Porting a Virtual Reality Kayak Application Across Two Head-Mounted Displays: Presence, Usability, and Attitudes Toward Tourism

Jorge González-Ortega, Agustin Venegas, Ismael Gallardo, and Felipe Besoain, *Member, IEEE*

***Abstract*—Tourism is an important economic activity for Chile. The use of Virtual Reality (VR) technologies have a positive impact on the reception of messages towards points of interest in tourism, influencing peoples' attitudes towards tourism and intention to visit. Building on previous research on tourism, virtual reality, and attitudes, we present a porting of a VR activity of Kayaking on a lake in Chile, to two VR devices (HTC Vive and Meta Quest 3) using the Unity Editor. Differences in perceived presence and usability of the developed software are analyzed, along with attitudes towards kayaking and tourism. Results indicate that there are no significant differences in presence, usability or attitudes between participants that used the HTC Vive or the Meta Quest 3 device. Meanwhile, the scores of presence, usability, and attitudes toward kayaking and tourism are statistically higher than the theoretical midpoint of the scales, suggesting that the virtual reality experience is associated with positive evaluations of the simulated activity. The results are analyzed and discussed in relation to the characteristics of both VR devices, as well as the methodological utility of the results.**

Link to graphical and video abstracts, and to code:
https://latamt.ieeer9.org/index.php/transactions/article/view/10516

***Index Terms*—Virtual reality, Attitude toward tourism, Tourism.**

I. Introduction

TOURISM represents a foundational dimension of human mobility and economic behaviour, having progressively evolved into a structured economic activity that sustains socio-economic interactions across societies and contributes to long-run economic growth [1]. In the contemporary global economy, tourism stands as one of the most significant economic sectors, supporting approximately 357 million jobs worldwide—around 10% of total global employment [2]. From a macroeconomic perspective, the sector contributed USD 10.3 trillion to global GDP in 2019, increasing to USD 11.1 trillion by 2024 [3]. In Chile, tourism accounts for approximately 9% of national GDP [4], with 635,656 individuals employed in tourism-related activities during the final quarter of 2024 [5], underscoring its relevance to the national economy. Given the economic and social importance of tourism, the development of effective promotional tools has become essential. Advances in digital technologies have enabled more immersive strategies that enhance users' sense of presence in destinations, such as 360° photorealistic imagery [6]. Among these technologies, virtual reality (VR) has emerged as a particularly promising tool for tourism promotion. VR-based experiences have been shown to positively influence visit intentions by providing engaging and meaningful information about destinations, although their adoption remains limited [7]. Prior research highlights VR's potential as an innovative medium for tourism communication [8], allowing users to experience attractions more tangibly when physical travel is not possible [9]. The impact of VR on tourism outcomes is commonly examined through individuals' self-reported attitudes and perceptions. Empirical evidence indicates that virtual visits are associated with positive attitudes toward destinations and higher intentions to visit them [10], including in heritage tourism contexts such as regional history museums [11]. One key variable in this process is *presence*, defined as the extent to which users feel immersed in the virtual environment, which has been consistently associated with more positive experiential evaluations [11]. Presence is closely linked to the technological characteristics of VR systems. Variations in hardware capabilities across devices can significantly affect realism and immersion [12], making it necessary to balance virtual assets and system performance when developing or porting VR experiences across platforms. Accordingly, the aim of this study is to port and develop an integrative virtual reality kayaking experience set on Lake Colbún, located in the Maule Region of Chile [13], for both the HTC Vive [14] and the Meta Quest 3 [15] head-mounted displays. The present work makes three main contributions. From a *technical* perspective, it documents the porting process of a VR kayaking experience from a PC-based tethered device (HTC Vive) to a standalone headset (Meta Quest 3), including the graphical optimization strategies required to meet the hardware constraints of the latter. From a *methodological* perspective, it provides empirical evidence on the comparability of presence and usability outcomes across two VR platforms, contributing to the growing literature on VR device interoperability in experimental research. From an *empirical* perspective, it reports post-exposure self-reported attitudes toward kayaking and tourism in a Chilean natural heritage context, offering data relevant to the design of immersive promotional tools for regional tourism.

This paper is organized as follows: Section 2 presents the

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J. González-Ortega, and Felipe Besoain are with the Department of Interactive Visualization and Virtual Reality, Faculty of Engineering, Universidad de Talca, Talca, 3460000, Chile (jorge.gonzalez@utalca.cl, and fbesoain@utalca.cl).

A. Venegas, and I. Gallardo are with the Faculty of Psychology, Universidad de Talca, Talca, 3460000, Chile (avenegas19@alumnos.utalca.cl, and igallardo@utalca.cl).

background and variables of interest for the VR experience and users' attitudes toward tourism and virtual reality. Section 3 outlines the proposed solution and its development. Section 4 presents the experiments along with the results. Finally, Section 5 presents the conclusions and future directions for research in this domain.

II. Background

A. HCI

Human-Computer Interaction (HCI) studies and designs the ways in which people interact with computers [16]. It is an interdisciplinary field that integrates psychology and computing to inform the design and evaluation of software, hardware, and interfaces, as well as the organizational and social aspects of computing.

Human–computer interactions occur through interfaces, which serve as the physical means (visual, auditory, haptic) for bidirectional communication between users and systems [17]. Three levels of interaction are commonly distinguished: physical, referring to operational mechanisms; cognitive, related to users' understanding of the system; and affective, associated with the emotional experience during use.

Advances in contemporary technologies have transformed the physical nature of computing devices. HCI has evolved from early computers occupying entire rooms to portable and wearable technologies such as smartphones and smartwatches. In this context, *Ubiquitous Computing* [18] describes the integration of computational capabilities into everyday objects and environments, enabling seamless interactions that respond to users' gestures and contextual cues [19]. Current research focuses on the design, application, and implications of such ubiquitous technologies, which enable varying degrees of immersion or presence, as exemplified by virtual reality systems, commonly implemented through VR head-mounted displays (HMDs).

Since virtual reality (VR) systems employ interaction methods that differ substantially from traditional systems—particularly due to the degrees of freedom mediated by VR devices and experiences—specific interaction principles must be considered to ensure software functionality, usability, and usefulness [20]. Among the most relevant principles are immersion, spatial orientation, and accessibility. The hardware used in VR enables novel interaction opportunities, including vision-based interaction, tactile feedback, and gesture-based input.

B. VR

Virtual reality technologies can be defined as media in which users are immersed through sensory information mediated by computational systems. Users cognitively interpret this information, generating a perception of reality that differs from their physical environment, while also being able to interact with and influence this representation through system inputs [21].

Multiple definitions exist regarding the levels of immersion, presence, and interaction that characterize VR experiences [22]. These range from low-immersion simulations displayed on desktop screens to highly immersive experiences enabled by HMDs (*Head Mounted Displays*), which position visual displays in front of the eyes and audio systems near the ears.

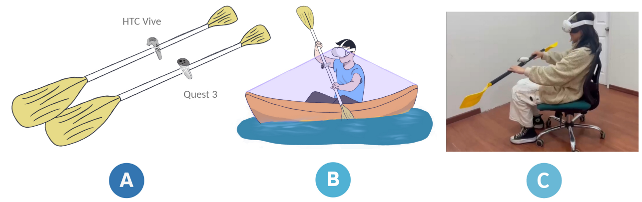

Fig. 1. Control and user interaction diagram: a) Illustrates the integration of Meta Quest 3 and HTC Vive controls at the center of the paddle. b) An illustration showing a user navigating with the paddle control and the corresponding Head-Mounted Display (HMD). c) Test Stand Example

The term "Virtual Reality" is also frequently used in media and advertising to broadly describe diverse technologies and applications [23]. A key characteristic emphasized in these contexts is VR's capacity to simulate new environments and support novel forms of interaction with software interfaces and other users.

Regarding capabilities and hardware, different types of virtual reality experiences can be distinguished [24]. For the purposes of this study, virtual reality is defined as immersive technology using an HMD to display a software-generated 3D environment with six degrees of freedom and controller-based interaction.

Both in tourism contexts [25] and other domains, several variables may influence the effects of virtual reality (VR) technology. Prior research highlights that a stronger sense of presence during VR-based therapy enhances its effectiveness [26], and that interaction-related factors, such as perceived usability, can influence the level of presence experienced during VR sessions [27]. The following section introduces relevant variables for the porting of the virtual kayaking navigation experience.

C. Variables of Interest

1) Presence: Presence refers to the general sense of "being there," regardless of whether that place exists in the physical world. It has been defined as "a subjective experience of being in one place or environment, even when one is physically situated in another" [28], such that the mediation of the virtual experience becomes largely unnoticed [29]. More recent research emphasizes that presence is closely related to the ability to act within the virtual environment in ways comparable to behavior in grounded reality [30].

The relevance of presence in virtual reality lies in its capacity to influence users' perceptions and attitudes. In tourism contexts, higher levels of presence during virtual visits have been shown to increase behavioral intentions to visit destinations in real life [25]. Similarly, in museum-related experiences, presence has been found to mitigate the impact of negative thoughts on attitudinal evaluations [11].

The level of presence experienced depends on both intrinsic factors, such as users' motivation and interest, and extrinsic factors, including experience quality and contextual conditions [31]. Additionally, characteristics of the VR device itself play a relevant role: higher perceived usability is associated with more positive subjective experiences, greater immersion, and consequently higher levels of reported presence [32].

2) Usability: Usability refers to how effectively, efficiently, and satisfactorily users can learn and use a system to achieve their goals [33]. It is a critical factor for system success, as poor usability leads to user frustration and abandonment [34]. Usability extends beyond the software itself, encompassing the interaction between users and systems within a specific context of use [35].

Core usability characteristics commonly considered include learnability, efficiency, memorability, robustness (recoverability), and user satisfaction [36].

Usability in virtual experiences or devices can be evaluated using various methods, among which design heuristics are widely applied. Design heuristics are experience-based cognitive rules that guide problem-solving and support the creation of systems with desirable usability properties [37]. Numerous heuristic sets proposed by different authors serve as a foundation for usability-oriented design and evaluation [38].

In VR development, hardware-related heuristics—particularly those concerning user comfort and system responsiveness—are especially critical [39]. Software performance must be smooth, with accurate tracking of user movements, requiring optimized graphics processing to maintain frame rates that adapt to HMD motion.

Usability can be assessed using both objective and subjective methods. Objective measures include task completion time, while subjective approaches rely on user-reported evaluations, often collected through questionnaires. One of the most widely used instruments is the System Usability Scale (SUS) [40]. Originally designed for general systems, the SUS can be adapted to specific contexts of use. It consists of 10 Likert-type items administered after system use, yielding a single usability score that can be interpreted using established acceptability ranges [41].

In summary, VR application development requires careful consideration of interaction, presence, and usability principles. For the porting and evaluation of VR experiences, it is essential that usability and presence outcomes remain consistent, as significant variations would undermine the perceived quality, effectiveness, and coherence of the experience across platforms or versions.

3) Attitudes: Attitudes are relatively stable and enduring evaluations of objects, situations, or entities in everyday life [42]. Psychologically, these evaluations serve important functions, such as maintaining self-esteem, organizing information, and preserving internal consistency [43]. As such, attitudes help structure both the internal and external world, influencing decision-making, behavioral intentions, and action. Positive evaluations toward a given object increase the likelihood of behavioral engagement with it [44]. Accordingly, attitudes are among the strongest predictors of future behavior [45], particularly when they are stable and easily accessible [46], making them a relevant measurement construct and intervention target.

Attitudes are dynamic and can vary across time and experiences. Prior research shows that virtual experiences are effective in fostering positive evaluations while simultaneously shaping behavioral intentions. In tourism contexts, immersive virtual visits have been shown to improve attitudes toward destinations, subsequently increasing intentions to visit them [10]. Moreover, positive attitudes toward tourist destinations are associated with a higher likelihood of revisitation [47], underscoring the importance of initiatives that promote favorable destination perceptions.

In line with this literature, the present study focuses on the porting of a virtual kayaking simulator set in a reservoir of regional natural heritage significance in Chile. By enhancing usability, the study aims to examine self-reported attitudes toward the region's natural heritage, and their potential relationship with behaviors related to visitation and conservation.

III. Solution Proposal

A. Porting of a VR Experience

The porting process builds upon the VR application developed in [13], originally created using the *Design and Creation* methodology to promote a tourist point of interest. The experience presents Colbún Lake, located in the Maule Region, Chile, through a kayaking simulation that combines navigational interaction with in-game informational messages about the location and its surroundings.

The original software was developed using Unity (version 2018) for the PC platform, relying on SteamVR for hardware management and targeting the HTC Vive headset. As both Unity 2018 and several SteamVR functionalities used in the original implementation have since been deprecated, the software was updated and ported to a current version of Unity. The objective of this process was to generate a new version compatible with the Meta Quest 3 platform, while also incorporating additional functionalities to support data collection for the study.

The virtual environment was implemented using Unity's terrain system, based on a height-map representing the geographical features of the area. Environmental elements such as vegetation and rocks were added to enhance realism. Navigation within the environment is achieved through a paddle attached to a VR controller, whose tracked movements are translated into kayak motion (see Fig. 1). As users approach buoys within the lake, contextual user interfaces are triggered, presenting visual and textual information about the site.

Two hardware systems were considered: HTC Vive and Meta Quest 3. The HTC Vive relies on a high-performance external computer for rendering, whereas the Meta Quest 3 is a stand-alone, Android-based device that performs rendering using internal processors. While the stand-alone nature of the Meta Quest 3 facilitates portability and deployment in diverse contexts, its internal processing constraints may affect graphical quality compared to PC-based VR systems. These differences motivate the examination of how hardware characteristics influence key outcome variables, such as attitudes toward natural heritage. The technical specifications of both devices are summarized in Table I.

TABLE I
TECHNICAL SPECIFICATIONS OF THE HARDWARE SYSTEMS USED

Item	Midrange Gaming PC and HTC Vive	Meta Quest 3, Standalone
Processor (n. of cores and main freq.)	Intel i7-8700, 6-core, 3.2 GHz	Snapdragon XR2 Gen 2, 6-core, 2.0 GHz
GPU (Clock Speed, Memory Bandwidth)	Nvidia GTX 1050 TI, 1291 MHz, 112 GB/s	Snapdragon Adreno 740, 590 MHz, 67 GB/s
RAM (GB)	16 GB	8 GB
Screen Resolution and FOV	2880 x 1600 px, 98°	4416 x 2064 px, 110°
Tracking System	Base Sensors Stations	Infrared Sensors and Inertial Sensors

Given the requirements of VR applications, both devices employ reprojection technologies to ensure stable display refresh rates. The Meta Quest 3 version targets a render rate of 50 FPS, which, combined with the device's Asynchronous TimeWarp (ATW) technology, maintains a stable 72 Hz display refresh rate by interpolating frames when necessary. Under typical usage conditions, the application averaged 48 FPS, with a minimum of approximately 40 FPS during initial loading, resulting in an estimated 5 stale frames per second. The HTC Vive version targets 90 FPS via SteamVR, leveraging Motion Smoothing to maintain the headset's 90 Hz refresh rate. These configurations ensure that both platforms meet their respective display refresh requirements while operating within their hardware constraints [48]. Ensuring compatibility with the Meta Quest 3 required compiling the application as an Android package, involving changes in the build process, libraries, and significant graphical optimization. The development, update, and porting process took approximately three months.

1) Porting: The software porting was carried out using the Unity Engine and the original project files. Unity enables multi-platform development with minimal platform-specific changes. The use of the Universal Rendering Pipeline (URP) allows the application to be compiled for different graphics APIs, specifically OpenGL ES for the Meta Quest 3 and DirectX 11 for Windows.

In the original version, the virtual environment was implemented using Unity's Terrain system, generated from heightmap data derived from the real geographical location, and a water shader employing a double-pass rendering technique to simulate reflections. While Unity's terrain system supports detailed environments through heightmap-based vertex displacement and texture blending, its computational cost increases significantly with terrain size, making it unsuitable for the hardware constraints of the Meta Quest 3.

To address this limitation, a terrain impostor approach was adopted. A terrain impostor is a static, optimized representation of complex terrain, characterized by reduced polygon count, simplified materials, and lower texture resolution. Height-map data were used to generate a 3D model, which was subsequently edited in Blender by segmenting the terrain and reducing polygon complexity. Materials similar to those used in the original Unity terrain were then applied, without texture interpolation, to ensure acceptable visual fidelity while meeting performance requirements (see Fig. 2).

Water representation in the original software is achieved using a vertex mesh and a shader that emulates key visual properties, including semi-transparency, wave motion, distortion, and reflections. For the ported version, a functionally equivalent shader was implemented using Shader Graph, a node-based system that enables cross-platform shader compilation.

Paddle movement is simulated using a controller attached to a mock-up oar. Within the virtual environment, a paddle object follows the controller's tracked motion and includes two sub-objects, one for each blade. When submerged, these sub-objects apply force to the kayak based on movement velocity, side, and depth, enabling realistic navigation dynamics.

2) ***New Features:*** To meet the research requirements, a messaging system and a logging system were implemented. The messaging system employs a unified data structure that assigns multiple messages to a single user interface element, replacing the original approach in which each message was defined as a separate object. An editor extension was also developed to allow retrieval, editing, and storage of message data in Unity .asset files.

The logging system was designed to collect task-related performance data in an event-based manner. Specifically, when users approach designated buoys, the system records the buoy identifier and the elapsed time since the start of the session. Upon completion of the experience, the data are exported to a .csv file with a timestamp. The average duration of the user activity was 400.49 seconds (6 minutes and 40 seconds).

IV. EXPERIMENTS AND RESULTS

A. User Study

1) ***Sample and Design*** *:* A total of 40 undergraduate students (57.5% male, $M_{age} = 21.70$, $SD_{age} = 3.93$, completed the study tasks. All respondents reside in Chile. Participants were randomly assigned to a single factor (Virtual Reality Device), between-subject design, with two virtual reality devices (HTC Vive vs. Meta Quest 3) as experimental conditions.

B. Procedure

Participants were recruited through campus advertisements and intentional sampling conducted by trained surveyors.

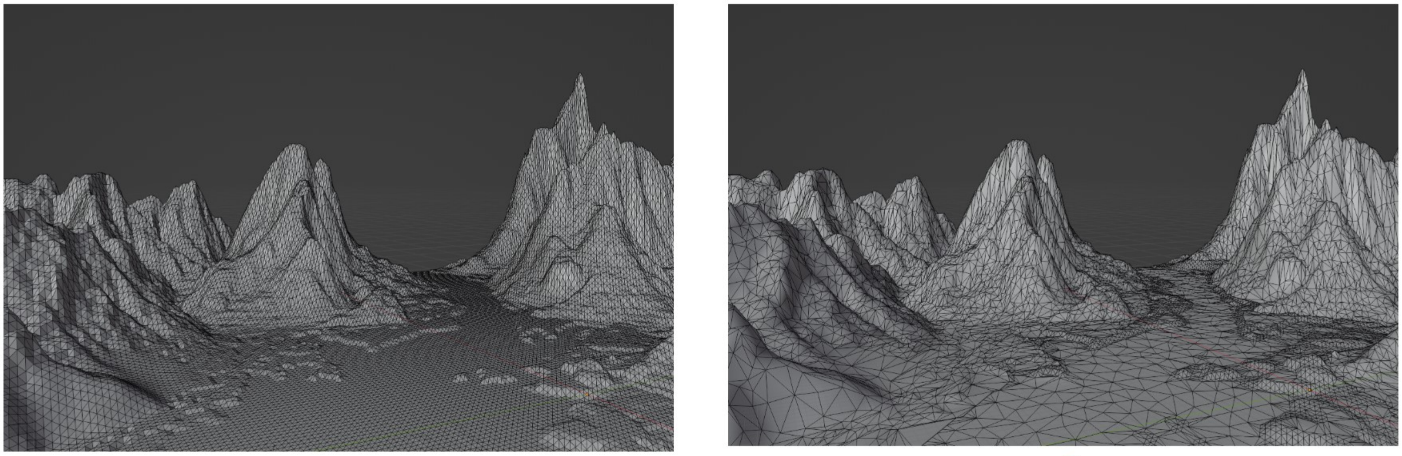

Fig. 2. Polygon reduction and culling of in-game terrain. a) Terrain object before optimization (131k triangles). b) Optimized terrain object (42k triangles), representing a 67.9% reduction in polygon count. This optimization was necessary to meet the hardware constraints of the Meta Quest 3, as the original terrain rendered the application unplayable on the standalone device.

Upon arrival at the laboratory, participants received an information sheet describing the study as research on virtual reality devices, including details on anonymity, confidentiality, and study duration. After providing informed consent, participants completed the virtual reality task while seated and holding a controller attached to a mock-up paddle (see Fig. 1, c).

Participants were randomly assigned to one of two conditions. One group used the HTC Vive headset, while the other used the Meta Quest 3. In both conditions, participants completed the same virtual kayaking task on a Chilean reservoir, with a duration ranging from 8 to 12 minutes. Following the VR experience, participants completed a questionnaire assessing the study's dependent variables on an independent laboratory computer. Finally, participants were debriefed and thanked for their participation. The study was approved by the Scientific Ethics Committee of the University of Talca (Protocol code 22-2024).

C. Variables

- **Independent Variable**
  - *Virtual Reality Device:* All participants completed the same virtual kayaking task on a Chilean reservoir. Half of the sample used the HTC Vive headset, while the remaining participants used the Meta Quest 3. The hardware characteristics of both devices are summarized in Table I.
- **Dependent Variables**
  - *Multimodal Presence Scale:* Presence was assessed using an adapted version of the multimodal presence scale developed by Makransky et al. [49]. The original 15-item scale measures physical, social, and personal presence using a Likert response format. For the present study, only the physical and personal dimensions were included, resulting in a 10-item scale with a seven-point Likert format (e.g., "I felt that the virtual body was an extension of my real body"). Given the high internal consistency of the scale ($\alpha = 0.894$), items were averaged to compute a general presence index.
  - *SUS Usability Scale:* Simulator usability was assessed using an adapted version of Brooke's System Usability Scale (SUS) [40]. The original 10 items were administered (e.g., "I would like to use this simulator frequently") using a Likert scale ranging from 0 to 7. To ensure consistency across dependent variables, scores were transformed to a 1–5 scale. The scale showed adequate internal consistency ($\alpha = 0.810$). Following standard scoring procedures, adjusted item scores were summed and multiplied by 2.5 to yield a total score ranging from 0 (very low usability) to 100 (very high usability).
  - *Attitude Toward Real-Life Kayaking:* Attitudes toward real-life kayaking were measured using six semantic differential items rated on seven-point scales anchored by opposing adjectives (e.g., 1 = not at all desirable; 7 = very desirable), following established attitude measurement procedures [50]. Given the high internal consistency ($\alpha = 0.928$), items were averaged to create a composite index, with higher values indicating more favorable attitudes.
  - *Attitudes Toward the Virtual Kayaking Activity:* Attitudes toward the virtual kayaking experience were assessed using four semantic differential items rated on seven-point scales. The items showed high internal consistency ($\alpha = 0.882$) and were averaged to form a single index, with higher scores reflecting more favorable attitudes toward the virtual activity.
  - *Attitude Toward Tourism:* Attitudes toward tourism were measured using a single semantic differential item rated on a seven-point scale ranging from negative (1) to positive (7) ("My opinion about engaging in tourism activities is:").

TABLE II
DESCRIPTIVE STATISTICS OF DEPENDENT VARIABLES

	Avg.	St. D.
Presence		
1. The virtual environment seemed real to me.	4.98	1.5
2. I had a sense of acting in the virtual environment, rather than operating something from outside.	5.08	1.3
3. My experience in the virtual environment seemed consistent with my experiences in the real world.	4.80	1.4
4. While I was in the virtual environment, I had a sense of “being there”.	5.28	1.2
5. I was completely captivated by the virtual world.	5.68	1.2
6. I felt like my virtual embodiment was an extension of my real body within the virtual environment.	4.78	1.6
7. When something happened to my virtual embodiment, it felt like it was happening to my real body.	4.43	1.4
8. I felt like my real arm was projected into the virtual environment through my virtual embodiment.	4.85	1.8
9. I felt like my real hand was inside of the virtual environment.	4.58	1.7
10. During the simulation, I felt like my virtual embodiment and my real body became one and the same.	4.63	1.8
General Presence Score	4.90	1.2
Usability (normalized, 1–5)		
1. I think that I would like to use this simulator frequently.	4.04	0.9
2. I found the system unnecessarily complex. (Inverse)	1.61	0.6
3. I thought the simulator was easy to use.	4.30	0.7
4. I think that I would need the support of a technical person to be able to use this system. (Inverse)	2.04	1.0
5. I found the various functions in this simulator were well integrated.	4.37	0.5
6. I thought there was too much inconsistency in this simulator. (Inverse)	1.88	1.0
7. I would imagine that most people would learn to use this simulator very quickly.	4.55	0.5
8. I found the system very cumbersome to use. (Inverse)	1.68	0.8
9. I felt very confident using the system.	4.45	0.7
10. I needed to learn a lot of things before I could get going with this simulator. (Inverse)	1.52	0.8
HTC Vive usability index (corrected inverted indexes and adjusted scale)	82.46	11.49
Meta Quest 3 usability index (corrected inverted indexes and adjusted scale)	82.40	13.36
Total usability index (corrected inverted indexes and adjusted scale)	82.42	12.40
Attitude toward kayaking in real life		
Kayaking on a lake in real life is: (a good idea/a bad idea; inverse item)	1.65	1.18
Kayaking on a lake in real life is: (negative/positive)	6.10	1.37
Kayaking on a lake in real life is: (not desirable/desirable)	5.68	1.65
Kayaking on a lake in real life is: (not likable/likable)	5.95	1.39
In general, my opinion regarding kayaking on a lake in real life is:	6.18	1.2
Total index of attitudes towards kayaking in real life (corrected inverted items)	6.09	1.13
Attitude towards the virtual kayaking activity		
The virtual kayaking activity I just did is: (a good idea/a bad idea; inverse item)	1.45	0.78
The virtual kayaking activity I just did is: (not likable/likable)	6.55	0.71
The virtual kayaking activity I just did is: (boring/fun)	6.40	1.00
In general, my opinion towards the virtual kayaking activity I just did is: (against/in favor)	6.48	0.78
Total index of attitudes towards the virtual kayaking activity (corrected inverted items)	6.49	0.71
Attitude towards tourism		
My opinion towards doing tourism activities is: (negative/positive)	6.18	1.1

D. Data Analysis

Data analysis was performed using IBM SPSS v25. The SUS was originally configured with a response scale ranging from 0 to 7 due to a platform setting error. To approximate the standard 1–5 response format assumed by Brooke’s scoring procedure [41], all item scores were transformed using the following formula:

$$usabilityScore = (1 + (originalvar. \times 4/7))$$

This transformation linearly maps the 0–7 range onto a 1–5 scale, preserving the relative distances between response options. Following this transformation, standard SUS scoring procedures were applied: scores on positively worded items had 1 subtracted, scores on negatively worded items were subtracted from 5, all adjusted scores were summed, and the total was multiplied by 2.5 to yield a final score ranging from 0 to 100. This procedure is consistent with Brooke’s original instructions and maintains comparability with published SUS benchmarks (e.g., scores above 80 are generally considered “good” usability [41]). Descriptive statistics were calculated for the dependent variables, and mean difference tests (Student’s t-test) were conducted to analyze the effect of different devices on reported presence and usability.

V. RESULTS

Two results of this work are presented below: (1) the ported VR experience, and (2) a user study with the VR experience.

A. VR Experience

The VR experience was implemented in Unity Engine version 2022.3.52f1 using C# as the programming language it is available at a GitHub repository (https://github.com/Agustin-Venegas/KayakVR-HTC).

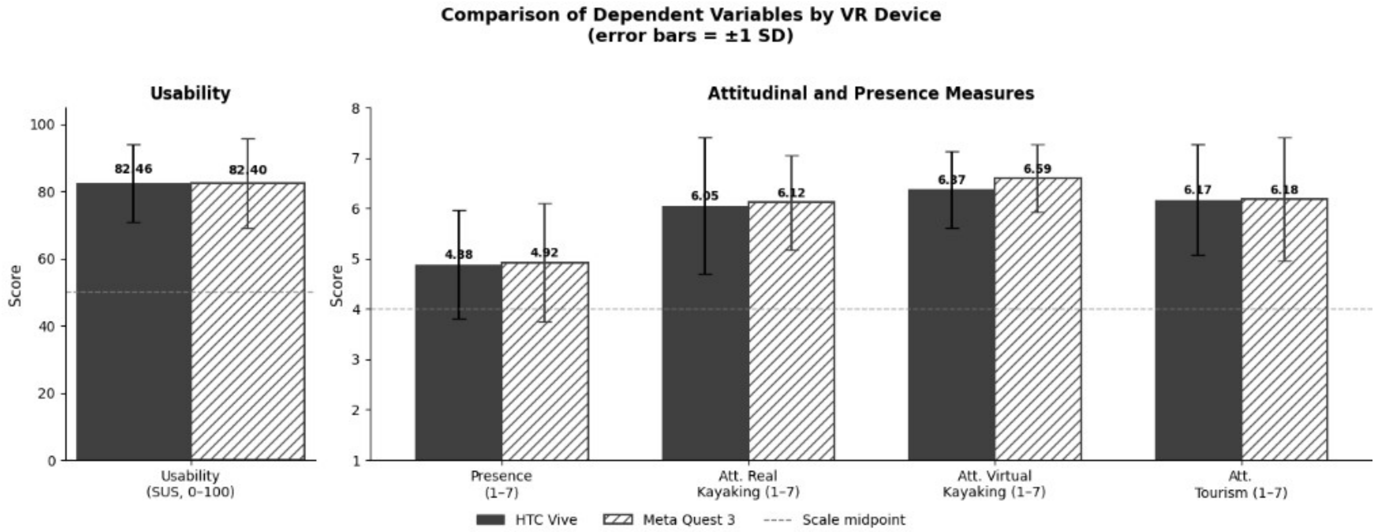

Fig. 3. Mean scores on all dependent variables by VR device (HTC Vive vs. Meta Quest 3). Error bars represent ±1 standard deviation. The dashed line indicates the theoretical scale midpoint. No statistically significant between-device differences were observed for any variable ($p > .05$).

B. User Study

Following the procedure described above, an initial porting check compared dependent measures across both simulation devices. Subsequently, overall mean scores were contrasted with the theoretical scale midpoints to assess the simulator's effects on the dependent variables.

1) Porting Check:

1) Presence: No statistically significant differences were found ($t_{(38)} = -0.10, p = 0.91$ $d = -0.035$) in presence levels between participants who used the HTC Vive virtual reality device ($M = 4.88, SD = 1.08$) and those who used the Meta Quest 3 virtual reality device ($M = 4.92, SD = 1.18$); meaning that no significant differences were detected within the current sample in presence levels across both versions of the software.
2) Usability: No statistically significant differences were reported ($t_{(38)} = 0.01, p = 0.98$, $d = 0.005$) in usability levels between participants who used the HTC Vive virtual reality device ($M = 82.46, SD = 11.49$) and those who used the Meta Quest 3 virtual reality device ($M = 82.40, SD = 13.36$); meaning that no significant differences were detected within the current sample in usability across both versions of the software. This is to be expected because the controller used in both devices is the same, changing only the control anchored to the kayak paddle (see Fig. 1).
3) Attitudes: No statistically significant differences were found ($t_{(38)} = -0.20, p = 0.84$, $d = -0.060$) in attitudes towards real kayaking between participants who used the HTC Vive ($M = 6.05, SD = 1.36$) and those who used the Meta Quest 3 ($M = 6.12, SD = 0.94$). No statistically significant differences were found ($t_{(38)} = -0.95, p = 0.34$, $d = -0.307$) in attitudes towards the virtual kayaking activity between participants who used the HTC Vive ($M = 6.37, SD = 0.76$) and those who used the Meta Quest 3 ($M = 6.59, SD = 0.67$). Finally, no statistically significant differences were reported ($t_{(38)} = -0.04, p = 0.96$, $d = -0.009$) in attitudes towards tourism between participants who used the HTC Vive ($M = 6.17, SD = 1.09$) and those who used the Meta Quest 3 ($M = 6.18, SD = 1.22$); meaning that no significant differences were detected within the current sample in attitudes or evaluations of kayaking, both in the real and virtual modes, nor in attitudes towards tourism, between both device conditions (see Fig. 3).

2) Scale Midpoint Comparisons and Distributional Analysis: The measures of presence ($t_{(39)} = 7.89$, $p < 0.001$), usability ($t_{(39)} = 22.90$, $p < 0.001$), attitude towards real kayaking ($t_{(39)} = 14.47$,$p < 0.001$), attitudes towards the virtual kayaking activity ($t_{(39)} = 26.56$,$p < 0.001$) and attitude towards tourism ($t_{(39)} = 14.68$, $p < 0.001$) were found to be significantly higher than the theoretical midpoint of the scale (Fig. 3). Meaning that, on average, participants reported a strong sense of presence within the virtual environment, evaluated its usability positively, and reported favorable attitudes towards both virtual and real kayaking, as well as towards tourism overall.

Table II presents the descriptive statistics for each item, as well as the overall average of the presence and usability measures. The overall average system usability (SUS) score was 82.42 ($SD = 12.40$). Usability for the HTC Vive device was 82.46 ($SD = 11.49$). For the Meta Quest 3 device the usability was 82.40 ($SD = 13.36$), reflecting adequate levels of usability for both devices.

Distributional analysis of the dependent variables revealed moderate negative skewness in usability scores ($skewness = -0.713$) and strong negative skewness in all attitudinal measures (real kayaking: $skewness = -1.525$; virtual kayaking: $skewness = -1.406$; tourism: $skewness = -1.630$), with 70%, 77.5%, and 75% of participants respectively scoring at or above 6 out of 7. Presence scores were more normally distributed ($skewness = -0.157$). These patterns suggest potential ceiling effects in the attitudinal and usability measures, which should be considered when interpreting the results.

VI. Discussion

The results indicate that the porting of the VR experience from HTC Vive to Meta Quest 3 was successful, as no statistically significant differences were observed in presence or usability between devices. This suggests that the immersive and user-friendly qualities of the experience were preserved across platforms, supporting the consistency of the user experience despite hardware differences. The negligible to small effect sizes observed across all comparisons (d range: -0.035 to -0.307) further suggest that any undetected differences, if present, would be of limited practical relevance. Nevertheless, given the relatively small sample size ($n = 40$), the possibility of Type II error cannot be entirely excluded, and future studies with larger samples should confirm these findings.

Presence levels for both devices were above the theoretical midpoint, indicating that participants reported perceiving the virtual kayaking experience as realistic and immersive. Both the HTC Vive and Meta Quest 3 effectively supported a sense of "being there," which can be partly attributed to the optimization of key performance factors during the porting process, particularly the use of platform-specific reprojection technologies (Asynchronous TimeWarp (ATW) on the Meta Quest 3 and Motion Smoothing via SteamVR on the HTC Vive) which maintained stable display refresh rates of 72 Hz and 90 Hz respectively, despite different application-level render targets.

In terms of usability, the simulator achieved high scores on both platforms ($SUS = 82.42; SD = 12.40$), reflecting adequate efficiency, effectiveness, and user satisfaction. Despite notable physical differences between the devices—such as headset weight and cable dependency in the HTC Vive—these factors did not significantly affect usability outcomes. This may be explained by the consistency of interaction mechanics across platforms, as the same controller-based input was used in both conditions, resulting in comparable usability evaluations.

From a technical standpoint, the porting process revealed several device-specific challenges that are relevant to the broader field of VR interoperability. The most significant was the incompatibility of Unity's terrain system with the Meta Quest 3's hardware constraints, which required the development of a terrain impostor approach, replacing a 131k-triangle model with an optimized 42k-triangle representation, achieving a 67.9% polygon reduction while maintaining acceptable visual fidelity. Additionally, the transition from SteamVR to the Universal Rendering Pipeline (URP) required substantial changes to the graphics pipeline, including cross-platform shader reimplementation using Shader Graph. These adaptations demonstrate that successful VR porting is not merely a technical exercise, but requires deliberate design decisions that balance performance constraints with experiential quality, a challenge that is likely to grow in relevance as standalone devices become more prevalent in research and applied contexts.

The absence of significant differences in attitudes toward real-life kayaking, the virtual kayaking activity, and tourism further indicates that the porting process did not alter participants' perceptions of the experience or its outcomes (see Fig. 3). Moreover, reported attitudes toward real-life kayaking and tourism were significantly above the theoretical midpoint, suggesting that both VR systems are associated with favorable self-reported evaluations. These findings support the use of both PC-based and stand-alone VR devices in experimental designs aimed at measuring post-exposure attitudes.

Overall, the results are consistent with the role of immersive VR experiences as platforms associated with positive self-reported attitudes and behavioral intentions. The findings align with prior research highlighting the potential of VR to influence attitudes and intentions [51], as well as studies demonstrating the effectiveness of VR visualizations and virtual tours in improving destination evaluations and visit intentions [10], [52]. In this context, the integration of VR experiences using contemporary wearable devices appears particularly promising for supporting positive behavioral intentions toward the featured sites [6].

A. Limitations and Future Work

Despite the contributions of this study to understanding the porting of VR experiences and their effects on user perceptions and attitudes, several limitations should be acknowledged.

First, the study did not include a control group using a non-immersive medium (e.g., desktop or flat-screen display). Although attitude scores were significantly above the theoretical midpoint, the inclusion of a control condition would allow a clearer assessment of the specific effects of VR simulations on attitudes. Nevertheless, prior research indicates that immersive VR systems elicit higher levels of presence than non-VR displays [53], and the primary objective of this study was to compare different VR devices rather than to contrast immersive and non-immersive technologies. Future studies should incorporate additional control groups to examine these comparative effects more directly.

Second, a potential limitation concerns the use of a single-item measure to assess attitudes toward tourism. While multi-item scales are generally recommended for reliability purposes, previous research supports the validity of single-item measures when the construct is concrete and well defined [54]. Future research should nevertheless expand the measurement of tourism attitudes by including multiple items that capture both general and specific dimensions of the construct.

Third, the study did not record participants' usage time during the simulator trials. Although usability measures were included to control for potential difficulties in operating the simulator, usage time may provide additional insights into how interaction duration influences attitudes and user experience. Future work should incorporate this variable, as it may be particularly informative for more complex experimental designs and iterative development processes.

Furthermore, a limitation concerns potential ceiling effects in the attitudinal and usability measures. Distributional analyses revealed strong negative skewness in attitudes toward real kayaking, virtual kayaking, and tourism ($skewness$ range: -1.406 to -1.630), with 70–77.5% of participants scoring at or above 6 on a 7-point scale. Usability scores also showed moderate negative skewness ($skewness = -0.713$). These ceiling effects may have reduced the variance available to detect between-device differences, partially explaining the absence of significant effects. Future studies should consider complementing self-report instruments with objective behavioral measures such as task completion time or navigation efficiency metrics.

Additionally, no a priori power analysis was conducted; the sample size was determined by participant availability. A post hoc power analysis revealed that, with $n = 20$ per group and $\alpha = .05$, the study had sufficient power to detect only large effects ($d = 0.8$: power $= 0.693$), with substantially lower power for medium ($d = 0.5$: power $= 0.338$) and small effects ($d = 0.2$: power $= 0.095$). Given that the observed effect sizes were negligible to small across all between-device comparisons, the possibility of Type II error cannot be excluded. Future studies should include larger samples and conduct a priori power analyses to ensure adequate sensitivity for detecting effects of smaller magnitude. Finally, the study did not assess social presence, focusing instead on usability, physical presence, and personal presence to address the core objective of comparing technical aspects across devices. Future versions of the simulation will include multi-user interaction features, enabling the examination of social presence and its effects on attitudes toward tourism and kayaking.

Overall, future work should address these limitations while continuing to refine the VR experience based on user feedback. From a technological perspective, this study represents an initial milestone within an ongoing development cycle. Subsequent phases will focus on enhanced functionalities, such as real-time multi-user interaction, and expanded virtual environments that integrate both physical and social dimensions, involving interactions with avatars as well as real participants.

VII. Conclusion

The results support several scientific and technical conclusions regarding the VR porting process.

First, equivalent levels of usability and perceived presence across devices indicate that the porting from HTC Vive to Meta Quest 3 was successful, without compromising the quality of the simulation experience. This conclusion is directly supported by the absence of statistically significant between-device differences across all dependent variables, accompanied by negligible to small effect sizes (d range: -0.035 to -0.307).

Second, participants reported positive attitudes toward virtual navigation, real-life kayaking, and tourism-related heritage, suggesting that the immersive experience is associated with favorable evaluations of both the activity and the represented environment. These scores were significantly above the theoretical midpoint of the scales across both device conditions, though the post-exposure design does not allow causal inferences about attitude change.

Third, the findings highlight the potential of portable, standalone immersive devices such as the Meta Quest 3 for being associated with positive self-reported attitudes toward tourism and heritage. This inference is based on the comparable attitudinal outcomes observed between the Meta Quest 3 and the PC-based HTC Vive, suggesting that the standalone device can serve as a viable alternative in contexts where portability is a priority. This is particularly relevant for on-site dissemination and promotional initiatives, as it removes the need for external computers or display infrastructure, thereby facilitating deployment in hard-to-access contexts, including rural areas in Chile.

From a design perspective, the results demonstrate that acceptable levels of presence and usability can be maintained despite reductions in graphical complexity. Although polygon count was reduced to optimize performance on the Meta Quest 3, both simulator versions achieved comparable outcomes in user experience measures. The documented porting challenges, particularly the terrain optimization strategy and graphics pipeline adaptation, offer practical guidance for researchers and developers working on cross-platform VR deployments in tourism and cultural heritage contexts. Looking ahead, future work should address the methodological limitations identified in this study, particularly the absence of baseline measures and control conditions, to establish stronger empirical grounds for causal claims regarding the effects of VR experiences on attitudes toward tourism and natural heritage. Overall, the study supports the conclusion that porting VR simulators across platforms is a viable and effective strategy for preserving experiential quality while expanding the applicability of immersive technologies for tourism and cultural heritage promotion.

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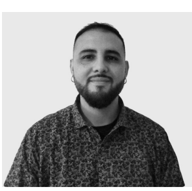

Jorge González-Ortega obtained his B.S. degree in Psychology from the School of Psychology at Universidad de Magallanes, Punta Arenas, Chile, in 2017, and the doctorate degree in psychology from the Universidad de Talca, Talca, Chile, in 2025. His areas of interest include research on attitudinal change and its relationship with emerging virtual reality technologies within the context of political psychology. He is currently a member of the research team at Mauletec, University of Talca, Chile.

Agustín Venegas is a 2025 graduate in Game Development and Virtual Reality Engineering from the University of Talca, Chile. His areas of interest include the use of VR Experiences and Immersive Technologies in Research, and Procedural Content Generation in Game Development.

Ismael Gallardo received his B.S. degree in psychology from the Faculty of Humanities, School of Psychology, Universidad de Santiago, Santiago, Chile, in 2001, and the doctorate degree in social psychology from the Universidad Autónoma de Madrid, Madrid, Spain, in 2006. Since 2023, he has been an Full Professor with the Faculty of Psychology, University of Talca, Chile. In collaboration with other researchers, some of these works have studied the effect of receptor variables (e.g., self-affirmation) or messages (e.g., rhetorical questions) and the incorporation of immersive technologies in classical contexts of persuasion, incorporating novel explanations for rare effects using first- and second-order cognitive mechanisms. His current research interests includes social influence and the study of attitudes and their processes of formation and change in VR environments.

Felipe Besoain (Member, IEEE) received his B.S. degree in Bioinformatic Engineering from the Faculty of Engineering, Universidad de Talca, Talca, Chile, in 2010. In 2012, he received a M.S. degree in Free Software and in 2018 a doctorate degree in Network Information Technologies from the University Oberta de Catalunya, Barcelona, Spain. In, 2021 he started a post-doctorate in social psychology at the Universidad de Talca, Chile, combining app development with current attitude change theory. He has been a researcher in various R&D projects with demonstrable experience in the development of mobile, immersive technologies (Virtual Reality) in the industry in health, agronomy, tourism, culture and heritage, among others. His current research and interest are the application of persuasive technologies in intelligent contexts for the promotion of health, tourism and cultural heritage, as well as the use of ubiquitous computing and mobile devices, gamification, and immersive technologies for the form/change of attitudes.