself forget.

I want this virtual-reality application to help two groups of people – those who need a push to get outside and those who physically cannot go outside. I do not want this virtual-reality experience to replace nature, but I think it will inspire more people to get out of their computer chairs and escape from day-to-day stress. Also, I would like to help those who cannot go outside – whether that be because they are stuck in a hospital bed, have a long layover at the airport, or live in regions where sunlight only lasts a few hours. I want this virtual-reality application to help these people escape to a beautiful, more peaceful place.
Acknowledgments

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# Table of Contents

Title Page ................................................................. i  
Abstract ................................................................. ii 
Artist’s Statement ......................................................... iii 
Acknowledgments ......................................................... v  
List of Tables ........................................................... viii 
List of Figures .......................................................... ix  
1 Introduction ........................................................... 1  
2 Background ........................................................... 3 
  2.1 Mindfulness and Mindfulness-Based Stress Reduction .......... 3 
  2.2 Shinrin-yoku ....................................................... 5 
  2.3 Virtual-Reality Immersion ....................................... 6 
3 Related Work ......................................................... 9 
  3.1 Mobile Applications ............................................... 9 
  3.2 Applications for Personal Computers (PC) ....................... 11 
4 Design and Implementation .......................................... 12 
  4.1 Reference ......................................................... 12 
  4.2 Software ........................................................... 19 
  4.3 Hardware ........................................................... 19 
  4.4 Modeling and Surfacing ......................................... 20 
  4.5 Layout .............................................................. 21 
  4.6 Animation .......................................................... 22 
  4.7 Lighting ............................................................ 23 
  4.8 Sound ............................................................... 23 
  4.9 Effects ............................................................. 23 
  4.10 Features ........................................................... 25 
  4.11 Gaze Tracking ................................................... 27 
  4.12 User Interface (UI) ............................................... 27 
5 Results and Discussion .............................................. 29 
  5.1 User Study ......................................................... 29 
  5.2 Discussion ........................................................ 32 
  5.3 Limitations ......................................................... 34
6 Conclusions and Future Work ......................................................... 35
   6.1 Conclusion ................................................................. 35
   6.2 Future Work ............................................................... 35

Appendices .................................................................................... 37
   A Gaze Tracking Implementation .................................................. 38
   B Asset Breakdown ................................................................. 43

Bibliography .................................................................................. 50
List of Tables

5.1 Emotion States included in the Derogatis Stress Profile . . . . . . . . . . . . . . . . 30
List of Figures

4.1 Hudson River School artists .................................................... 15
4.2 Megascans artists ................................................................. 16
4.3 Digital artists ........................................................................... 17
4.4 Images taken during a study of forests in South Carolina ............. 18
4.5 Equipment needed to operate standalone headsets versus tethered headsets .......................................................... 19
4.6 Grass asset .................................................................................. 20
4.6 Visual elements throughout environment .................................... 22
4.7 Comparison with and without atmospherics ............................... 24
4.8 Night scene with fireflies ............................................................. 25
4.9 Lighting scenarios for each each time of day. ............................. 26
4.9 User Interface ............................................................................. 28
4.10 User Interface during game play ............................................... 28
5.1 The mean Likert score of positive emotions for participants using Sanctuary ........................................................ 31
5.2 The mean Likert score of negative emotions for participants using Sanctuary ................................................................. 31
1 Control ring during game play ..................................................... 38
2 Blueprints for main character ....................................................... 39
3 Blueprints for standing icon interaction ....................................... 40
4 Blueprints for sitting icon interaction ......................................... 40
5 Blueprints for control ring ............................................................. 40
6 Blueprints for sound off icon interaction ..................................... 41
7 Blueprints for sound on icon interaction ...................................... 41
8 Blueprints for day scene icon interaction .................................... 41
9 Blueprints for sunset scene icon interaction .............................. 42
10 Blueprints for night scene icon interaction ................................ 42
Chapter 1

Introduction

Stress is often described as a feeling of being overwhelmed, worried or run-down [24]. It has become increasingly common amongst all demographics in the past decade. Stress can be caused by many factors including relationship difficulties, a hectic work life, financial problems, and family issues. In such situations, people with stress or anxiety tend to have negative emotional and even sometimes physical responses.

Now more than ever, we are feeling the stresses of big-city life and inescapable technology. Crowded cities and artificial light, namely, have lead to increases in health problems including anxiety, depression, addiction, heart attacks, strokes, and even cancer [28].

The big city life is not an easy, relaxing life. It often involves a busy work life, heavy pollution, crime, and a generally fast-paced lifestyle – all of which add to our day-to-day stressors. These things can often take a toll on our health whether we care to admit it or not.

Technology has also added to our day-to-day stressors, particularly after the invention of the smartphone. The smartphone and devices like it change our eyes, ears, backs, and brains. The artificial light from our screens is affecting melatonin production reducing restful sleep. Social media and streaming services on our devices has even decreased the desire to attempt a full night’s rest. One study found that some people routinely consume more screen time throughout the day than sleep at night [28].

It is in our best interest, both on a personal health level and as a community, to find a way to combat stress and anxiety. Once we reduce stress, our bodies are better equipped to deal with other health problems – or better yet, reduce the likelihood of other health problems developing at
This paper describes the motivation behind and development of an immersive virtual-reality environment application that combines all the benefits of mindfulness practices, nature, and virtual-reality therapy to create a powerful tool that can combat the stressors of modern life.
Chapter 2

Background

Existing methods aimed at decreasing stress and anxiety include the use of mindfulness training, restorative natural environments, and virtual-reality interventions [29]. My goal is to incorporate these three techniques into an easy to use mobile application.

2.1 Mindfulness and Mindfulness-Based Stress Reduction

One technique for treating stress, depression, and other psychological disorders is through cognitive behavioral therapy (CBT). CBT refers to a process or method where a patient learns to recognize the relationship between their thought and behavior [46]. Negative thought leads to negative behaviors, while positive thought leads to positive behaviors. During this process, the therapist helps the patients to understand their current mindset to identify any harmful, unhelpful, or false thoughts that can trigger stress or other health problems [31].

The practice of mindfulness meditation is very similar in theory to cognitive behavioral therapy. Mindfulness meditation involves paying attention to each event experienced in the present moment within our body and mind, with a non-judgmental, non-reactive and accepting attitude [27]. The practice strives for true acceptance of how we experience our realities, promoting a sense of freedom and acceptance over habits of brooding, unnecessary negative thoughts, and “auto-pilot” mindless living [8].

Within the past few decades, an interest in mindfulness meditation has grown in the medical community. Mindfulness-Based Stress Reduction (MBSR) was developed in the late 1970s by Dr.
Jon Kabat-Zinn, a professor of medicine emeritus at the University of Massachusetts. His eight-week course, from which MBSR derives its roots, guided participants verbally and physically through meditation and yoga resulting in less anxiety and enhanced perceived well-being [16].

Since Dr. Kabat-Zinn, thousands of studies have been done showing the benefits of mindfulness practices. Mindfulness does not just seem to boost mood and perception – the effects go deeper [57].

- Stress decreases. Mindfulness practices can shrink the brain’s jumpy fight-or-flight center, the amygdala, according to 2013 research out of the University of Pittsburgh and Carnegie Mellon University resulting in less anxious behavior.
- Attention increases. Another study, done at the University of Wisconsin-Madison, found that people who meditate regularly have different patterns of brain electricity, potentially leading to more efficient attention-paying and learning [56].
- Mood improves. The brain also releases serotonin, dopamine, and endorphins, all linked to a good mood.
- Blood pressure drops. The effect is not just temporary, as a Medical College of Wisconsin study showed that people who meditated twice a day for 20 minutes lowered their blood pressure by 5 mm Hg.
- Pain often diminishes. It appears to change the activity in key pain-processing regions of the brain – in one study, meditators experienced a 40% reduction in pain intensity. For many clinicians, meditation has become an alternative to prescribing opioids for acute pain [20].
- Swelling subsides. It can reduce stress-induced inflammatory conditions such as arthritis and asthma.
- Digestion runs more smoothly. Stress triggers the stomach-churning fight-or-flight instinct, shutting down digestion. When relaxed, the body reboots the parasympathetic nervous system, which gets digestion flowing [12].
- The list goes on [35] [41] [34].

The benefits are so profound and achieved at such low cost that hospitals across the country are increasingly using meditation, yoga, guided imagery and similar mindfulness practices as part
of the health-care offerings to patients undergoing surgery, pain management, cancer treatment and more. Corporations such as Google, American Express, and Nike have been jumping on the bandwagon, taking mindfulness training programs to their staff [56].

Mindfulness practices can even greatly benefit those unburdened by the stressors of adulthood. In a study at the University of North Carolina at Wilmington, scientists taught preschoolers yoga poses and meditations, and after just two weeks of practice, these kids had better attention, awareness, gratitude and happiness compared with a control group of children. Further studies have proven that children practicing mindfulness show more kindness, better math scores, fewer ADHD symptoms, more self-control, and less depression [38].

With any popular movement comes criticism, and the practice of mindfulness is no exception. One of the greatest concerns is that the movement is being romanticized [47]. Many psychologists and so-called Buddhist purists believe that mindfulness is largely misunderstood by the public who hope to reach enlightenment through practice. These critics suggest that enlightenment is not the end goal, but rather it is part of the journey [36]. In other words, we should practice mindfulness for the therapeutic benefits that come from routine practice rather than for the romanticized and unattainable enlightenment that we hope to someday reach [59]. As long as we practice mindfulness meditation with humble goals, it will be well worth the effort.

2.2 Shinrin-yoku

So, how can we practice mindfulness? Quite easily as it happens. Almost nothing is required – just a space to think, space to breathe, space between ourselves and our reactions. Many have found this kind of space in nature. The general benefit of surrounding oneself in nature is probably unsurprising, but it is only recently that scientific studies have been able to prove what so many cultures have believed for thousands of years.

In Japan, for example, when one immerses themselves in nature we are practicing what is called shinrin-yoku, or forest bathing. Shinrin in Japanese means “forest”, and yoku means “bath [28].” Therefore, shinrin-yoku means bathing in the forest atmosphere, or taking in the forest through our senses. This is not a form of exercise, or hiking, or jogging. It is simply being in nature, connecting with it through our sense of sight, hearing, taste, smell, and touch. Indoors, we tend to use only two senses, our eyes and ears. Outside is where we can smell the flowers, taste the fresh
air, look at the changing colors of the trees, hear the birds singing and, feel the breeze on our skin. And when we open up our senses, we begin to connect to the natural world.

Thanks to scientists like Dr. Qing Li, one of the world’s foremost expert in forest medicine, studies have shown that shinrin-yoku and other forms of restorative natural environment immersion can benefit sleep, mood, and immunity. There is now a wealth of scientifically backed data proving that shinrin-yoku can reduce blood pressure, lower stress, improve cardiovascular and metabolic health, lower blood-sugar levels, improve concentration and memory, lift depression, improve pain thresholds, improve energy, boost the immune system with an increase in the body’s count of natural killer (NK) cells, increase anti-cancer protein production, and help one lose weight [28].

With the overwhelming number of studies and positive data coming in on shinrin-yoku, the health benefits of forest bathing are not often questioned. What is being questioned is the popularity the movement has gained in the last few years. Critics say that shinrin-yoku has turned being outdoors into a fad [10]. A walk in the park has turned into a trendy wellness decision that needs to be documented on social media. Suddenly, the public is buying books on the best ways to practice shinrin-yoku – how to walk with a purpose, which trees produce the most enriching hormones, what time of day is most fulfilling, etc. These critics fear that these kinds of forest bathers are missing the point – and they are. Perhaps the most important rule of shinrin-yoku, and any other form of meditation for that matter, is to listen to your body and do what feels best. The point is to listen to yourself above others. If we are letting others dictate how we practice shinrin-yoku, we accomplish nothing.

2.3 Virtual-Reality Immersion

The final component of the application is virtual-reality immersion. Virtual-reality is a computer-simulated three-dimensional environment that allows users to perceive virtual objects as real. Immersion occurs when the users real-world view is replaced with computer-generated images and the view of these images change based on the position and orientation of the users head. Such immersion often uses head-mounted displays (HMDs) such as Google Cardboard or Samsung Gear VR. Non-immersive virtual-reality occurs when users are able to view the virtual world, but they are still aware of the real world – for example, viewing the virtual environment on a monitor [30].

In a clinical setting, the HMD achieves immersion by blocking out competing stimuli, with-
drawing the patient from the “anxiety-inducing sights and sounds of the ‘sick patient’ environment.” Immersive virtual-reality has been shown to provide better pain relief than movies or video games because the HMDs can heighten subjective experience of immersion and provide a sense of being physically located in the virtual world. HMDs can also reproduce and enhance the distractive qualities of guided imagery for those who cannot visualize successfully [55]. Until recently, virtual-reality technology has been remarkably expensive, motivating work to find alternative ways of generating therapeutic distractive imagery. One approach to improve cost and accessibility was to leverage thin computing clients such as smartphones and tablets to create a casual “pick up and use” head-mounted display [29].

There are a few ethical concerns regarding the use and development of virtual-reality therapy including physical and mental effects, regulation, and cost. Some studies have shown effects during and after virtual-reality exposure including a disconnect between reality and virtual-reality, undesired flashbacks, and cybersickness – a type of motion sickness caused by the virtual-reality experience [26]. If severe and widespread enough, VR therapy developers and clinicians should divert their efforts to mitigating these effects.

Another ethical concern is how developers and clinicians should receive VR therapy accreditation. Due to the relative newness of virtual-reality, there is not yet much overlap between clinicians who know best how to treat patients and developers who can create the functionality of the VR application. For now the best solutions points towards a partnership between the two professions so that both the medical aspects and the technological aspects are being met at the highest standard. Additionally, there should be studies and trials performed to ensure the safety and efficacy of VR therapy applications.

Finally, like any novel medical practice, cost is a limiting factor. Since virtual-reality in the field of science and medicine is still very much in the early stages, the costs of virtual-reality research, development, and equipment would be significantly higher than some of the traditional methods. However, like the vast majority of technological advances, costs decrease with time. In a decade or two, VR therapy could be an affordable alternative to traditional therapies; though for now, VR therapy may remain unaffordable to most. It is, however, promising to see the rising number of mobile VR games developed for free by developers such as myself. Virtual-reality therapy mobile applications, like Sanctuary, have the unique opportunity to provide patients with the help they need at their convenience and with little to no cost.
In the mobile application this paper describes, I have created an immersive, virtual-reality environment in hopes of unlocking the combined benefits of mindfulness, shinrin-yoku, and virtual-reality therapy to help combat stress and promote general relaxation.
Chapter 3

Related Work

Several applications have been created that offer solutions for providing experiences on a digital platform. During the research portion of this project, I came across many applications that have addressed concepts that I, too, wanted to address. Many of the following applications have characteristics in common with Sanctuary – including promoting mindfulness and meditation, surrounding the user in beautiful environments, utilizing virtual-reality technology, providing their services on a mobile platform, and, finally, offering their service at an affordable cost. However, all these applications fail to offer the user an experience that combines all of these features.

3.1 Mobile Applications

During my research, I came across many mobile applications whose mission was to combat stress through mindfulness and meditation. The two most popular mobile applications that fit into this genre are Calm and Headspace: Meditation, that rank first and second, respectively, in the free Health and Fitness category in Apple’s App Store [4]. The Calm app provides users with the opportunity to choose guided meditations tailored for them. The sessions range in length, from 3 to 25 minutes, and in focus with topics ranging from anxiety, sleep, forgiveness, and breaking habits. Calm has a great auditory and visual appeal with a beautiful user interface, nature sounds, background music and animated backgrounds [6]. Headspace: Meditation, similarly, offers guided meditation focused on increasing mindfulness, managing stress, improving sleep quality, and even bettering relationships. Headspace: Meditation encourages the user to meditate every day and track
it in the app in order to develop a habit. This app is auditorily-based and visually consists of a
simple user interface with stylized backgrounds [22]. One downside to these apps is the cost. Calm and Headspace: Meditation offer free trials and a handful of free meditations, but long term usage will cost the user about $12.99 a month, $59.99 and $94.99 a year, or $299.99 and $399.99 for a lifetime subscription, respectively. While both of these apps do a phenomenal job at providing the user with the opportunity to receive a tailored meditation session on-the-go, they lack the immersion of a virtual-reality, computer generated environment at an affordable price.

There is a small subset of affordable mobile applications that attempt to immerse the user in a calming, virtual-reality environment; however, these environments are created using 360 degree, images or videos [21] [53]. The difference between their two-dimensional environments and my three-dimensional environment is notable. The problem with two-dimensional, virtual-reality environments is that everything in the space is flattened because we have lost that third axis, the z axis that defines the depth of a scene. Even if the panoramic image is projected onto a sphere around the user, there is not a way to separate the layers between what in the environment is closest to the user and what is furthest. In three-dimensional environments, however, those layers are separated which creates parallax. Parallax is the apparent displacement of an observed object due to a change in the position of the observer, and it is crucial to creating a sense of depth. Parallax can only exist when there is some distance between foreground, mid-ground, and background objects. If you were to hold an object up at eye level and tilt your head back and forth, the relationship between the object you are holding and the background changes. Conversely, if you were to focus on an object on a large, flat surface like a wall and tilt your head back and forth, the relationship between the object you are focusing on and the background does not change. This is because there is no space between the object and the background. Parallax and the illusion of depth is a visually-critical component of immersive virtual-reality.

Alternatively, there a few three-dimensional, virtual-reality mobile applications that offer immersive experiences at an affordable price. However, these games are more often than not thrill-seeking, adrenaline-pumping action experiences – quite the opposite kind of experience Sanctuary attempts to produce. Some examples of the experiences these kinds of apps provide include skydiving simulations [54], roller coaster rides [17], and haunted-house explorations [45] among others.
3.2 Applications for Personal Computers (PC)

There are also a handful of PC-based virtual-reality immersive applications that offer experiences similar to Sanctuary. The application I have found most similar to Sanctuary is called Guided Meditation VR, and it falls into this category. Guided Meditation VR and similar apps require head mounted displays with wires that connect to a computer – limiting the users mobility [37]. This kind of system does not run cheap. It costs about $500 for a average PC and another $400 for a VR headset like the Oculus Rift [14]. Because of the high cost of equipment needed for this VR system, these are the kind of applications most often designed for medical clinics to aid in both physical and mental therapies. With the ever-increasing processing power of smart phones, it will not be long before these static VR therapy systems will be replaced with mobile versions.

The scope of my application has the potential to reach users of the aforementioned applications without some of their disadvantages. Moreover, these findings have exposed an opportunity to develop a virtual-reality, immersive, computer-generated environment for a mobile device to promote mindfulness, meditation, and relaxation at an affordable cost.
Chapter 4

Design and Implementation

This chapter covers my general process for the creation of the computer generated environment and the artistic decisions that were made throughout the production pipeline.

4.1 Reference

My process for the design of any environment begins with references. When I research, I look for interesting color, composition, lighting, and object combinations that I might be able to apply to my work. For this piece, I found visual inspiration from the paintings of Hudson River Valley artists, renderings by Megascans artists, and digital art by artists that I follow regularly.

4.1.1 Hudson River Valley Artists

Lighting and post-processing design was influenced most by the Hudson River Valley artists, Thomas Cole, Thomas Moran, and Asher Brown Durand, who created works with vivid colors while staying true to nature’s color palette.

In Evening in Arcadia, Thomas Cole depicts a land arch over a small body of water and two females playing music and dancing. Thomas Cole was a master of juxtaposing the grandness of nature with the meekness of humanity, and he was the first artist to paint North American landscape in the romantic style [48]. The color palette is pastel where the light hits with tones of umber and deep greens in the shadows. The lilac sky with peachy-pink clouds were inspiration for my own sky.

Thomas Moran preferred the west coast and often painted scenes from Yellowstone and the
Rocky Mountains like the scene called *Autumn Landscape*. Moran keeps the palette balanced with cool tones in the foreground and background and the warm tones, characteristic of autumn, in the mid-ground. This thoughtful separation depicts the season without overwhelming the viewer with a full palette of warm tones. I tried to keep this in mind when creating the scene with the setting sun. It was important to convince the user of the time of day without overwhelming the user with an completely orange-tinted scene.

In Asher Brown Durand’s Monument Mountain, The Berkshires, the viewer’s eye follows the curve of a broken tree through the painting before meeting a small brook surrounded by stumps and broken limbs. This piece speaks out against man’s destruction of the landscape. The color palette is made up of greens, blues, and umbers. Durand warms up the green with shades of yellows including sienna and ochre. I kept this in mind, particularly, when creating the grass. This piece directed the color palette of the day scene.

4.1.2 Megascans Artists

Artists like Dan Woje, Jorge Rocha, and Leon Labyk created CG environments using Megascans assets and influenced my layout and compositional decisions.

In *Forest Undergrowth*, Dan Woje has created a convincing deteriorating log with hyper-realistic assets from Megascans. It seemed clear to me that the artist had a methodology to the layout and composition of this scene. Woje likely began with the ground plane and the log, added filler assets like twigs and mushrooms, and then filled the rest of the scene with leaves and forest debris. I emulated this methodology when creating my scene.

Jorge Rocha used Megascans to create a clearing filled with vibrant mossy rocks in his piece called *Moody Forest*. Rocha’s work made me realize the need for a clearing in my environment. Forests are often very dark even in the middle of the day because the dense tree growth blocks light from reaching the forest floor. A clearing lets me surround the user in a well-lit, convincing mountainous forest environment.

In *Old Path* by Leon Labyk, I was able to see how Megascans assets might render in Unreal Engine. After seeing Labyk’s work, I was more motivated than ever to see what I could create combining these two powerful tools.
4.1.3 Other Digital Artists

Other digital artists – including Roman Chaliy, Anato Finnstark, and Magdalena Swiderska inspired me to bring my environments to life by pushing color and lighting.

Roman Chaliy’s *Legendary: Game of Heroes* inspired me to push the limits of lighting for a mobile application. While god rays remain too expensive for mobile apps in Unreal, I was able to achieve a similar look surrounding the halo of the sun. Atmospherics scatter the light creating a subtle haze around the sun.

I loved how the orange light from the setting sun contrasted with the vivid purple and blue shadowy areas in *The Smell of Dead Leaves* by Anato Finnstark. This look was so compelling that I, too, decided to add a subtle purple tint to the shadows in my environment.

Magdalena Swiderska’s work *Wild Forest* has been a favorite of mine for quite a while. I love the unusual combination of sea foam green and deep magenta for a forest scene. From Swiderska’s piece, I noted her use of fog to decrease scene size. The fade from crisp foreground to hazy background is exactly how I wanted my environment to look.

4.1.4 Field Study

In addition to online references, I captured my own reference images during field studies in South Carolina forests which informed what kind of plants would exist in my forest environment. During the field study, I observed the relationship between myself and the plants and trees around me. I also made a list of the types of flora I found in the environment so that I could create a realistic depiction of the forest.
Figure 4.1: Hudson River School artists
(a) *Forest Undergrowth* by Dan Woje [58]

(b) *Moody Forest* by Jorge Rocha [44]

(c) *Old Path* by Leon Labyk [25]

Figure 4.2: Megascans artists
(a) *Legendary: Game of Heroes* by Roman Chaliy [7]

(b) *The Smell of Dead Leaves* by Anato Finnstark [15]

(c) *Wild Forest* by Magdalena Swiderska [49]

Figure 4.3: Digital artists
Figure 4.4: Images taken during a study of forests in South Carolina
4.2 Software

Like most 3D projects, a collection of software is needed to produce a visually appealing, efficient, and high-quality project. For asset creation I needed robust software that would give me the freedom to create organic forms, while having the option to reduce polygon count. ZBrush allowed me to do just that [42]. After ZBrush, assets were brought into Maya where meshes, topology, and UVs were finalized [5]. Some assets and high-quality texture files – including albedo, cavity, normal, roughness, opacity, and translucency – are from Megascans [43]. A tool for image manipulation was required to tweak texture files individually, so they were brought into Adobe Photoshop [2]. I used Substance Designer to seamlessly tile the ground plane texture [3]. All of the sound clips were downloaded from Free Sound [39]. Finally, everything was combined in Unreal Engine 4 where layout, animation, lighting, effects, post-processing, and packaging were performed [18].

4.3 Hardware

It was very important from the beginning that this virtual-reality, mobile application be easily accessible both financially and technologically. For this reason I have published the Sanctuary app free on Apple’s App Store and Google Play. Additionally, I have designed the app to be used on any smartphone ($350) with Google Cardboard ($15) and similar mobile-mounting headsets ($2 - $50) [19]. These headsets cost much less than their PC-based counterparts such as Oculus Rift and HTC Vive which cost $399 and $499, respectively – not including the cost of controllers and a computer to run the equipment.

![Google Cardboard](image1.jpg)
![Oculus Rift](image2.jpg)

Figure 4.5: Equipment needed to operate standalone headsets versus tethered headsets
4.4 Modeling and Surfacing

During asset creation, variety is most essential. It is important to have a wide range of options from which to choose. My forest consists primarily of pines, ferns, and rock formations. To avoid repetition I created between six and a dozen versions of each of these elements. For each asset I had to find a balance between quality and efficiency. Game environments, like the forest in Sanctuary, must maintain a relatively low polygon count to ensure efficiency on a mobile device. A polygon (poly) is a plane figure bound by edges; in computer graphics, quadrilaterals and triangles are used most often. Plants like ferns and grass were created using a very low number of polygons. While trees and rocks were made as higher poly models and reduced many times to a more manageable polygon count. All the textures used for surfacing this environment were high quality scans. Most assets have an albedo/color map, a normal map, and a roughness map. Additionally, all closed assets – assets that are formed from spheres, cubes, and cylinders – like tree trunks, mushrooms, and rocks have cavity maps, while open assets – assets that are formed from flat planes – like grass, ferns, and pine tree needles have opacity and translucency maps.

(a) Grass Model Geometry

(b) Grass Model with Surfacing and Default Lighting

Figure 4.6: Grass asset
4.5 Layout

After visual research and organizing my assets, I began with layout. At this stage, I had an idea of how I wanted my scene to look and feel. This particular environment is 360 degrees, so I began by breaking the scene down into sections. Each section has a visual element that leads the viewer’s eyes throughout the scene. Once these pieces are placed, smaller assets are added to fill the space.

My key visual elements, or hero assets, include a fallen tree, a winding rock formation, and a hill – each about 120 degrees from each other to maintain visual interest no matter which direction the user looks. Each hero asset has a reason for being included. With an environment as vertically-driven as a forest, it is important to include elements that provide contrast – such as a fallen pine tree. The winding rock formation begins close to the viewer and ends far away from the viewer creating depth within the environment. Finally, the hill closes off the scene which helps to keep the space intimate.

(a) View of the fallen tree
4.6 Animation

Animation in the scene is subtle to encourage inner focus rather than outer distraction. Since this environment consists of inanimate objects, animation was used more as an effect than for game play mobility. All grass, plants, and branches have a subtle animation applied to simulate wind. Additionally, the night scene includes an animated firefly effect.
4.7 Lighting

The lighting in the environment is simple. There is a light that controls global illumination, a directional light that controls the sun's location, and three directional lights to light small areas beneath the trees. For the sunset scene, the position, rotation, and color of the directional lights change slightly to elongate the shadows and enhance a feeling of warmth. In the night time scene, the sunlight has changed to bright moonlight, and the clouds are replaced with a starry sky. While there is still some global illumination and directional light, the most interesting lights emanate from the fireflies which give off a soft, blinking glow. Light color also plays a big role in the night scene with deep purples from the moonlight contrasting with the warm, yellow firefly lights.

4.8 Sound

Many meditation apps feature classical music to soothe the user [22] [6]. According to a 2015 Finnish study, listening to classical music enhances activity of genes involved in dopamine secretion [23]. However, a truly immersive environment is best constructed when visual and auditory elements work seamlessly together to create a high-quality, convincing space. Therefore, I have chosen ambient sounds that one would likely find in a real-life forest environment. During the day, the user hears birds chirping and a nearby babbling brook; while at night, the birds are replaced by crickets and cicadas. The ambient music is a subtle, yet effective way to increase the user’s immersion. If at any point the user prefers a more quiet space, a mute option turns off all sound.

4.9 Effects

There are three effects that I felt were critical to the aesthetic of this environment: atmospherics to create the illusion of fog, a particle effect to replicate fireflies, and a post-processing effect for color correction to increase cohesion throughout the environment.

Atmospheric fog is often found in mountains; however, the primary reason it exists in this environment is to help scatter light and to reduce the size of the environment. By adding a light layer of fog, I was able to greatly reduce the number of assets needed to fill the visible space. This is a crucial feature when creating a low poly environment efficient enough for a mobile device. Additionally, atmospherics scatter the light to reduce contrast in over-shadowed areas.
Figure 4.7: Comparison with and without atmospherics

My personal favorite feature is the particle effect for the night scene. While simple in theory, the effect adds life and character to the environment. As the particles float around the user, they sporadically emit a soft glow to help light the environment.
Finally, the post processing effect includes subtle, but effective color correction including a minimal tint, an increase in saturation, and a boost in contrast. Together these additions add a lot of character to the environment.

### 4.10 Features

I chose to keep this mobile application as straightforward, clean, and user-friendly as possible because I want to provide a stress-free experience. For that reason, I have carefully considered and narrowed down my list of features for *Sanctuary*. The following features are controlled using the reticle. This allows the user to select from the menu using only their gaze.

First I allow the user to decide the position in which they will experience the environment – sitting or standing. Both sitting and standing height choices were made by trial and error based on what felt most natural to myself and those who tested the application. Second I allow the user to disable the ambient sounds – which are already subtle to avoid distracting the user during their time of peace. Finally I added a sunset version of the environment featuring an orange and lavender sky and a night time version which features a starry sky, a particle effect (to simulate fireflies), and a slight change in ambient sound.
Figure 4.9: Lighting scenarios for each time of day.
4.11 Gaze Tracking

The primary method through which the user interacts with the environment is gaze tracking. This is *not* the same as eye tracking. Eye tracking measures what your eye sees and does not see – as if rays were being sent from both pupils and the objects hit were recorded. This kind of technology is very new, and companies, like Tobii, are only just now implementing versions that are accessible to the public [51].

Rather than knowing the users gaze based on calculations, the gaze-based interactions in *Sanctuary* are signaled by the location of the reticle, the center point of the user’s view. Though it is less precise, it is still highly effective. More on the implementation of gaze tracking can be found in Appendix A.

4.12 User Interface (UI)

The user interface in the application is clean and user-friendly. The main menu contains three buttons that allow the user to enter the environment, read about the app and how to use it, and close the app. This portion of the user interface utilizes touch-based interactions, so the user will put on the Google Cardboard headset only after choosing to *Begin*. 

(a) Main Menu
The user interface during game play is more original. A control ring surrounds the user and contains icons that control the app’s features. Its color is light green so that it contrasts enough with the environment to be visible but not distracting. From left to right, the control ring holds icons which enable the day scene, the sunset scene, the night scene, no sound, sound, the sitting position, and the standing position. The buttons, or icons, in the scene display images rather than words so that this application is not limited by language.
Chapter 5

Results and Discussion

This chapter assesses Sanctuary’s successes and failures as a virtual-reality, immersive-environment mobile application both objectively, by participants of a user study, and subjectively, by myself. The results of these analyses follow.

5.1 User Study

Early on I knew I wanted to organize a user study on Sanctuary for a few reasons. First I wanted to see how Sanctuary could be expected to perform once it is released to the public on Apple’s App Store and Google Play. It would also give me an opportunity to ask what the users like and dislike about the app so that tweaks could be made before deployment. Finally I wanted to prove that this app had a positive effect on users.

5.1.1 Survey

The survey has three components. The first component assesses how the user is feeling before using the application. The second portion asks how they felt after using Sanctuary. Finally, the users were asked to fill out an open-ended section and a few multiple choice questions asking what they liked and did not like about the app.

The questionnaire used to evaluate the effectiveness of this application is based on Derogatis Stress Profile (DSP). DSP is a psychological survey to measure individuals’ stress dispositions and is standard in psychological studies [11]. Basically, the questionnaire is divided into eighteen adjectives
describing common human emotions. As illustrated in Table 5.1, nine of the eighteen are related to positive emotions, while the other nine are related to negative emotions. The scoring system used is known as Likert scale with a range of 0 to 5 [32]. The positive and negative emotions are randomly ordered in the questionnaire to reduce the likelihood of mindless clicks.

<table>
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<th>No</th>
<th>Positive</th>
<th>Negative</th>
</tr>
</thead>
<tbody>
<tr>
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<td>Frightened</td>
</tr>
<tr>
<td>2</td>
<td>Strong</td>
<td>Annoyed</td>
</tr>
<tr>
<td>3</td>
<td>Interested</td>
<td>Upset</td>
</tr>
<tr>
<td>4</td>
<td>Comfortable</td>
<td>Tired</td>
</tr>
<tr>
<td>5</td>
<td>Peaceful</td>
<td>Afraid</td>
</tr>
<tr>
<td>6</td>
<td>Calm</td>
<td>Shaky</td>
</tr>
<tr>
<td>7</td>
<td>Relaxed</td>
<td>Angry</td>
</tr>
<tr>
<td>8</td>
<td>Confident</td>
<td>Sad</td>
</tr>
<tr>
<td>9</td>
<td>Happy</td>
<td>Nervous</td>
</tr>
</tbody>
</table>

Table 5.1: Emotion States included in the Derogatis Stress Profile

After the users have taken the preliminary survey, experienced Sanctuary, and answered the concluding survey, we can begin processing the results. In this stage, we calculate the summation values of all positive and negative emotion scores before and after the participants have used the application. Then, the equation below will be used to calculate the mean, \( \bar{x} \), value of the changes where \( a \) refers to total Likert score value of positive or negative emotions and \( n \) refers to the number of participants.

\[
\bar{x} = \frac{1}{n} \left( \sum_{i=1}^{n} a \right)
\]
5.1.2 Results

The effects of undergoing this virtual-reality experience are shown in the next two figures.

![Figure 5.1](image1): The mean Likert score of positive emotions for participants using Sanctuary

![Figure 5.2](image2): The mean Likert score of negative emotions for participants using Sanctuary

It can be observed that mean Likert scores for almost all positive emotions are higher after the participants have used the application. Conversely, there were significant reductions to almost all of the negative emotions after the participants used Sanctuary.

Overall, using the Derogatis Stress Profile, the results indicate that using Sanctuary improves mood and decreases stress.
5.2 Discussion

Reflection on a project like this is certainly a daunting task. While there are many portions of this project that were done well, there seem to be just as many that could be improved. Nevertheless, the following sections analyze a few of the most notable strengths and weaknesses of Sanctuary.

5.2.1 Strengths

After having Sanctuary analyzed objectively and subjectively by both myself, peers, loved ones, and participants of the user study, a few particular successes within the app begin to stand out.

First the consensus seems to be that a kind of idealized environment has in fact been created. The forest environment is realistic but has a clear, aesthetic appeal. This, in part, is a reflection of the cohesion between asset variety, surfacing, layout, and lighting. The large variety of assets to choose from in conjunction with high-quality textures from Megascans helped in creating a realistic environment, while strategic layout and theatrical lighting that pushes hue and contrast made the space more visually pleasing. It should be noted that these are also the stages of pipeline for which I had the most visual reference. Who knew that thorough and exhaustive research could actually pay off?

On a similar note, the amount of asset variety was a major strength in this environment. In addition to having between 5 and 10 versions of each asset type (plant, rock, tree), I also made multiple materials with slight hue and saturation adjustments. This greatly increased the number of unique assets in each category. For example, I had 10 pine tree models – all of which varied in height and branch fullness or sparsity. Because these pine trees were really the only trees filling the forest, to increase variability, I decided to create three bark materials with varying hues and saturations. After applying these to the pine tree trunks, I was able to get 30 unique pine trees. This makes a huge difference when building a forest with a few hundred or even thousands of trees. I also applied this technique to the grass assets. There were only two grass models that varied in geometry, but with Unreal Engine’s “Color Variation” node, I was able to procedurally vary the grass material so subtly that the grass blended together without looking duplicated.

The last aesthetic success is the lighting within the environment – which is actually the last area I would ever, personally, claim as a success. To me, lighting can always be improved. The
highlights and shadows could always be pushed, while global illumination always needed tweaking. Nevertheless, most of the positive feedback I received concerned lighting. Stepping back, I can see that the lighting brought so much life to the environment and turned the scene from a flat, mess of geometry into a seamless forest oasis.

Finally, I wanted to address functionality, which was, for me, a constant source of anxiety and fear. I had experience creating environments. I knew the steps required for modeling, surfacing, layout, animation, lighting, and even most of the effects. What I did not, however, know was Blueprints –Unreal Engine’s built in node-based scripting tool. I had never used Unreal Engine, built an app, or created content for virtual-reality and there was a lot to learn. The greatest functionality component was, of course, the implementation of gaze tracking. Another concern was how to create an intuitive user interface both before and during the user’s virtual-reality experience. A thorough understanding of this technical aspect of the project required hours of watching tutorials and even more hours reading documentation, forums, and the YouTube comments from these tutorials. Needless to say, I figured it out! There are certainly components that I will continue to improve, but, overall, I am very pleased with Sanctuary’s functionality.

5.2.2 Improvements

You can always tell how much you’ve learned by length of your ‘re-do’ list. My list is long, but for the purposes of this paper, I will only address those most relevant.

My first regret is playing it safe with layout. Looking back, the environment could be more visually appealing with a interesting placement of assets on top of a more thoughtfully sculpted landscape. Specifically, I would open up the environment a bit more by adding a cliff so that more open sky is visible. In the future, I would like to experiment with layout design to create dramatic landscapes. Combining these landscapes with realistic assets would push the concept of an idealized environment to another level.

In addition to flora, I would have liked to add some subtle sightings of fauna. Even just a few butterflies or birds flying above or ladybugs crawling below would have brought the scene to life. This would require rigged models and more advanced animation, but nothing that couldn’t be done with more time.

A technical weakness of the application is the long load time during scene changes. When the user alternates the time of day, they must wait between 10 and 30 seconds – an unbearably
long amount of time during game play – before the new scene is completely loaded. With time and patience, I should be able to reduce this in the future.

Finally, one of my biggest regrets is that of not orchestrating the user study sooner. I gave myself two weeks between the user study and the final submission deadline. Had I given myself even just one more week, I could have made more changes based on the feedback given during the study. On a similar note, I could have proven that my results were statistically significant by testing a control group and performing a t-test.

5.3 Limitations

There are two key limitations by which my project was bound.

Mobile limitations required that the quality of the environment be reduced to a more manageable size. This limited the size of texture files, the complexity of models, and the computational power of the mobile application. Creating a mobile application also reduced the degrees of freedom that were possible for a virtual-reality game. While tethered headsets have six degrees of freedom and can track rotation and translation on the three x, y, and z axes, mobile headsets are bound to only three degrees of freedom – lacking the ability to track translations.

While virtual-reality has brought forth the unique opportunity of sharing experiences with those who might not otherwise have been able to experience it, we must not forget its limitations. virtual-reality lacks in the ability to replicate the senses of smell and touch. Molecules have a direct effect through the nose and skin that is not obtainable through virtual-reality. To get the greatest benefit of the outdoors, one should experience it in its entirety – by touching and smelling the leaves, sap, and flowers.
Chapter 6

Conclusions and Future Work

6.1 Conclusion

_Sanctuary_ exploits virtual reality to help ease users into a relaxing mental state through visual and auditory elements. Using industry-standard pipeline software and accessible virtual reality hardware, I have created a mobile application that is as aesthetically appealing as it is technically challenging.

Users are immersed in an environment that truly captures the ideals of both transcendentalists and the Hudson River Valley artists including spirituality, idealism, and the importance of nature. This application makes the user feel as though they are escaping to the outdoors without ever having to step outside. It also encourages users to make time for the real outdoors – to truly immerse themselves, and all of their senses, in nature.

The creation of _Sanctuary_ has truly felt more like a passion project than anything. The hopes I have for this mobile application and what it represents – a push away from overwhelming stress and towards acceptance – are boundless.

6.2 Future Work

It is my aim to continue to work on this application and others with similar concepts well into the future. In the short term, I would like to add the option to change the season in which we visit this environment. For example, the user can chose ‘winter’ and ‘nighttime,’ and the app
creates a scene with the snow-covered forest and snow falling from the moonlit, starry sky. Over
the next year, I would like to add additional environments including a seaside cliff, a garden, and
perhaps even more stylized, fantasy environments. I would also like to test these environments on
more virtual reality headsets and on an array of platforms for comparison. Eventually, by combining
my knowledge of virtual reality environments with the resources of hospitals and universities, I hope
to help those with psychological and physical diseases find a way to ease their pain and stress.
Appendices
Appendix A  Gaze Tracking Implementation

Gaze tracking and gaze-based interactions are a key feature of Sanctuary. Since this is a mobile, controller-free application, I needed a solution for allowing the user to interact with the environment in order to access various features. The best solution is a timed, gaze-based interaction between the reticle, the center point of the user’s view, and an object in the scene. In this case, the user interacts with control ring that surround them once the user has chosen to enter the environment.

![Figure 1: Control ring during game play.](image)

Gaze tracking was implemented in Blueprints which is a scripting system based on the concept of using a node-based interface to create game play elements from within Unreal Editor. As with many common scripting languages, it is used to define object-oriented classes or objects in the engine.

The following describes the Blueprint implementation of the gaze tracking method in this Unreal Engine project.

Gaze tracking begins with the creation of a Blueprint Interactive Interface. Unreal Engine describes a Blueprint Interface as, “a collection of one or more functions - name only, no implementation - that can be added to other Blueprints. Put simply, Blueprint Interfaces allow different Blueprints to share with and send data to one another. The use of Blueprint Interfaces allows for a common method of interacting with multiple disparate types of Objects that all share some specific functionality [1].” Within the interface, I have created a function called `Interact`. This function will
be used between the character object and the user interface objects later defined.

Now that the *Interact* function is defined, we must properly call it. Our Blueprint Character contains the functionality of checking the user’s gaze and deciding whether or not the gaze interacts with our UI icons.

When the user presses *Begin* from the main menu, they can insert the phone into their Google Cardboard headset. The character’s position is initialized at a sitting position, first. Simultaneously, our *Gaze Check* function is being called. *Gaze Check* begins by getting data from the Blueprint Character’s camera, or the ‘eyes’ of the viewer. We get the camera’s location and create a ray from that location to a location 4,000 units forward to ensure we hit our desired interactive object. If something breaks the ray, that is, if an interactable object gets hit, then we store that object into a variable, if not, that variable remains ‘null’ or empty. If *Gaze Check* is called and we have hit a valid interactable object, then we send a message through the Blueprint Interactive Interface to that object so that it can perform its function.

![Figure 2: Blueprints for main character.](image)

It is worth noting that for every interactable object there is a one second delay before continuing to perform its functionality. This reduces the likelihood of accidental interactions due to jerky movements.
If Gaze Check defines the interactable object as the ‘stand’ icon, then we relocate the player’s character to a predetermined height.

Figure 3: Blueprints for standing icon interaction.

If Gaze Check defines the interactable object as the ‘sit’ icon, then we relocate the player’s character to a predetermined height.

Figure 4: Blueprints for sitting icon interaction.

No matter the height of the character, the control panel’s position will remain 10 units below the character’s camera, or eyes.

Figure 5: Blueprints for control ring.
If *Gaze Check* defines the interactable object as the ‘sound off’ icon, then all sound assets in the scene will be muted.

![Figure 6: Blueprints for sound off icon interaction.](image)

If *Gaze Check* defines the interactable object as the ‘sound on’ icon, then all sound assets in the scene will be turned on.

![Figure 7: Blueprints for sound on icon interaction.](image)

If *Gaze Check* defines the interactable object as the ‘day’ icon, then we unload the current level and load the day scene level. This feature uses Unreal Engine’s ‘Precomputed Lighting Scenarios’ feature which allows a single level to store and display multiple lighting setups, giving us the flexibility of dynamic lighting, but at the fixed cost of precomputed lighting [52].

![Figure 8: Blueprints for day scene icon interaction.](image)
If *Gaze Check* defines the interactable object as the ‘sunset’ icon, then we unload the current level and load the sunset scene level.

![Figure 9: Blueprints for sunset scene icon interaction.](image)

Finally, if *Gaze Check* defines the interactable object as the ‘night’ icon, then we unload the current level and load the night scene level.

![Figure 10: Blueprints for night scene icon interaction.](image)
## Appendix B  Asset Breakdown

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<th>Asset Name</th>
<th>Variants</th>
<th>Geometry Creation</th>
<th>Texture Creation</th>
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Bibliography


