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Title: Designing and Creating a Relaxing and Immersive Nature Virtual Reality Environment with Suitable Locomotion Techniques

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Category	*Min*	*Max*	Chosen
Requirement Analysis and Design	*0*	*20*	20
Theoretical Analysis	*0*	*25*	0
Experiment Design and Execution	*0*	*20*	5
System Development and Implementation	*0*	*20*	15
Results, Findings and Conclusions	*10*	*20*	10
Aim Formulation and Background Work	*10*	*15*	10
Quality of Paper Writing and Presentation	*10*		10
Quality of Deliverables	*10*		10
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Total marks		**80**	**80**

NaturePill: Designing and Creating a Relaxing and Immersive Nature Virtual Reality Environment with Suitable Locomotion Techniques

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ABSTRACT

Interaction with nature, whether it be walking in a forest or simply sitting on a park bench, can lower stress levels and improve a person's wellbeing. However, in modern times, availability and access to "real" nature is decreasing. Accessing nature through any means (even through virtual exposure) is known as a "nature pill", and is important for our society. This paper explores design alternatives for a virtual nature pill that can be experienced at home and shows how the end result of an executable Virtual Reality environment was made using Unity. This multi-sensory environment allows the user to explore and interact with objects including a branch and benches in the scene, which was made with the intent of being as relaxing and immersive as possible. This paper focusses on how the design and implementation decisions were made regarding locomotion, sound design, and water features that would add to the relaxing experience.

KEYWORDS
Virtual Reality, Nature Pills, Virtual Nature, Technological Nature, Immersion, Interaction, Locomotion

1 Introduction

Spending time in nature has a positive impact on people's mental health and wellbeing [1], by helping reduce stress [2], improve sleep [3], and bring greater happiness and life satisfaction [4]. However, not everyone has access to nature sites, whether it be due to distance, lack of time, or lack of transportation and/or mobility. Given the benefits of nature interaction, healthcare providers in some countries have started to prescribe exposure to natural surroundings, often referred to as "nature pills".

As technology improves, we have found a shift in habits in urban environments, and with the availability of online shopping and virtual meetings with friends, the need to go outdoors decreases, which leads to increased screen time and time spent indoors. Therefore, there is a need to seek alternative ways to access the benefits of nature. One solution is a so-called a nature pill, which in the context of our study is a digitised exposure to nature. Research shows that even just looking at nature can help recover from mental fatigue [5], and from stress [6], and creating a virtual environment allows people to explore nature from the comfort of their own homes.

Feeling immersed in an environment corresponds to feeling being physically present in the non-physical world. The feeling of presence corresponds to how real the user feels the virtual environment is. We hypothesize that by incorporating exploration, interaction, and the use of multiple senses in one virtual environment, the user will feel more immersed in it. The more immersive, the closer it is to a real environment, and the more benefits of real nature can be captured. Before testing this hypothesis, a virtual environment needs to be constructed, and the design of such an environment is the focus of this project.

We created a natural forest environment to serve as a nature pill. The environment allows the user to explore a small section of a virtual forest, allowing interaction with certain elements in the scene such as a branch and benches, all while being completely immersed with the inclusion of sight, hearing, smell, and touch. To the best of our knowledge, no previous nature pill incorporates all these aspects.

The research questions that will be addressed in this paper are as follows: what is the best environmental design to incorporate touch and sound? Smell design was researched by the co-investigator of this project and is not discussed in this paper. What nature features should we add to the virtual environment in order to maximise relaxation, with respect to water elements? What is the most suitable locomotion technique for our natural environment given the challenges of a fixed element in the scene, and that we want to maximise immersion while minimising motion sickness experienced in VR (cyber sickness)? We looked at literature for motivations to support the design of our environment to answer the research questions. The suitability of our design and the created environment was confirmed through heuristic evaluation to see whether these research questions were successfully answered.

2 Background and Related Work

See appendix A for a comparison of the review papers discussed here, as well as what effects each study measured to compare real and virtual nature.

Virtual nature environments have been created in the past to test what effects virtual nature can have on an individual. McAllister et al. [7], Kjerllgren et al. [8], and Brooks et al. [9] showed that 2D screen-based exposures produced similar positive effects on an individual compared to exposure to real nature. Their studies did not place users in an immersive, nor explorative environment, which led to some participants feeling bored [8, 9]. Adding immersion and exploration could be more useful in reproducing the positive effects of nature, as a more immersive environment (by increasing screen size) has been found to generate stronger stress reducing effects [8].

VR headsets could allow users to be completely immersed in a virtual environment. Browning et al. [10], Calogiuri et al. [11], and Yu et al. [12] have done studies making use of 360-degree videos of nature, which can be experienced in VR. Browning et al. [10] found that exposure to virtual nature had effects similar to real outdoor nature exposure. Calogiuri et al. [11] compared real and virtual nature walks using 360-degree videos, but motion sickness negatively impacted their findings. Yu et al. [12] compared the influence of virtual and urban VR environments on restoration, and generated greater psychological benefits when participants were immersed in the forest environment. These three environments were not interactive, and users were only passive spectators of first-person videos.

Computer Generated Virtual Reality (CG-VR) environments create a lot of new opportunities to allow users to explore and interact with the environment, and as development tools become increasingly powerful, this allows more realistic and immersive environments to be developed. Yeo et al. [13] found that CG-VR offers a qualitatively different experience when compared to the television and 360-degree video exposure methods. Their CG-VR environment allowed users to move around in an underwater scene within the confines of the room and enabled interaction with fish and coral using provided handheld controllers. The environment was not created with the intent of relaxation, and users could not venture beyond the bounds of a single room.

Deltcho et al. [14] created a CG-VR forest environment to compare the restorative effects of nature of that forest environment to a slide show presented in VR. They found that the explorative environment promoted restorative effects, and that the artificial nature of the forest did not negate the benefits of the virtual nature walk. Their study is an excellent example of an environment that uses all four senses you would usually experience in a virtual forest. The environment was rendered in real time in high resolution with realistic lighting (sight), had nature sounds (hearing), used forest air freshener in the real room (smell), and had somatosensory feedback[1] (touch) by having users stand on a rumble pad that would shake slightly upon every step taken in the VR environment. Though all these senses were incorporated, their environment did not allow for interaction with objects in the scene, and the addition of this could lead to a more pleasant user experience.

[1] "The somatosensory system is the part of the sensory system concerned with the conscious perception of touch, pressure, pain, temperature, position, movement, and vibration, which arise from the muscles, joints, skin, and fascia." [15]

3 Design Overview

3.1 Approach and Tools

The design and the development of the environment followed an agile model with iterative development cycles of the various elements in the scene. Each aspect of design was chosen based on previous research in the field and what made sense given our research intentions. The goals of the design were to make an environment as realistic, immersive, and relaxing as possible. Some choices were open ended, with more than one option being viable, and so both alternatives are implemented, to be tested by our heuristic testers.

Design iterations started with a low fidelity prototype sketch that can be seen in figure 1, upon which feedback was given before creating an Experience Document, a document detailing the design choices for the environment. A slide show of our chosen design was then presented to the evaluators, who gave appropriate feedback, after which changes were made to the Experience Document before implementation was done. During development, feedback on design was also given and the environment was adapted accordingly.

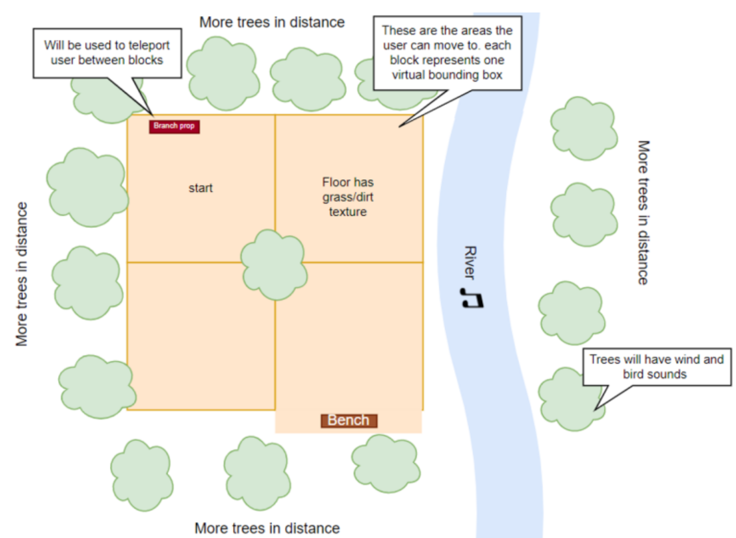

Figure 1: The first prototype sketch of the environment**.**

We had three development iterations, the first being a "first playable", allowing users to move around but with some placeholder objects still being present. The second iteration refined and implemented locomotion alternatives and replaced placeholders with their intended objects. The third and final iteration added final details to the scene and incorporated sound design.

The environment was created using the Unity Game Engine (Unity Technologies), with coding done in C#. For VR development, we opted to use OpenVR and SteamVR SDKs (Software Development Kits), which supported VR cameras and controllers, and is well documented. Each individual researcher's work was integrated from an early stage using Unity Collaborate, which was essential given that all work was done on the same environment.

Final heuristic evaluation was done on the HTC Vive Pro VR headset, using HTC Vive controllers (see figure 2), and so design and development was done with this device in mind. The environment was run on the VR-capable experiment lab computers, with a NVIDIA GeForce RTX 2080 SUPER graphics card. Optimisation of the environment is not a primary focus of this paper, but it is still important for any elements added to not be inefficient, in order to prevent reduced frame rates and increased latency, which can lead to cyber sickness [16].

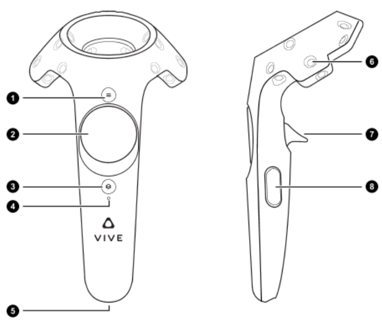

Figure 2: HTC Vive Controllers.

3.2 Environment Elements and Layout

The world created was designed to be an immersive, relaxing, realistic, forest environment. Suitable biomes were researched by the co-investigator of this project, but in summary, the choice of biome was based on familiarity [17], and what was found to be preferred in past research. The three most suitable forests were tundra [18], coniferous [18], and deciduous forests [19, 20]. A deciduous forest biome was found to be ideal for our environment given its familiarity, support for preference, and ease of obtaining models for our Unity Environment. To go along with this biome, calming water features and sounds needed to be chosen. Details on the research behind the decisions made are discussed in section 4, but figure 3 gives an overview of the final environment layout.

In addition to visual nature components, we wanted to incorporate elements of touch to increase immersion. In a real forest, you'd be able to brush your hands through plants and feel the wood of trees. Given the constraints of what we can do in a 3 by 3m real room, a branch seemed like an appropriate object that one could pick up, hold, and feel in the real world while seeing it and carrying it around the virtual forest. To motivate its usage about the scene, we added functionality that allows for its use as an aid for locomotion (more information on this in section 5.2).

A bench was also added since it could be placed in the corner of the real room, and when in a particular area of the forest, the user could align the real to the virtual bench, sit on it, and feel its texture while taking in the forest ambiance, as one would in real nature. Implementation details on alignment are discussed in section 5.3. Bench positions were chosen based off what would be visually appealing given the orientation of the bench, mostly about the river since it is one of the most detailed aspects of the scene. Chosen positions can be seen in figure 3, where the arrows represent the direction the user would face if they were sitting on the bench.

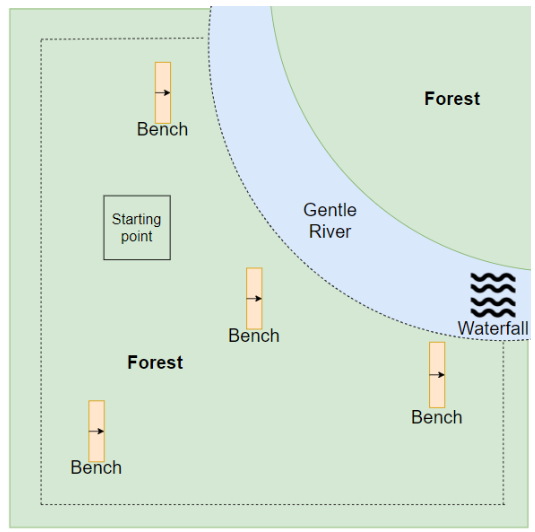

Figure 3: A top-down diagram of our environment, with labeled components. The dotted lines represent player boundaries.

4 Environmental Design

4.1 Water Features

Exposure to freshwater and "blue space" has been shown to play an important role in promoting mental health [21, 22]. Evolutionary and cultural theories suggest that this positive association with water bodies is due to the significance of water in human survival and well-being, through biological needs and/or learned experiences [23]. White et al. [24] find that blue spaces are associated with higher positive affect and perceived restorativeness. In addition, Aquatic-Green scenes were significantly better for restorativeness than green scenes alone, indicating that the interaction between water and land may be valuable. They suggest that in order for aquatic environments to be attractive and restorative, interesting light patterns and reflections of light should be used. Nasar et al. [25] find that reflective water (instead of clear, see-through) is most desirable. Herzog [26] compared different waterscapes, and found that rivers, ponds, lakes and mountain waterscapes were rated significantly better than swamps, which makes sense following the previous point, since swamps are dull in colour. Sakici et al. [27] find that wide, natural water surfaces are most relaxing, creating a sense of tranquility, more than artificial water features such as fountains.

We did not find research that compared rivers to lakes explicitly, supporting one over the other in terms of relaxation, and so the decision between a lake or river remained open. Based on the above-mentioned findings, we chose a wide, slow-flowing river, as can be seen in figure 4. Low flow and low turbidity are preferred in larger rivers [28], so slow-flowing, non-murky, reflective water is what we aimed to achieve. Han et al. [18] find that more complex environments are more preferred and restorative, which motivates the addition of rocks, branches, and grass around the riverbank.

Figure 4: A screenshot of the river.

The addition of a waterfall was another aspect of interest. There is an appeal to waterfalls, especially among tourists, as it is a popular recreational activity to visit waterfalls on vacation [29]. However, harsh water jet sounds were found not to be pleasant or relaxing [30], which we wanted to avoid. We chose to add a waterfall, to make the environment more complex and interesting, (also adding to restorativeness [18]) but place it far enough away so as not to have harsh water crashing sounds near to the user. This also benefitted our rendering speeds (since the rendering of detailed water particles would no longer be necessary and rendering artifacts are more hidden).

Figure 5: A screenshot of the waterfall.

4.2 Sound Design

Table 1 shows a summary of sounds that were added to the environment.

Audio Item	Sound Description	Use
Wind in trees	Sound of wind rustling through leaves	2D sound – heard everywhere
Birds in trees	Chirping of songbirds	2D sound – heard everywhere
Water flowing	Water sounds associated with a river	3D sound - attached to the river
Waterfall	Waterfall sounds	3D sound - attached to waterfall
Teleportation sound(s)	Standard SteamVR teleportation sounds, to give auditory feedback during each step of teleportation	Heard during entire teleportation process described in section 5.2

Table 1: Audio clips added to the environment.

Gentle wind sounds were added to match the gentle swaying of the tree leaves. Ratcliffe et al. [31] found that bird songs and calls were most associated with perceived attention restoration and stress recovery, in contrast to hooting or squawking sounds associated with owls, crows and magpies. Morning bird song sounds were thus chosen accordingly.

Soft flowing river sounds were added to match the gentle flow of the river. Caution was taken when adding waterfall sounds, since the sound of crashing water could potentially make for a less relaxing experience [30]. Player boundaries were thus carefully placed so that the user cannot approach the waterfall too closely, thereby limiting the volume of the crashing water as a consequence of Unity’s 3D sound system. As the player goes further from the placed sound source, the volume decreases (this is known as volume attenuation) and this technique is used for both the river and the waterfall sounds. The 3D effect of hearing it louder based on the direction your head is facing helps to navigate the scene and increases realism, as that is how you would hear a river and a waterfall in real nature.

5 Locomotion

5.1 The Player and Locomotion Overview

Often in video and VR games, users are assigned an avatar, which is a graphical representation of the player’s persona in the virtual world, used to increase immersion. Due to the difficulties in realism of mapping an avatar to the player, the player was not assigned a physical avatar, but instead has the SteamVR gloves in the virtual environment to correspond to the hand(s) used to hold the controller(s).

The player can walk around within bounds of the physical room (until a grid appears indicating they should stop before colliding with real world objects, see figure 6). To go further, the player will need to use a VR locomotion technique. There are various types, each with their own advantages and disadvantages, summarised in table 2.

Ease of alignment with the bench in the real world is something we need to consider when choosing a locomotion technique. There is a physical bench in the real room, but the player is only aligned virtually when the user navigates to certain points in the scene using a locomotion technique, after which they can sit on it. We do not want the bench to be following around the user as they move in the virtual environment. To align exactly to certain points in the scene requires a certain level of precision in locomotion, which most techniques cannot provide without causing nausea.

Given that we want a relaxing environment, and want to minimise cyber sickness while retaining immersion, the following two alternative methods of locomotion from table 2 were implemented. First, to advance beyond the bounds of the room, the user can use VR short-ranged teleportation using handheld controllers and the branch (optional). Because despite teleportation being non-continuous, Buttussi et al. [32] found that there were no significant differences for presence between teleportation, leaning (moving in the direction the player leans), and joystick locomotion. Second, the player will also be able to use arm swinging locomotion, which is continuous, more realistic and more immersive than teleportation. However, the user will need to use teleportation for aligning with the bench. Details on the specifics of these locomotion techniques are discussed in the sections to follow.

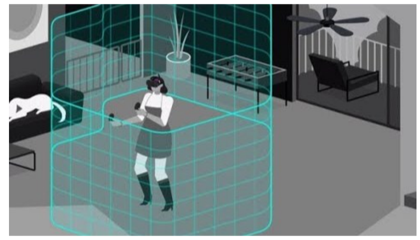

Figure 6: An Example of a room boundary grid.

5.2 Teleportation and Incorporation of the Branch

To teleport without using the branch (if it is still on the floor), the user can hold down the HTC Vive controller's top trackpad button (top of button 2 of figure 2), upon which a teleportation arc (arched beam in figure 7) will span from the controller to where the user is pointing. When the user lets go of the top trackpad button, the screen fades out of their previous (virtual) location and fades into the location they were pointing to. This represents a change in viewpoint within the scene and thus instantaneous travel to a new location.

SteamVR's teleportation system and scripts were used, with some code adjustments being made to the script. To prevent the user from teleporting onto trees or out of the boundaries of the virtual environment, Unity's NavMesh[2] was used to create a map of where the user could physically travel. In SteamVR's Teleport C# script, the teleportation position is changed from the first object the teleportation arc intersects to the nearest point on the NavMesh's walkable area. When attempting to teleport beyond the player boundaries (outlined in figure 3), the walls become slightly opaque to give visual feedback as to why they cannot go beyond that point.

Name	Description	Advantages	Disadvantages	Suitable?	Bench alignment?
Real walking	Walking freely with limited physical space	Realistic and Immersive	Requires very large room	No (limited room size)	No
Walking in place	Tracking steps through treadmill input devices or leg trackers	Immersive	Requires suitable tracking technology	No	No
Joystick	Using a controller to direct movement	Popular, easy to implement	Known to cause motion sickness compared to teleportation [32]	No	No
Teleportation	Pointing to where want to go and viewpoint jumps to that point	Popular, easy to implement. Found to cause less nausea than other techniques [32]	Non-continuous, breaking immersion momentarily.	Yes	Yes
Arm swinging	Swinging arms while remaining stationary	Immersive, can feel like walking in place	Not very popular, no libraries	Yes	No
Reorientation	Walking freely in a physical space, until the boundary of a room, where the user turns around physically but not virtually	Real walking part feels comfortable and immersive	Non-continuous, breaks immersion when reorienting, taking longer than teleportation	No	No

Table 2: Comparison summary of relevant locomotion techniques from Boletsis' literature review [33].

[2] Unity's Navigation Mesh, an abstract data structure, often used to aid non-playable characters to navigate a room.

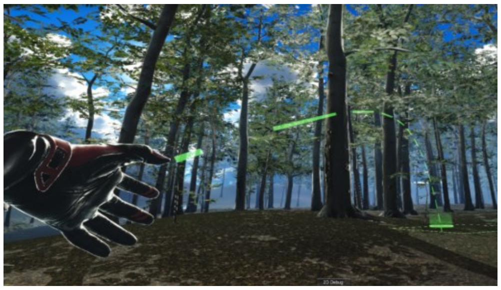

Figure 7: Example of a teleportation arc.

A branch of suitable length (so it fits in the real room) and thickness (for holding) was found in real nature, and an HTC Vive tracker was mounted on the top of the branch. A Unity GameObject[3] is associated with the tracker, and the object's position and orientation relative to the player is recorded. After adding a modelled branch to the scene, the tracker GameObject is then placed at the top of the virtual branch (as the tracker is for the real branch). This maps the branch's real motions to the ones that can be seen in the virtual environment. Figure 8 shows the tracker on the real and virtual branch, and what it looks like to the user when looking at it with a VR headset. The virtual tracker placeholder is turned off for users in order to increase immersion.

A **B** **C**

Figure 8: The real branch with the tracker (**A**), the virtual branch with (**B**) and without (**C**) a placeholder object.

Teleportation uses the branch if the tracker is more than approximately 60cm above the ground, upon which the teleportation arc spans from where the branch ends to where the user will teleport. Similar to teleportation without the branch, the arc appears when the user holds down the HTC Vive controller's top trackpad button (top of button 2 of Figure 2) with their other hand, and when they let go they will teleport to the nearest point on the NavMesh to where they are pointing. This functionality was all added by adapting SteamVR's teleportation script.

Ideally, when the user puts down the controller and picks up the branch, virtually the glove would be changed into a controller so the user can see where it has been placed so that it can be retrieved later, and see a glove attached to the branch so as not to break immersion. However, SteamVR's native hand system does not allow for interchanging gloves for controllers during runtime, and there was no way to detect where the user's real hand was placed on the branch. This meant that we were forced to choose only one virtual representation for the controllers. Virtual gloves seemed to be the most immersive overall, with movements mapping well from real hands to the virtual gloves. This means that when the user picks up the branch, the glove representing the controller they put down is still visible.

5.3 Aligning to the Bench

We need a suitable way for the user to move to the bench in the virtual space so that the position of the bench in the real-world maps to what the user sees in VR. It allows for the user to comfortably see, sit on, and feel the bench's texture while still wearing the VR headset. In order to align precisely to the bench, the user can teleport to fixed teleportation markers in the scene labelled as "Take A Seat" to prompt the user. Each of these markers are placed near a transparent bench and turns from blue to green when the arc intersects with them, as can be seen in Figure 9. Once they teleport there, the virtual bench will become opaque to indicate that the bench is ready for sitting. The position of the bench relative to the player is kept accurate using an HTC Vive tracker attached to the bench (see figure 10A), which Unity can track in the scene. When the user moves away from the bench virtually by teleporting or arm-swinging, a transparent bench is seen (instead of an opaque one) to indicate that it is no longer correctly aligned.

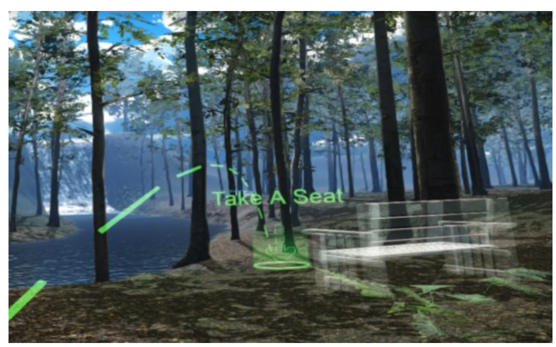

Figure 9: Locked teleportation to the transparent bench.

Figure 10A shows a player looking towards the bench in the real room while wearing a VR headset, figure 10B shows what they would see when they are aligned (the bench being in front of them as it is in the real world), and figure 10C shows what they see if it is not aligned: a transparent bench which is not aligned to the bench in the real room. Without the visual difference between an aligned and nonaligned bench, the user might think they could sit on the

[3] A Unity object used to represent and record the state and position of an object in the virtual world.

unaligned bench if they simply walked forward, and would then walk into the real bench or a wall by accident, since it is closer to them than they expect. This could potentially cause injury, which is why the entire alignment process is so important.

Figure 10: The player in the room looking towards the bench with attached tracker (**A**) and what they would see if they were (**B**) or were not (**C**) aligned with the bench in the virtual world.

Since there is a real bench in the virtual room at all times, when not aligned with the bench the room boundaries (seen in figure 6) need to be in front of it so as to prevent collisions and the potential injuries mentioned earlier. However, after teleporting to the dedicated markers (and are thus aligned with the real bench), we want two things to happen: the boundaries need to extend to be behind the bench to indicate that it is now approachable, and when sitting on the bench itself, we do not want the user to be able to see the grid as it will reduce immersion. The boundaries therefore need to be able to adapt to include or exclude the bench depending on whether or not the user's virtual position aligns with the bench in the real world. Since SteamVR's built in room boundary (or 'chaperone') system does not natively allow for changing the size or turning on and off the grid during runtime (for safety reasons), we made our own system. It uses SteamVR's functions, except that it now allows for enlarging the grid when in the vicinity of the virtual bench and turns off the grid entirely when the user is sitting on it. In script we can tell when a user is sitting on the bench by seeing how far away the Head Mounted Display is from directly above the bench. If the distance is small enough, it is likely the user is sitting on the bench and so the grid can be turned off.

Snap turning is when, upon pressing a button, the scene rotates while the user stays in place, and the user sees what they would if they rotated in the real world. Although it is often used in combination with teleportation in games, we decided to turn off this functionality entirely. Although turning it off limits user capability and freedom, snap turning is both unrealistic by itself and causes immersion issues with the bench. Snap turning near the bench, given that it is still in the same place in the real room, would require repositioning the virtual bench to keep the user aligned. This is true for both the transparent placeholder and the opaque bench, if we want the mapping between them with teleportation to be accurate and realistic. Benches moving around as if by telekinesis is neither realistic nor immersive. Turning off snap turning in the environment was the best solution to this, and users can still easily navigate the environment and turn in-person as the real room has enough space to do so.

5.4 Arm Swing Locomotion

When the user wishes to use arm swing locomotion, they can hold down both trigger buttons (button 7 of figure 2) and swing the remotes in order to move in their view direction. The user cannot hold the branch (since both trigger buttons need to be pressed on the controllers) or align with the bench, due to the lack of precision arm-swinging provides. The user needs to be at exact co-ordinates in the scene for the alignment to work how we intend it to, and one way one could do that with arm swinging is once the user is close enough, it snaps the user to the correct place. However, the sudden snapping would be very disorienting and nauseating, which we want to avoid, and so users can only align using teleportation which is much more precise with the teleportation markers.

The arm-swinging system was implemented from scratch in C# by tracking Unity GameObject positions. An empty GameObject was added to the player's camera rig to track which way the user is facing, and the user is moved in the forward direction when arm swinging.

Implementing a reliable and intuitive boundary system to prevent users from arm swinging into the river or onto steep hills was an important consideration. The system implemented works as follows: when the user approaches one of the five boundary GameObjects in the scene, it will go from invisible to slightly transparent to indicate that there is a wall blocking movement. Nielsen's feedback and visibility of system status heuristic [34] motivates the use of a wall to give visual feedback. When the user is up close to it and should stop walking, the wall becomes more opaque and the user can no longer move closer towards the wall. This is achieved by looking up how far away the user is from the NavMesh when they approach the wall. The NavMesh does not extend beyond the player boundaries seen in figure 3.

Nielsen's consistency heuristic [34] states that it should be clear to users whether or not events mean the same thing. Following this logic, the wall was chosen to be a semi-transparent white so as to not be confused with the regular physical room boundary system, also known as the "chaperone", which was chosen to be a semi-transparent blue grid.

6 Results and Discussion

6.1 Evaluation Methodology

To evaluate the success of the virtual environment created, we had three experts perform heuristic evaluation and give feedback on our environment. Heuristic evaluation [35] is a way of finding usability issues in a designed user interface, by having 3-5 evaluators give feedback linking to a set of usability heuristics. It is best to find specialists in the field [36], so we chose our heuristic evaluators accordingly.

Evaluators were each asked to dictate problems they experienced during their testing of the virtual environment. For each problem identified, they were to determine the heuristic best relating to the identified problem and give a severity rating ranging from 0 (no issue) to 4 (extremely urgent to fix). Any additional comments were welcomed. The form given to the evaluators, with a list of 12 heuristics from Sutcliffe et al. [37] and their associated descriptions, can be seen in appendix B.

In addition to identifying problems, the same set of questions were asked to each evaluator. They aimed to see which alternative implemented was preferable, as well as ask a few open-ended environment-related questions. This is not a validated questionnaire as this evaluation was set to be more qualitative than quantitate, with no intention of doing statistical analysis on the results. The questions asked and answers received are recorded in appendix C.

6.2 Results from Heuristic Evaluation and Questions

To determine severe issues that would require fixing, Table 3 shows the usability issues detected with a severity rating of 3 or above (with 4 being the highest severity). Only issues relevant to this paper's research interests are recorded here.

Problem	Heuristic	Frequency
Initial rumble of controllers during tutorial is distracting	Realistic feedback	1
No representation of hand attached to the branch	Natural engagement	1
Teleporting with the branch requires two hands (one on controller and one on branch)	Support for learning	3
Missing visual markers to orient oneself when not by the river	Navigation and orientation support	2
Hitting the bench marker is too difficult, and sometimes confusing on whether successful	Realistic feedback	2
The virtual benches are floating above the ground	Compatibility with the user's task and domain	2
Bird sounds are repetitive	Natural engagement	2

Table 3: Issues detected with a severity rating of 3 or above.

Fixes were made in order of severity and what was viable given the amount of time we had left. Although navigation was mostly intuitive according to the evaluators, there was a sense of loss in direction due to the lack of a distinct central object, and this has since been addressed with the placement of two large dead trees surrounded by tree stumps. Turning off SteamVR's in game teleport tutorial (causing the rumble) was also easily fixed. Less severe but easily fixed issues that were mentioned during evaluation were also comfortably addressed in the time we had left, such as making only nearby walls become visible when trying to cross boundaries, and increasing the audio volume of the wind.

Bench-related issues were important, so the bench model was given longer legs so they were touching the ground and no longer floating, and non-aligned benches were made more transparent than before to be clearer when not aligned. Unfortunately, SteamVR's teleport points were not adjustable to make it easier to align through teleportation, so an entirely new system would have to be made for this, which we had no time for. This is left for future work.

The issues with hand representations while holding the branch have already been discussed in Section 5.2, and we were not able to change this in the given time. The branch's model was adjusted by the co-investigator of the project to include more details (such as the knobs) of the real branch. A suggested fix to the awkwardness of needing to use a controller while using the branch is to mount a button to the branch to be used to initiate teleporting, but this is out of scope for this project and left for future research as well.

Based on the responses to the open-ended questions, the inclusion of some sort of button mechanism on the branch would make teleporting with it much better, since holding the controller would then no longer be longer necessary. Arm swinging was preferred but sometimes caused nausea, so having the alternative to teleport was suitable. It does suggest that if there were an intuitive, non-nauseating way to align to the bench through arm swinging, this might have made the environment more relaxing.

The evaluators felt present, and most things breaking immersion were addressed, but not all issues due to time constraints. Overall, it seems the environment definitely has the potential to be used in a relaxing manner, as intended by a nature pill.

6.2 Discussion

Overall, the evaluators were satisfied with sound design and felt that it contributed well to making the environment more relaxing. The bench and the branch turned out to be a good way to incorporate touch, with one bench being the highlight for our first evaluator, and the branch being nice to use due to its weight and texture.

Water features were thoroughly researched before adding them, with a slow flowing river and a waterfall feature being included in our final environment. Users were unable to approach the waterfall too closely to prevent jarring sounds.

Which of the two locomotion techniques implemented is the best remains debatable, since arm swinging was found to be immersive, but teleporting was less prone to cyber sickness and was the only solution we found suitable to the bench alignment issues.

Finding a way to align the user to the bench using arm-swinging would be interesting to investigate for future research. A suggestion would be to use a combination of the currently implemented arm-swinging system and redirected walking [38, 39]. Redirected walking is a locomotion technique that allows users to explore large virtual environments when real walking in a smaller real room. It uses so-called redirection techniques to add small mismatches between virtual and real-world movements to manipulate the user's real-world path so that they do not collide with anything in the real room. Designing, creating, and testing a system like this to align with real world objects could be an interesting future investigation.

7 Conclusions

This project's aim was to design and create a relaxing, explorative virtual nature pill that was both interactive and immersive through the use of multiple senses. Though our three expert evaluators had some positive feedback, proper user testing would need to be done to see how effective the environment is at its intentions. This environment is a good starting point, but some changes to the intuitiveness of aligning to the real-world bench, and being able to use the branch's teleportation feature without the need of a second controller, would need to be looked into prior to additional testing.

We implemented good locomotion mechanics for navigating the scene given the problems that come with real props in the room while wearing a VR headset. We answered the research questions by looking at literature and through design iterations. Touch was best incorporated with a bench and a branch, and relevant nature and feedback sounds worked well in the environment. A wide, reflective, slow flowing river with a distant waterfall were found to be an ideal balance of restorative and interesting. Both locomotion techniques implemented had their advantages and disadvantages, with arm-swinging being the most immersive and teleportation being less nauseating and good for alignment with real-world objects.

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Appendix A: Comparison of previous work

Author and reference	Main research goal	How did they measure their success?	Summary of most important findings	Number of participants	Type of virtual environment (360-degree video, etc)	Could users look in direction of choice?	Could users move in direction of choice?	If in VR, was cyber sickness addressed?	Senses used in virtual environment (taste not applicable)			
									Sight	Hearing	Touch	Smell
McAllister et al. [7]	Finding the effects of virtual contact with nature on positive and negative effect.	Perceived restorativeness Perceived positive and negative affect	Nature videos had better positive affects, less negative affects, and better perceived restorativeness compared to the non-nature control video.	220	2D video presentations on a screen	No	No	N/A	Y	Y	N	N
Kjerllgren et al. [8]	Comparing restorative effects of relaxation in natural environment and a simulation (slide show) of the same environment.	Physiological measures (pulse and the systolic and diastolic blood pressure), self-reported psychological measures (e.g. a scale for measuring stress levels) , and qualitative reports	Real nature resulted in higher degrees of altered states of consciousness and energy than simulated nature, but both were equally efficient in reducing stress.	18 (all suffering from stress and/or burnout syndrome)	2D images on a Slideshow	No	No	N/A	Y	N	N	N
Brooks et al. [9]	Comparing the effects of nature and the built environment (in winter and warmer seasons) through contact with real nature and pictures of nature, tested through 3 studies.	Self reported standardised measurements.	Seasons did not influence nature contact effects on mood. Only actual nature increased positive affect, but negative affect and happiness were improved (to a lesser degree) by nature photographs.	120 (study 1) 116 (study 2) 47 (study 3)	2D images on a Slideshow	No	No	N/A	Y	N	N	N
De Kort et al. [6]	Does a more immersive environment have stronger restorative and stress reductive effects?	Physiological (skin conductance level and heart period) and self-reported affect	A more immersive projection (through increasing screen size) has a higher restorative potential.	80	2D video presentation on a screen	No	No	N/A	Y	Y	N	N
Browning et al. [10]	Comparing simulated nature experiences with real outdoor interaction.	Skin conductivity, and self-reported restorative and mood	6 minutes of virtual (VR) nature exposure produced similar effects as real outdoor nature exposure of the same length, both being superior to no exposure to nature.	65	360-degree video	Yes	No	Cybersickness and its potential effects on results were not addressed nor examined.	Y	Y	N	N
Calogiuri et al. [11]	Comparing simulated nature walk (while sitting or walking on a treadmill) with a real outdoor nature walk.	Environmental perceptions (presence and restorativeness), physical engagement (treadmill and real-life walking speed, heart rate, perceived exertion), perceived affective responses (enjoyment and affect) and qualitative information	The psychophysiological responses of the real nature walk were not reproducible in the virtual environment.	26	360-degree video	Yes	No	Poor image quality, and the conflict between the individual and the video's pace lead to many participants feeling cyber sick, negatively impacting results.	Y	Y	N	N
Yu et al. [12]	Comparing the influence of forest and urban VR environments on restoration.	Physiological (blood pressure, heart rate, and salivary tests) and self-reported psychological responses.	Greater psychological benefits were found when participants were immersed in the forest environment.	30	360-degree video	Yes	No	To address cybersickness, participants were free to sit or stand while immersed, and were told they could drop out at any time of discomfort. Very few participants reported dizziness, but the influences of the minor dizziness is unknown.	Y	Y	N	N
Yeo et al. [13]	Comparing the effects of three increasingly immersive forms of virtual nature: Television, 360-degree videos, and interactive Computer-Generated Virtual Reality (CG-VR).	Self-reported experienced presence, boredom, mood, and nature connectedness	VR had greater presence over TV, with CG-VR producing the best results.	96	2D video presentations on a screen, 360-degree video, Interactive CG-VR environment (the last will be used in the next comparison fields)	Yes	Yes, within the confines of the room	Cybersickness and its potential effects on results were not addressed nor examined.	Y	Y	N	N
Deltcho et al. [14]	Comparing the restorative effects of virtual nature of a slide show in VR and an explorative VR forest.	Self reported restorative effects, skin conductivity, and heart rate. Two short mental arithmetic quizzes.	Computer generated nature in VR can promote restorative effects. Artificial nature of the forest did not negate the benefits of walking in a virtual forest.	22	Slideshow viewed in VR, and an explorative CG-VR environment (the last will be used in the next comparison fields)	Yes	Yes, within 1600m bounds	Cybersickness and its potential effects on results were not addressed nor examined.	Y	Y	Y	Y

Appendix B
Heuristic Evaluation Form
NaturePill

Instructions: Please dictate problems experienced during the testing of our virtual nature environment. For each problem, please select a heuristic from Sutcliffe et al. [37] best relating to the identified problem, as well as a severity rating from the columns below. Any additional comments relating to the problems identified or the environment as a whole, are welcome. Then please answer the open-ended questions in as much detail as possible.

Heuristics:

1. Natural engagement.
Interaction should approach the user's expectation of interaction in the real world as far as possible. Ideally, the user should be unaware that the reality is virtual. Interpreting this heuristic will depend on the naturalness requirement and the user's sense of presence and engagement.

2. Compatibility with the user's task and domain.
The VE and behaviour of objects should correspond as closely as possible to the user's expectation of real world objects; their behaviour; and affordances for task action.

3. Natural expression of action.
The representation of the self/presence in the VE should allow the user to act and explore in a natural manner and not restrict normal physical actions. This design quality may be limited by the available devices. If haptic feedback is absent, natural expression inevitably suffers.

4. Close coordination of action and representation.
The representation of the self/presence and behaviour manifest in the VE should be faithful to the user's actions. Response time between user movement and update of the VE display should be less than 200 ms to avoid motion sickness problems.

5. Realistic feedback.
The effect of the user's actions on virtual world objects should be immediately visible and conform to the laws of physics and the user's perceptual expectations.

6. Faithful viewpoints.
The visual representation of the virtual world should map to the user's normal perception, and the viewpoint change by head movement should be rendered without delay.

7. Navigation and orientation support.
The users should always be able to find where they are in the VE and return to known, preset positions. Unnatural actions such as fly-through surfaces may help but these have to be judged in a trade-off with naturalness (see heuristics 1 and 2).

8. Clear entry and exit points.
The means of entering and exiting from a virtual world should be clearly communicated.

9. Consistent departures.
When design compromises are used they should be consistent and clearly marked, e.g. cross-modal substitution and power actions for navigation.

10. Support for learning.
Active objects should be cued and if necessary explain themselves to promote learning of VEs.

11. Clear turn-taking.
Where system initiative is used it should be clearly signalled and conventions established for turn-taking.

12. Sense of presence.
The user's perception of engagement and being in a 'real' world should be as natural as possible

13. Additional heuristic (Please specify)

Severity Ratings:

1. No usability issue
2. Slight usability issue, should only be fixed once other problems have been solved and there is time available
3. Minor usability issue, fix with low priority
4. Major usability issue, important to fix with higher priority
5. Extreme usability issue that needs to be fixed immediately

Problem	**Heuristic**	**Severity**	**Comments**

Appendix C: VR-Environment Specific Questions, and answers given by the three evaluators

Was navigating the scene intuitive?
1. Yes, but there should be a central distinctive object to help orient myself in the scene.
2. Yes, though I wish there were an easier way to turn about the scene (possibly snap turning).
3. Yes, though I wish there were more natural boundaries and possibly a central object to help orient about the environment.

Did you prefer teleporting with or without the branch, and why?
1. Although needing to use both hands was a bit clunky, I enjoyed the feeling of the texture of the branch, so with.
2. With the branch due to the heft of the branch, its realistic mapping, and the longer movement arm made for easier aiming.
3. Without, since I did not find the use of two hands natural.

Did you prefer arm-swinging or teleporting, and why?
1. In other games, I generally prefer teleporting, but I enjoyed the arm-swinging more once I got used to a skiing motion. So I preferred arm swinging since it was more realistic and relaxing.
2. Teleportation, since arm-swinging can make me nauseous in any game.
3. Arm swinging since it felt very natural and matched well with the environment.

Did you experience any cyber sickness (discomfort, nausea, dizziness, etc.)? If so, how severe was it, and what do you believe caused it?
1. Although I am susceptible to cyber sickness, I did not experience any.
2. Yes, I felt quite nauseous trying arm swinging, so I stuck with teleportation. The rest of the environment did not make me nauseous.
3. A little bit of dizziness from arm-swinging, but not at all severe.

What was your favourite part of the environment?
1. The bench placed around the middle of the environment. Very well placed, it was peaceful.
2. I loved the ground textures, they mapped well to what I would expect in such a forest.
3. The river and the hills around it.

Did you feel present? Was there anything you felt broke immersion?
1. I did feel present, but there were some small details I mentioned in the heuristic section which occasionally broke immersion.
2. Yes, I felt present, I wanted to examine things just as I would in real life. But the clouds, minor water (speed) inconsistencies and repetitive bird sounds sometimes broke immersion.
3. Yes very present, though the popping of objects, ability to walk through trees, and bench alignment struggles did sometimes break immersion.

Do you feel relaxed?
1. I can see how it could be, though I was focusing on giving feedback this time I think I would be if doing this in my own time.
2. I was focusing too much on evaluation, but I believe it (the environment) would do a good job at doing so if I were not focusing on giving feedback.
3. Yes, fairly relaxed.