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Threshold space design: using water element for phase transition from physical space to virtual space with different law of gravity

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This study focuses on exploring the transition stage between physical and virtual space by considering the difference in law of gravity between physical and virtual environments. The concept of Threshold Space design is a series of transition stages which can be utilized to enhance the virtual reality (VR) experience. Unlike most VR researches, which primarily focuses on head-mounted displays (HMD), this study examines the user's perception between physical space and virtual space. The Threshold Space design method allows users to experience the upcoming stage in advance. More than a simple intermediate space, it addresses confusion and disorientation in VR that can occur due to two phenomena: conflict between brain recognition and visual perception; visual-vestibular mismatch. The Threshold Space is particularly applied at the transition stage to improve the VR experience by allowing users to adapt to gravity changes that directly affect bodily sensations. As a result of analyzing existing VR transition models, the framework model was designed to utilize Threshold Space to combine two transitions into one to allow users to phase smooth transition. A critical space transition model using water as a connecting medium was designed to provide the experience of gravity change between physical and virtual space based on the established framework model. This design, consisting of five stages, uses the Threshold Space stage model to promote a smooth and immersive transition for users.

Keywords: threshold space; virtual reality; transition; user experience

1 Introduction

In VR applications, users often encounter unfamiliarity in virtual spaces composed of physical laws that differ from their own physical environment. Kim, Kwon, and Jung (2023) classified and explained the physical laws that vary in virtual spaces into five categories. Gravity, for example, greatly influences users' movements and motions.

Figure 1. left) Echo Arena, middle) Goliath: Playing with Reality, right) Shores of Loci. 1.[1]

The Echo Arena (left) in Figure 1 simulates a weightless state, requiring users to adjust their movements while manipulating a disc in a frictionless environment. Goliath: Playing with Reality (middle) is a VR animation experience featuring altered gravity that shifts from low gravity to anti-gravity, presenting a space where walls and ceilings are indistinguishable. Shores of Loci (right) is a VR experience where users navigate through an ever-changing landscape, exploring and interacting with the environment. These virtual spaces manipulate gravity to provide immersive environments not experienced in physical space. However, users can lose their sense of direction when confronted with virtual spaces that have different gravitational laws, leading to a loss of control over tools and space. This disorientation can cause feelings of embarrassment (Gross & Stone, 1964) and is attributed to the discrepancy between users' visual perception and inputs from the vestibular system (LaViola, 2000).

In VR, users access virtual spaces instantly upon donning an HMD, resulting in a heightened visual-vestibular mismatch when entering spaces with physical laws that greatly differ from reality. Accessing spaces with physical laws dissimilar to reality can cause accessibility issues from the perspective of users who rely on past experiences for recognition (Merleau-Ponty, 1962). According to this theory, VR content often defies physical laws, creating new ones in a boundless space without physical limitations. Consequently, users experience a conflict between their visual perception and physical presence in the real world, which can leave a negative impression on their virtual experiences.

Dee (2001) and Boettger (2007) proposed the concept of Threshold Space as a means to provide an optimal experience for users by reducing the gap between physical and virtual spaces. This concept involves transitional spaces that enable connections, transformations, and meaningful experiences in a blended environment (Dee, 2001; Boettger, 2007). A threshold, distinct from a boundary, refers to a transitional stage that exists between spaces and represents a pathway or portal (Benjamin, 1927). Implementing Threshold Space can help mitigate the negative effects of heterogeneous VR experiences, ultimately enhancing user comfort and immersion.

This study analyses the role of Threshold Space in consideration of differences in physical laws, such as gravity, to reduce users' embarrassment and disorientation during the transition between physical and virtual spaces. The collision between brain recognition and visual perception and the visual-vestibular mismatch phenomenon are examined. Based on these theoretical considerations, limitations of existing VR transition models are identified, a Threshold Space framework model is created, and a new model that applies it is proposed. A new model, connecting physical and virtual space, implemented water element as a medium, and the potential for Threshold Space to provide

[1] Source: Meta Oculus.com

users with engaging and immersive experiences was confirmed. Based on these findings, future research directions and improvement plans are presented, including considerations for various media, physical laws, user experience testing and evaluation, and adaptation to various applications.

2 Threshold Space in VR

The dictionary definition of 'threshold' denotes the beginning of a new event or development, transcending the boundaries of physical space to include psychological, emotional, social, and economic realms. Dovey & Wood (2015) underscore the importance of understanding public/private urban interfaces and the potential of thresholds as places of becoming and transformation. These thresholds create functional and meaningful experiences, considering the different needs of various users. Holl, Pallasmaa, & Pérez-Gómez (2006) further discuss the significance of addressing thresholds from multiple design perspectives, encompassing social, cultural, and environmental factors, to create inclusive spaces within the phenomenology of architecture. As such, the importance of the threshold as an intermediary has been elucidated by numerous researchers and has expanded in the field of architecture into the concept of Threshold Space.

2.1 Threshold Space in architecture

In architecture, several theorists have provided definitions of Threshold Space. Benjamin (1927) differentiates the threshold as a zone containing transformation, passage, and wave action, distinct from a boundary. Teyssot (2008) suggests that a window serves as a paradigmatic example of a threshold between interior and exterior spaces. Hernes (2004) categorizes the threshold as one of the three categories of boundaries—ordering, distinction, and threshold—that regulate space. Boettger (2010) defines Threshold Space as a critical space that allows movement and transition by providing spatial volume and bodily presence. Lastly, Dee (2001) describes Threshold Space as an area that connects spaces, mediums, or objects, offering unified, subtle, and complex transitions.

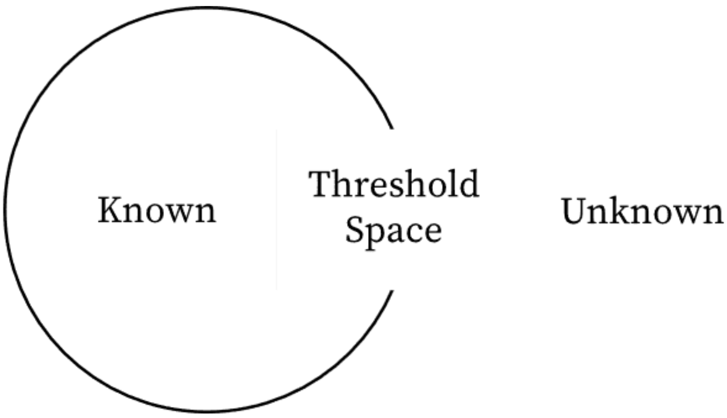


Figure 2 Definition of Threshold Space - bridging Known and Unknown Spaces

These definitions underscore the significance of Threshold Space that connects different environments, acting as intermediate area to facilitate movement and transition. In architecture, Threshold Space is understood as a dynamic intermediate area that merges the worlds of the outside and the inside. This space creates a zone without functional and formal boundaries, preparing the user for a transition to another unpredictable space from their current location, as illustrated in Figure 2.

2.2 Threshold Space between physical space and virtual space

Based on the literature review above, the reasons for selecting Threshold Space as a method for designing the transition phase are as follows:

1. The concept of threshold implies spatial ambivalence, making it an interesting medium for studying relationships and the spatial experience of the intermediate space it provides.
2. Threshold defines separateness and suggests connectedness. Being in the Threshold Space allows individuals to have various perspectives on states of separation and those connected by the Threshold Space.
3. As the boundary between physical space and virtual space gradually blurs, Threshold Space takes on a new meaning. Experiences within Threshold Space traverse through the blurry boundary.

In this paper, Threshold Space refers to the space that is reflected when transitioning between physical and virtual spaces, playing a role in facilitating the user's experience in interactive virtual spaces and enhancing the sense of immersion. Therefore, a transition stage is designed using the concept of Threshold Space, considering the response of the vestibular system when moving into a space with different physical laws. This approach can create a smooth transition between physical and virtual spaces, providing users with a comfortable and comprehensive experience.

3 Embarrassment and disorientation in VR

3.1 Discrepancies in perceived and expected verticals in VR

As proposed by Merleau-Ponty (1962), the human body and psychological phenomena are not separate domains but are two layers of 'existence' that continuously interact. When immersed in a virtual environment using a HMD, users experience perceptual inconsistencies due to the difference between their physical space and the virtual space they perceive through visual information. Two primary phenomena contribute to this confusion: Brain Recognition and Visual Perception, and Visual-Vestibular Mismatch (Table 1).

Table 1 Comparison of Phenomena: Conflict between Brain Recognition and Visual Perception vs. Visual-Vestibular Mismatch, including Definitions, Causes, and Solutions.

Phenomena	Conflict between Brain Recognition and Visual Perception	Visual-Vestibular Mismatch
Definition	A phenomenon where information from different senses (e.g. sight and hearing) conflicts with each other, causing a discrepancy in perception.	A phenomenon where the visual information received by the eyes does not match with the vestibular information received by the inner ear, causing disorientation, dizziness, and motion sickness.
Cause	Inconsistency or contradiction between the information received by different senses.	Inconsistency or contradiction between the visual information and the vestibular information.
Solution	Designing virtual spaces that take into account the consistency between the information received by different senses.	Designing virtual spaces that minimize the differences between the visual and vestibular information, such as providing appropriate biomechanical feedback, using consistent

visual references, and avoiding sudden movements or changes.

When users move to a virtual space with physical laws that they cannot experience in reality, the sudden change in their surroundings can cause them to lose their sense of direction, leading to confusion. As seen in Table 1, there are two phenomena behind this: the first is the conflict between brain recognition and visual perception, and the second is the visual-vestibular mismatch.

Stein et al. (2010) suggest that providing consistent information between different senses can help reduce perceptual conflicts for the conflict between brain recognition and visual perception. They found that providing audio signals that match visual signals in a virtual environment can improve users' spatial perception and reduce confusion. Regarding the solution for visual-vestibular mismatch, Keshavarz and Hecht (2012) found that providing appropriate biomechanical feedback, such as using motion platforms or tactile devices, can help reduce discrepancies between visual and vestibular information in virtual environments. They also discovered that using consistent visual references, such as a fixed horizon line, can help reduce motion sickness in virtual environments.

In designing an effective Threshold Space, it is crucial to consider both brain recognition, visual perception, and visual-vestibular mismatch to mitigate confusion and disorientation in VR experiences.

3.2 The impact of gravity on user experience in VR

In virtual environments, users encounter deviations from physical reality due to factors such as gravity, time, scale, environmental factors, and modelling (Kim, L. et al., 2023). These factors influence the conflict between brain recognition and visual perception, leading to discrepancies and visual-vestibular mismatches. To better understand these effects, we have conducted an analysis of the impact level, reasons, and related references for each of these factors in the context of virtual environments.

Table 2. Reasons for the influence of deviations from physical laws in virtual environment.

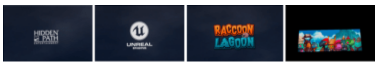
Category	Level of Impact	Reason
Gravity	High	Affects vestibular system, proprioception, motion perception, and interaction Disorientation and motion sickness due to deviations from expected gravity
Time	Low	Differences in time perception or time manipulation are less disruptive to the user experience Limited effect on vestibular system and proprioception
Environment	Low	Users can adapt to changes in environmental factors (e.g., lighting, weather) Reduced effect on the vestibular system and proprioception
Scale	Medium	Changes in scale may cause mild disorientation but affect less on the vestibular system Users can adapt to different scales with relative ease
Modelling (Shape&Object)	Medium	3D modelling can improve the user's understanding of the virtual environment

Table 2 confirms that gravity has the most significant influence on user experience, affecting the vestibular system, proprioception, motion perception, and interaction (Laviola et al., 2017). Deviations from expected gravity levels can lead to disorientation and motion sickness. In contrast, time has minimal impact on the user experience and limited effects on the vestibular system and proprioception (Cummings & Bailenson, 2016). Users can adapt to changes in environmental factors such as lighting and weather, with minimal impact on the vestibular system and proprioception (Riecke et al., 2006; Larsson et al., 2004). Scale changes have moderate effects, causing mild disorientation, but do not significantly affect the vestibular system, as users can adapt to different scales relatively easily (Azarby et al., 2023). The modelling category also represents a moderate impact. As unique modelling forms, that cannot be reproduced in the real world, it can create new experiences and challenges for users who must adapt to new forms and interactions. Therefore, understanding the effect of gravity among the types of virtual spaces with different physical laws is of paramount importance for optimizing the user experience in virtual environments.

3.3 Analyzing gravity changes and transition design in VR experiences

One of the crucial aspects that contribute to the VR experiences is the variance in gravity. These changes can manifest in different forms, such as 'zero gravity', 'low gravity', and 'partial gravity'. 'Zero gravity' represents situations where users can move freely in a weightless condition. Although it allows users to navigate without physical constraints in the VR environment, it may also induce confusion and motion sickness. 'Low gravity' conditions portray weaker gravitational forces than those on Earth. These scenarios can provide experiences such as higher jumps or slower falls to the users. Lastly, 'partial gravity' indicates situations where users can move in space without a force pulling them in a constant direction. It offers more free movement, but it might impair spatial orientation and immersion. Understanding the impact of each type of gravity on VR experiences and reflecting this understanding in the transition design is critical. This approach can minimize user confusion and motion sickness while providing a realistic 3D spatial experience.

Table 3. Examples of VR applications utilizing 2D medium UI design for transition scenes.

Name of App	Image of Virtual Space	Type of gravity	Transition scene	Design Device
Echo Arena		Zero-gravity		Text Fade in/out
Goliath: Playing with Reality		Low-gravity → Anti-gravity		Text Push Button(physical movement)
Raccoon Lagoon		Low-gravity		Text Fade in/out
Lone Echo 2		Zero-gravity		Text, Simple Animation, Fade in/out
Star Shelter		Zero-gravity		Fade out, Animation, Press trigger mission (physical movement)

VR apps with gravity changes, which significantly impact on disorientation and motion sickness, were chosen, and their transition designs were analyzed as presented in Table 3. Due to the longer loading times required by many VR apps compared to 2D medium, multiple image cuts are displayed in sequence rather than as a single scene during the transition stage. In Table 3, several apps implement transition designs such as Text, Simple Animation and Fade in/out.

However, VR is a first-person 3D medium demanding a strong sense of immersion and realism for users to experience space rather than simple images. Therefore, unlike 2D interfaces, VR should be designed to provide users with a new spatial experience within a 3D environment. This necessitates a new approach, considering spatial variables to enable users to intuitively understand space.

Table 4 examples of virtual reality applications incorporating spatial variables in transition design.

Name of App	Image of Virtual Space	Type of gravity	Transition scene	Design Device
Shores of Loci		Zero-gravity		Changes in time, sea level, and gravity
Freediver: Triton Down		Gravity > Buoyancy		User's line of sight changes (from above water to below water surface)

Certain apps showcase an approach that takes spatial variables into account. For example, Shores of Loci and Freediver: Triton Down, as illustrated in Table 4, employ effective transition designs. Shores of Loci demonstrates spatial connectivity in transitions regarding time, sea level, and gravity. Instead of listing cuts, the physical and virtual spaces are connected through changes in environmental light color. The weightless state of the virtual space is depicted in advance during the transition stage, allowing users to anticipate the experience. Freediver: Triton Down also focuses on spatial aspects, emphasizing the transition to a virtual space that starts at sea. During the transition stage, an animation is displayed as if the user's gaze dives from above the water's surface to below it. These two cases serve as exemplary instances of VR transition design, exhibiting spatial connectivity and visual coherence. However, there is still face limitations in establishing a connection between the physical space before users don the HMD and the subsequent virtual space.

4 5-phasing threshold space transition model

In the context of this study, the design of a Threshold Space aims to serve as a device that bridges perception at the turning point of different physical laws in each virtual environment. By focusing on virtual spaces with varying gravity, as classified by Kim, L. et al. (2023), and excluding other categories of physical laws, a comprehensive step model for the overall Threshold Space transition can be established. This approach enables the maintenance of consistency across various VR experiences, leading to a smoother user experience. To achieve this, the current VR Transition Model has been analyzed, and the Threshold Space Transition Model is redefined accordingly. Particular attention was devoted to analyzing the transition of Oculus Quest 2, considering its considerable influence in the VR landscape with a dominant market share of 66% as of October 2022, and its Oculus app was reported to engage an estimated 2.41 million daily active users, thus presenting it as a representative model for this study (Karn et al., 2023).

4.1 Current VR transition model

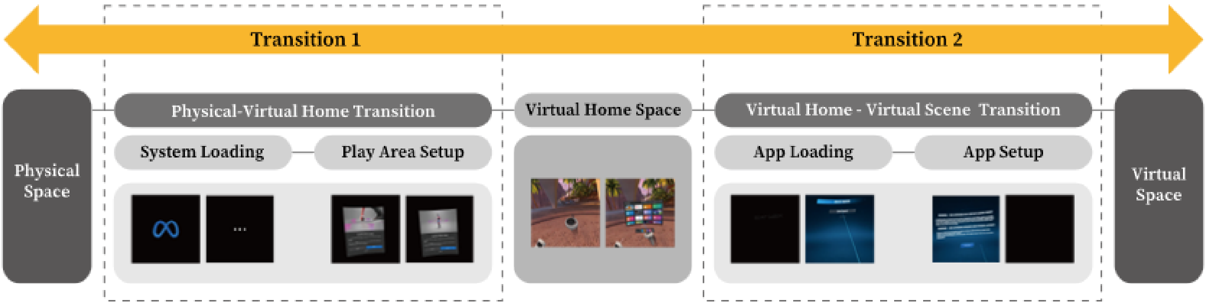


Figure 3 Current Meta Quest transition model from physical space to virtual space

Currently, the VR transition model has two transition sections, as shown in Figure 3. The first transition assigns a floor to the user's location, sets a specific area or applies a room size, guides first-time users through tutorials and social media accounts. This initial transition culminates in the virtual home space, a space that bridges the physical and virtual realms. The second transition begins when the user selects an application with the various scenes listed to enter the virtual space. Each app has its own toggle, often featuring a company logo and app name.

However, breaking the transition into two separate sections has some drawbacks. First, splitting the process into two parts can hinder user immersion as they have to navigate through multiple steps to access the desired virtual space (Cummings & Bailenson, 2016). Split transitions can potentially confuse or frustrate users, disrupting the overall experience.

In conclusion, the two-tier structure of the current VR conversion model has inherent limitations that can hinder the user experience.

4.2 Threshold space framework model

To address the problem of the two-tiered structure of the current VR transition model and improve the user experience, we propose a Threshold Space framework model. This model combines the two transition sections into one cohesive single process by dividing them into five gradual steps. By streamlining the transition model, users can be kept engaged, and physical and virtual spaces can be connected more seamlessly.

Figure 4 illustrates the phasing of the user experience scenario for the Threshold Space. The framework model consists of a total of 5 steps, and our aim is to create a gradual transition model with three stages of immersion experience, such as initial immersion, post-immersion, and full immersion.

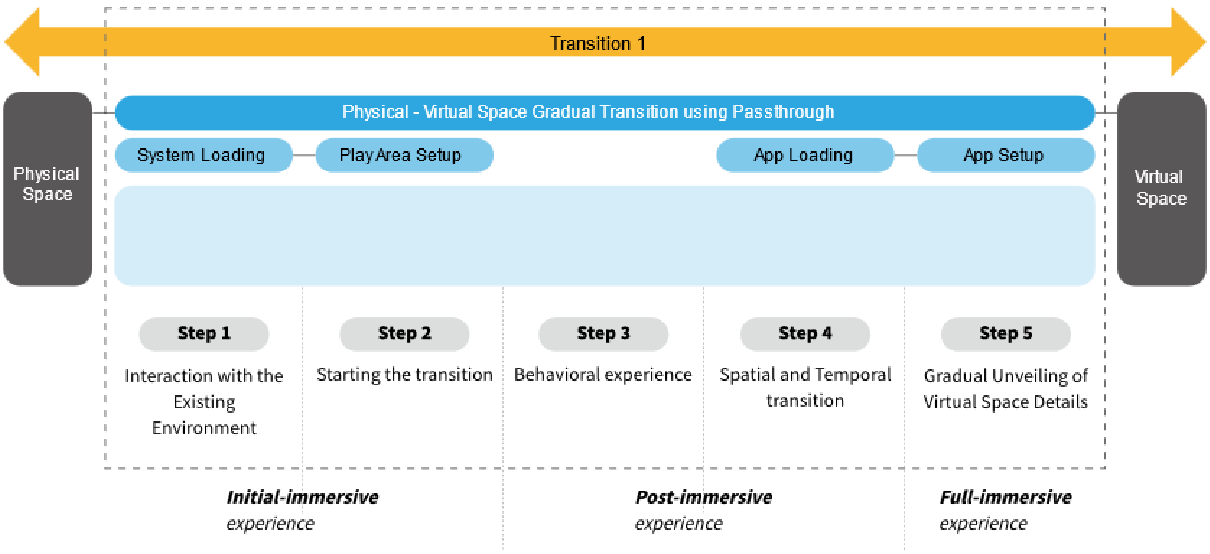


Figure 4 Phasing the user experience scenario of Threshold Space Step Model

4.2.1 Step 1. Interaction with the existing environment

Utilizing the passthrough function, the aim is to enable natural interaction with the existing environment, creating a more immersive experience for users. For certain types of physical laws, the integration of 3D modelling of real-world objects is considered, assisting users in better understanding the transition between physical and virtual spaces. Steps

4.2.2 Step 2. Start the transition

In order to smoothly initiate the transition from the physical environment to the virtual space, sensory cues such as sound and motion are employed. These cues are designed to be distinct from those experienced in reality, indicating to users that they are entering a different realm. By strategically utilizing sound and light, the transition is made more intuitive and engaging for users, effectively guiding them towards the virtual

4.2.3 Step 3. Behavioral experience in the virtual space

To ensure a comfortable and realistic user experience, behavioral experiences within the virtual space are designed to mimic daily human movements (Witmer & Singer, 1998). This is achieved by providing appropriate biomechanical feedback that allows users to feel a sense of familiarity and naturalness while navigating the virtual environment. By incorporating movement patterns that users are accustomed to, the virtual space becomes more intuitive and accessible, contributing to a seamless transition and immersion.

4.2.4 Step 4. Space-Time transition

To facilitate the user's navigation between different virtual environments, visually distinct layers of space-time are implemented. These layers serve as a guide for users, enabling them to choose and transition to the desired virtual environment from their current location. By providing clear visual cues and delineations between various virtual spaces, users can more easily understand their options and make informed choices during the transition process.

4.2.5 Step 5. Gradual unveiling of virtual space details

To enhance user immersion and engagement, the virtual space is designed to gradually reveal its details to users. As users explore and navigate the environment, they are encouraged to identify objects and elements within the virtual space, deepening their perception and understanding of it. This gradual unveiling of details ensures that users are not overwhelmed by the virtual environment, allowing for a more enjoyable and immersive experience.

This 5-step framework model, which enables gradual changes, allows users to enjoy various sensory experiences and actively induce psychological transitions through spatial experiences. Therefore, to create a transition stage between physical space and virtual space applying the Threshold Space concept, the production follows this series of Threshold Space framework models.

5 Threshold Space design

5.1 Pre-setting Threshold Space

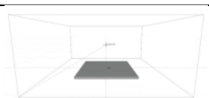
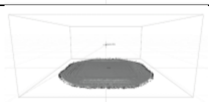
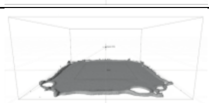
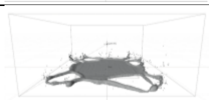
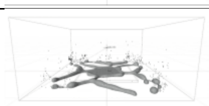
5.1.1 Pre-design considerations for Threshold Space design

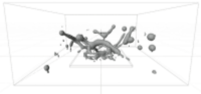
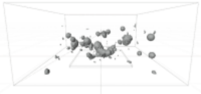
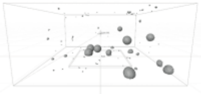
Before designing the Threshold Space transition model, some basic elements were established to solve problems related to gravity and improve the user experience in the virtual environment.

- Gravity setting of virtual space: The physical space is set to Earth's gravity, and the virtual space is set to zero gravity. This design approach aimed to show a gradual transition from $9.807 m/s^2$ to $0 m/s^2$.
- Connecting medium setting -Water: In order to reduce users' sensory conflict and disorientation, a continuously visible medium was selected to connect physical space and virtual space. Water, affected by gravity changes, is not only suitable for visually expressing these changes but also an element that users can easily recognize changes in the environment. This is because water changes due to gravity changes have already been encountered through various media.

5.1.2 Simulation of water state change according to gravity change using Blender Add-on Flips Fluid

Table 5 Blender add-on 'Flips Fluid'

Frame Rate	Scene Image	G-force	Surface Viscosity	Surface Tension
1fps		$-9.81m/s^2$	0	0
20fps		$-9.81m/s^2$	0	0
39fps		$0m/s^2$	0	0.1
78fps		$0m/s^2$	5	1
107fps		$0.3m/s^2$	0	0

145fps		0.3m/s²	1	0
159fps		0m/s²	5	1
163fps		0m/s²	0	1
218fps		0m/s²	0	1

As shown in Table 5, Blender Add-on Flip Fluids were used to simulate water state changes corresponding to gravity changes. The g-force, Surface Viscosity, Surface Tension, and Sheeting Effects values were adjusted to create a space where the water changes according to the change in gravity.

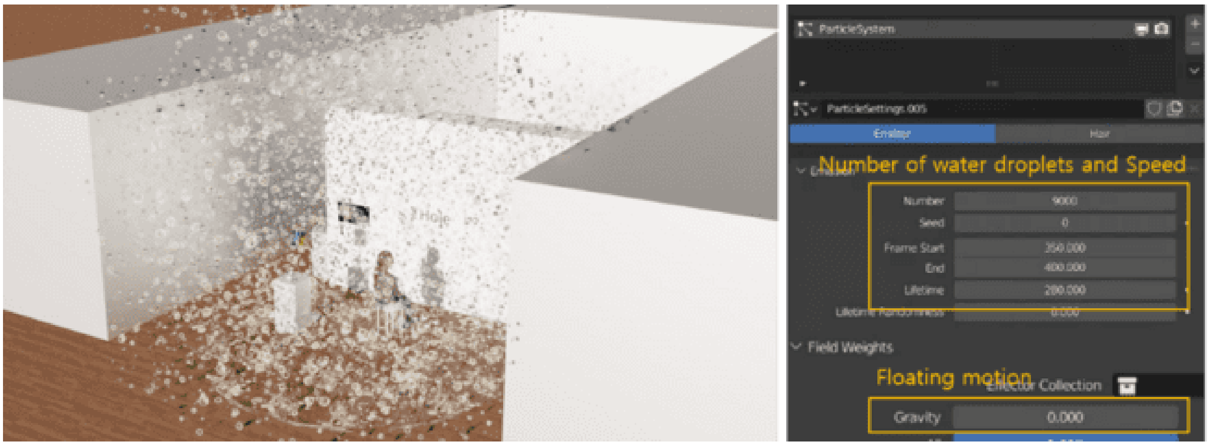


Figure 5 Visual representation of the zero-gravity section using a Particle System to simulate water droplets and floating motion, creating a realistic weightless virtual environment.

In order to implement the Threshold Space within a virtual environment, a variety of modelling methods were investigated to identify the most appropriate representation technique. The decision was made to utilize both the Particle System and Flip Fluids in conjunction, as relying solely on Flip Fluids exhibited limitations in effectively portraying the changes across different stages. In the zero-gravity section, configurations for the quantity of water droplets and floating motion are adjusted to more accurately represent the virtual and weightless state, as demonstrated in Figure 5. Employing a more flexible Particle System in combination with the Flip Fluids add-on is the preferred approach.

5.2 Threshold Space Design Model

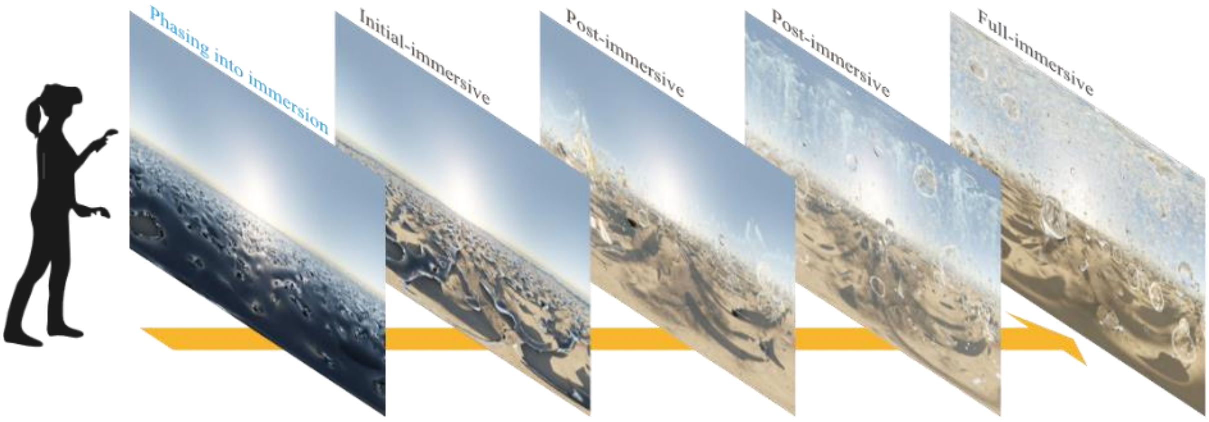


Figure 6. Path of the Threshold Space Design Model using water as a medium for entering virtual space

Figure 6 demonstrates the Threshold Space Design Model, which allows for a gradual adaptation to the changing spaces while entering a virtual space with different gravity, using water as a medium. This model focuses on the process of entering a specific app's virtual space from the physical space before wearing the HMD. Each step is carried out based on the previously described framework model, with the primary aim of establishing a solid foundation for the transition.

Figure 7 left) Actual appearance of the experiential space, right) Screen shown by passthrough (first person view)

5.2.1 Step 1.

As shown in Figure 7, when the user dons the HMD, the pre-installed water image from the physical space is displayed in the virtual space using the passthrough function. The passthrough function allows users to view their original environment even after wearing the HMD. The Oculus Quest 2 was utilized for this prototype, which displays a monochrome image when using the passthrough function; however, the Oculus Quest Pro, released in December 2022, offers a color version of the passthrough.

- Visual Matching of Physical and Virtual Spaces

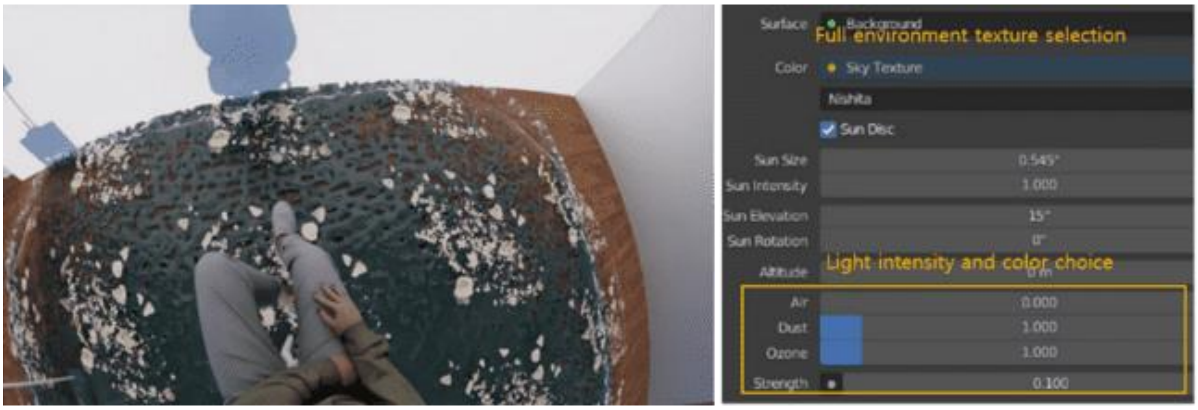


Figure 8 left) A Scene where Water Receiving the Current Gravity Value Spreads (First Person View), right) Environment Texture Change

5.2.2 Step 2.

When the user selects the app, the gravity value of the passthrough space changes. As illustrated in Figure 8 (left), the water transforms as the gravity value shifts, and light and sound from the virtual space are introduced into the passthrough space. To cue the user, we use Sky Texture for exterior lighting and sound instead of indoor lighting, as demonstrated in Figure 8 (right).

Figure 9 left) A Scene where Water Gradually Changes under Gravity in the Passthrough Space (First Person View), right) User in Actual Experience

5.2.3 Step 3.

As the user approaches the virtual space, the extent of water changes increases. The rising water prompts the user's physical movement, transitioning them toward a post-immersive experience. In this step, as shown in Figure 9 (right), the user actively observes the surrounding space, eliciting physical movements such as standing up, attempting to touch a water droplet, or turning their head to look around.

- Encouraging Physical Movement and Engagement

Figure 10 left) Floor Texture in Virtual Space is Included (First Person View), right) Expression of User's Gaze Change by Moving the Camera Position (First Person View)

5.2.4 Step 4.

As shown in Figure 10 (left), the texture of the virtual space is gradually unveiled as water, serving as a connecting medium, rises. The ascent occurs slowly to match the user's proprioceptive sense and vestibular system. In the current design, when gravity decreases and water rises, the floor texture is revealed as sand, presenting a natural change to the user.

- Revealing the Virtual Space Through Gradual Ascent

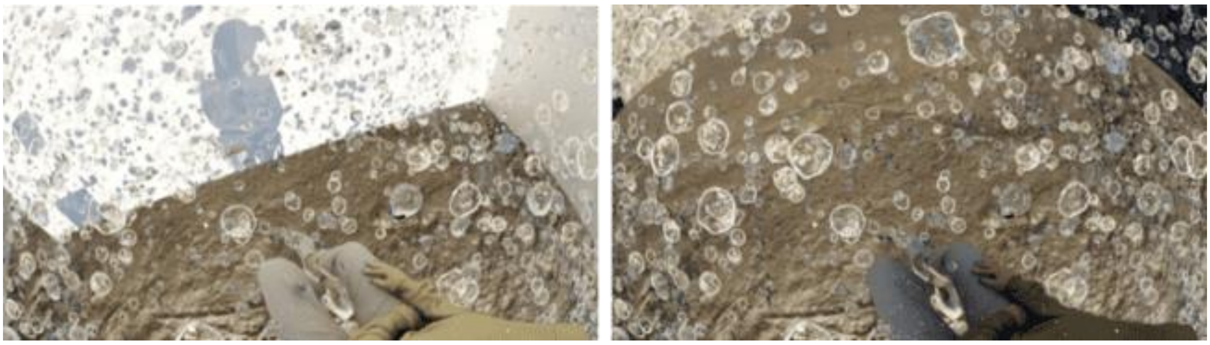


Figure 11 left) Water Changes to a Weightless State (First Person View), right) Physical Space Information Completely Disappears (First Person View)

5.2.5 Step 5.

The user prepares for a fully immersive experience just before entering the virtual space. In Figure 11 (left), the walls of the physical space are visible, but in Figure 11 (right), they are not. During this step, elements of the virtual space are introduced while elements of the physical space are gradually removed. In this manner, when the gravity of the virtual space reaches a weightless state, the surroundings become visible through floating water droplets, and other elements of the virtual space are progressively revealed.

- Gradually removing elements of the physical space

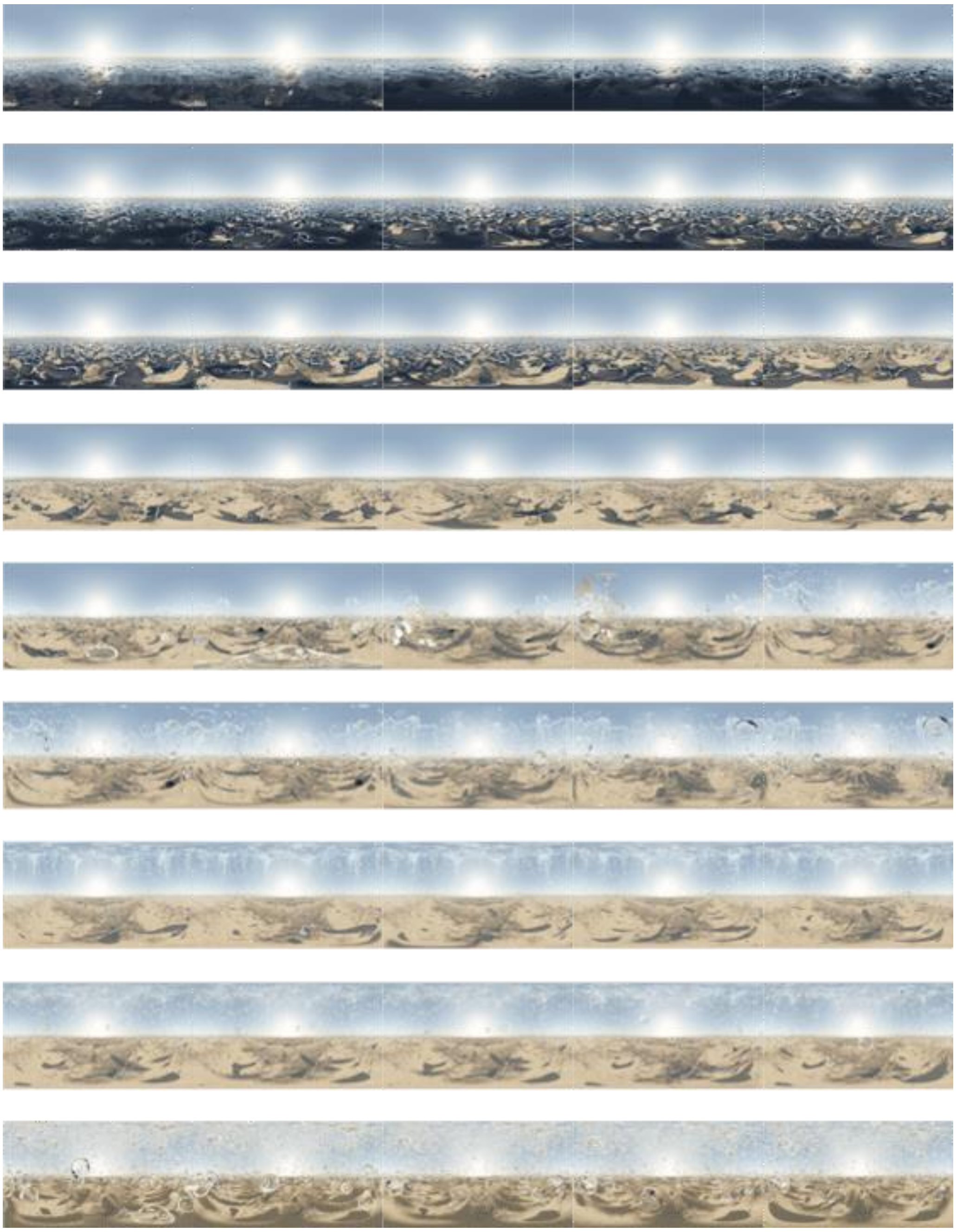


Figure 12 Threshold Space Design Model 1000 frame range video capture for VR

Figure 12 shows the transition between the physical and virtual spaces. As a result, the Threshold Space design model presented in this study focuses on reducing sensory conflict and disorientation that may arise due to gravity changes between the two environments.

To facilitate smooth transitions, the Threshold Space framework model visually aligns physical and virtual space, encourages physical movement and engagement, and progressively removes elements of the physical space while gradually aligning the virtual space with the physical environment. By utilizing a five-step process, the model promotes seamless transitions to virtual space, improving user experiences and minimizing discomfort.

6 Conclusion and future works

This study addresses two phenomena, the conflict between brain recognition and visual perception and the visual-vestibular mismatch, that users experience during the transition phase between physical and virtual space. The study successfully explores the importance of Threshold Space in promoting immersive user experiences. By analyzing the role of Threshold Space between physical and virtual spaces, the need for a phased transition to minimize disorientation and discomfort faced by users due to differences in physical laws such as gravity was identified. Through the design and implementation of a prototype, using water as a medium to create a visual reference that connects physical and virtual spaces, the potential of Threshold Space to provide users with an engaging and immersive experience was confirmed. The framework consists of five steps, and by detailing each step, the concept of a critical intermediary space with an emphasis on effectiveness was expanded. This includes providing light and sound from the virtual space, as well as the user's physical movement and visual information to the passthrough space. It is expected that users will value a transition design that allows for gradual change rather than a radical transition, UX/UI design based on a 2D medium, and a Threshold Space that gradually transitions users between spaces while maintaining sensory engagement. The framework model's step-by-step approach provides a solution for enabling the design of virtual environments personalized to each user's unique sensory experience.

However, despite the potential value of this model, it is worth noting that it comes with certain limitations. The model might not be universally applicable, particularly in cases where the disparity between the real and virtual environments is negligible. The utility of the framework may diminish in such contexts, constraining the universal applicability of the model. Moreover, the transition experience between real and virtual environments is profoundly subjective, contingent on personal sensory perception and psychological dispositions. As such, our model may not perfectly accommodate every unique user experience.

The five-step process of the Threshold Space transition model, designed based on the framework model, effectively combines physical and virtual spaces, encourages user participation, and gradually reveals the virtual environment. However, it should be noted that the current model primarily focuses on the process of entering the transition from physical space to virtual space. Future research can expand this model by exploring additional sensory cues to further improve user experience and immersion in the virtual environment. This can be achieved by extending the framework model to consider the transition from virtual space back to physical space and designing a model based on it.

In order to expand the results of this thesis and review and improve in depth in line with the direction of future research, the following improvement plan was established:

- Investigation of other media: Water was used as a medium in the prototype design. Future research will explore the use of other media to provide a more extensive immersive experience in a virtual environment.
- User experience testing and evaluation: To better understand the effectiveness of the proposed design prototype, there is a need to conduct user testing and evaluation. This will provide valuable insights into user satisfaction, immersion and presence while interacting with critical spaces, which will guide design improvement.

- Integration with advanced VR technologies: As VR technologies continue to evolve, the Threshold Space can be expanded by integrating technologies such as tactile feedback and eye tracking.
- Adaptation to various applications: The Threshold Space concept can be adapted and applied to various fields such as education, medical, entertainment, and training simulations.

Through further research, the plan is to explore the application of the Threshold Space transition model in these domains and evaluate its impact on user experience and efficiency in this context.

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