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Exploring Mysteries in VR: A Journey Through Brazilian Folklore and Legends

Maria Andréia Formico Rodrigues [**GIRA Lab, Universidade de Fortaleza** | ***mafr@unifor.br***]
Thiago Narak C. de Oliveira [**GIRA Lab, Universidade de Fortaleza** | ***thiago.narak@gmail.com***]
Denise Q. M. Teixeira [**CCT, Universidade de Fortaleza** | ***denisequindere@gmail.com***]

Programa de Pós-Graduação em Informática Aplicada (PPGIA), Universidade de Fortaleza (Unifor), Av. Washington Soares, 1321, Fortaleza, Ceará, 60811-905, Brazil.

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Abstract: This paper presents "Caturama VR," an English-localized VR game that immerses players in Brazilian folklore, portraying the adventures of Caturama, a young indigenous hero. It features a VR-optimized interface, dynamic inventory management, visually captivating special effects, and first-person animated hands for deep narrative interaction within a mystical environment. Employing advanced 3D graphics, the game enriches the educational exploration of folklore, aiming to cultivate an appreciation for indigenous cultural heritage. Rigorous pre-user VR testing, conducted in-house by the development team acting as players, has significantly boosted interaction quality, gameplay balance, immersion, presence, and overall performance, laying a solid foundation for forthcoming advancements and real-user UX evaluations.

Keywords: VR Serious Game, Narrative Interaction, Folklore Legends, Cultural Heritage

1 Introduction

Digital serious games blend the appealing aspects of computer and video games with educational goals. They combine fun, engagement, and structured play with learning through interaction, adaptability, and feedback [Schell, 2008]. These games not only motivate players with rewards and creative problem-solving but also foster social interaction and emotional engagement through storytelling, all while focusing on educational objectives [Prensky, 2001; Luz Junior *et al*., 2021].

In the context of our digital era, serious games, especially those employing Virtual Reality (VR), hold immense potential in promoting and exploring cultural heritage, a largely untapped aspect despite the widespread popularity of gaming for leisure. This approach offers a novel method for appreciating and understanding diverse cultural stories, marking a new phase in interactive learning.

The work of Anderson et al. [2010] is a key example in this field, utilizing advanced gaming technologies. They leverage not only enhanced graphics and sound but also sophisticated AI for simulating realistic character behaviors and decision-making processes [Anderson *et al*., 2010]. This approach is particularly effective in VR settings, where the immersive quality of the games can bring Brazilian folkloric tales to life with unprecedented realism and interactivity [Cascudo, 2015]. The integration of VR into serious gaming opens up new avenues for cultural education, allowing users to experience and learn about cultural heritage in an engaging, interactive, and deeply personal way.

In the gaming field, VR is widely acclaimed for delivering immersive experiences that greatly enhance the player's sense of presence [Pallavicini *et al*., 2019]. This immersive environment can lead to heightened emotional engagement, distinguishing VR for its ability to captivate users [Jerald, 2015]. However, despite its renowned immersion and enhanced emotional connection, game development in VR presents unique challenges, including addressing hardware limitations and the associated high costs of advanced technology [Pan and Steed, 2019]. Developers must also focus on user comfort and health to prevent issues like motion sickness and eye strain [McCauley and Sharkey, 1992]. The complexity of creating immersive content, designing intuitive user interfaces for a fully immersive environment, and overcoming technical limitations such as latency and resolution are also significant hurdles [Yao *et al*., 2014]. Additionally, the fragmented VR market poses compatibility challenges, and the overall higher cost of development due to specialized equipment and skilled personnel further complicates the process.

This paper outlines the evolution of *Caturama* [Teixeira *et al*., 2023], from an initial desktop prototype game exploring Brazil's folklore to its current, significantly expanded and revised VR experience (Figure 1). The narrative follows the young indigenous protagonist, Caturama, from an Amazon forest tribe as he discovers legendary beings like Iara, Curupira, and the Pink Dolphin, with the latest version introducing Saci and Victoria Regia. This VR adaptation not only originally extends the story and is now fully localized in English, covering the user interface, narratives, and all textual content, but also introduces new computing implementations through varied strategies. These include advanced player interaction with new characters, minigames, immersive visual effects, and tailored control schemes optimized for VR environments. Significant updates also include a VR-optimized interface, a floating inventory system, first-person virtual animated hands for Meta Quest 2 that mirror real-world player actions with synchronized game control actions mapped to the hand controllers, environmental navigational cues, and an enriched Game Over screen. These improvements aim

to deepen the educational exploration of Brazilian folklore in a technologically advanced setting, ensuring a more engaging and culturally rich gaming experience. Caturama VR is notable for its advanced 3D graphics, showcasing visual lighting and shading effects, collision dynamics [Serpa and Rodrigues, 2020], and algorithms for character behavior, motion control [Serpa *et al*., 2020], navigation [Barbosa and Rodrigues, 2006], decision-making [Rodrigues *et al*., 2015], and sound effects. The game's culmination emphasizes the importance of respecting and preserving these legends as integral to the tribe's traditions and beliefs. Through this virtual journey, players can gain an appreciation for these folklore legends, understanding their significance in the tribe's culture and the broader value of preserving such diverse cultural heritages.

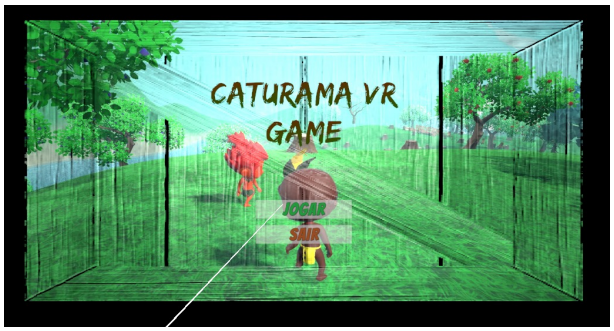


Figure 1. Opening scene of the Caturama VR game, experienced through the immersive Meta Quest 2 device.

2 Related Work

This section delves into two key areas of research: the integration of Brazilian folklore into digital gaming and the advancements in VR gaming. It explores how these domains enrich cultural understanding and immersive gaming experiences, respectively.

2.1 Brazilian Folklore in Digital Gaming

Initial endeavors into incorporating elements of folklore legends into games featured basic mechanics in simple 2D formats such as roulette, memory, and card games.

In contrast, the research conducted by Firmino Junior et al. [2020] represents a more sophisticated approach, situating itself within the landscape of digital games that champion Brazilian cultural heritage. Using the Unity3D engine and RETAIN methodology [Gunter *et al*., 2008], they developed a prototype game teaching the Brazilian legend of Japuaçu, a fascinating Amazonian narrative on indigenous people's access to the fire [Firmino Junior *et al*., 2020]. Although further game development is needed to comprehensively understand the legend, including refining checkpoint systems, the prototype showed promising results. Its potential was underscored by an initial testing score of 54.2 out of 63, highlighting its capacity to foster cultural knowledge. Likewise, the research of Carvalho et al. [2015] employs a prototype game to impart Brazilian folklore to students. This approach enriches cultural awareness by incorporating authentic Brazilian geography and folklore [Carvalho *et al*., 2015]. The study evaluates the effectiveness of traditional teaching versus game-based learning via a controlled case study. Keller's Instructional Materials Motivational Survey [Cook *et al*., 2009] is utilized to evaluate student motivation, intending to enhance technology integration in classrooms and cultural learning. Furthering this endeavor is the game *Seres do Folclore Brasileiro* [Domingues, 2022], which aims to facilitate elementary history education by encouraging the discovery and identification of Brazilian folklore characters hidden within the game's scenario.

Aritana and the Harpy's Feather [Duaik *et al*., 2014], a 2D platform game, weaves indigenous culture and mythology into an engaging casual gaming experience. The gameplay mechanics focus on skill and timing, integrating traditional platform elements with a unique ability system inspired by indigenous artifacts, creating a deep connection with Brazilian cultural heritage with striking visuals and immersive storytelling. The action RPG *Guerreiros Folclóricos* [Unique, 2018] underscores a significant milestone in encapsulating Brazilian cultural heritage. Featuring Kambaí, an indigenous warrior set on a quest to reclaim his lost powers, this game parallels Brazil's quest for better representation in the gaming industry. The plot navigates the contest between nature preservers and disruptors, encapsulated in Kambaí's battles against folkloric adversaries, in an engaging narrative imbued with rich aesthetics. *Tropicália* [Franqueira, 2023] inspired by 16-bit era RPGs and Super Nintendo classics, adds another layer of Brazilian culture into gaming. Kaique, a small Guarani warrior, embarks on a journey to rescue his kidnapped girlfriend from the deity Tau, resulting in an immersive and interactive gaming experience. Lastly, the recent launch of *Lendas* [KaioGxLendas, 2023], a 3D survival and exploration game, showcases the gaming community's increased focus on preserving Brazilian cultural heritage. Filled with special visual effects, the game's living ecosystems are the stage for confrontations with creatures drawn from Brazilian folklore.

In summary, these games collectively emphasize the significance of preserving and interpreting Brazilian heritage via gaming, demonstrating their potential to represent folklore and shape future research endeavors.

2.2 VR Games with Immersive Narratives

Several titles like *Ghost Giant* [Mike Epstein, 2019], *Moss* [Mccaffrey, 2023], *Coexist VR* [de Oliveira and Rodrigues, 2023], *Red Matter* [Vertical Robot, 2018], *Call of the Sea VR* [Out of the Blue Games, 2023], and *Maskmaker* [InnerSpace France VR, 2021] showcase how VR can create engaging narratives. These games tackle also common VR challenges such as motion sickness by focusing on hand-driven interactions and minimizing extensive movement, which enhances player comfort.

More specifically, *Ghost Giant* [Mike Epstein, 2019], known for its empathetic storytelling [Thunderful Games, 2019], allows players to influence the story through their decisions, fostering a deeper connection to the characters. *Moss* [Mccaffrey, 2023] uses hand and arm movements for interaction, effectively reducing motion sickness while maintaining player immersion. *Call of the Sea VR* [Out of the Blue

Games, 2023] combines exploration and puzzle-solving on a mysterious island, deepening the immersive experience. In *Maskmaker* [InnerSpace France VR, 2021], players craft masks to explore different identities and stories, enriching the gameplay. *Red Matter* [Vertical Robot, 2018] delivers a suspenseful story set during a space cold war, noted for its strong visuals and engaging narrative.

2.3 Final Remarks

Unlike previously mentioned related works that dive into Brazilian folklore, *Caturama VR* is a serious 3D game that incorporates advanced 3D graphics and mechanics. Moreover, although being a prototype game, *Caturama VR* integrates Brazilian legends through a singular narrative into its gameplay, inventory, special effects, and minigames, offering a unique blend of interactive storytelling and cultural immersion.

Caturama VR distinguishes in the domain of Brazilian cultural heritage games by integrating folklore directly into VR gameplay mechanics. Unlike *Aritana and the Harpy's Feather*, which focuses on platforming skills, or *Guerreiros Folclóricos*, which relies on narrative to convey cultural themes, *Caturama VR* embeds folklore into both the gameplay and decision-making processes. In contrast to titles like *Tropicália* and *Lendas*, which use traditional game genres to explore cultural narratives, *Caturama VR*'s use of VR enhances the immediacy and immersion of these cultural interactions.

In addition, *Caturama VR* shares common ground with VR games like *Ghost Giant*, *Moss*, *Coexist VR*, and *Maskmaker* in its focus on interactive storytelling and player engagement. Similar to these titles, *Caturama VR* utilizes hand-driven interactions to enhance player comfort and minimize motion sickness, a common strategy in VR game design to maintain immersion.

However, *Caturama VR* stands out by integrating Brazilian cultural legends directly into its gameplay mechanics and narrative. This integration goes beyond the empathetic storytelling of *Ghost Giant*, where players' decisions impact the story, by embedding cultural education within its interactive elements. Unlike *Moss*, which focuses purely on physical interactions to maintain immersion, *Caturama VR* combines these interactions with culturally-themed puzzles and spells that have narrative consequences, offering a richer layer of gameplay.

While *Call of the Sea VR* and *Caturama VR* both emphasize exploration, the former does so on a mysterious island setting with puzzle-solving elements, whereas *Caturama VR* leverages exploration to deepen the player's understanding of Brazilian folklore. *Maskmaker* provides a similar approach to identity exploration through mask crafting, but *Caturama VR* extends this concept by using cultural symbols and narratives to enhance the storytelling, making the exploration of identities not just a gameplay mechanic but also an educational journey.

Finally, compared to *Red Matter*, which delivers a visually impactful narrative in a sci-fi setting, *Caturama VR* uses its cultural themes to create a unique educational experience that is rooted in real-world culture and heritage, setting it apart in terms of its educational objectives and cultural depth within the VR landscape.

3 Game Design and Development

In developing Caturama VR, we aimed to highlight the significance of cultural heritage, particularly Brazilian folklore. Currently, the game narrative centers around the legends of Iara, Curupira, Pink Dolphin, Saci, and Victoria Regia. In our game, these characters embody Resilience, Strength, Adaptability, Cunning, and Harmony, respectively, each symbolized by sacred gems, reflecting the serene and interconnected essence of the Amazonian ecosystem. To reinforce the goal of acquiring these precious stones and to immerse players in a magical fantasy experience, the game incorporates enchanting and magical special effects. These carefully crafted elements not only enhance the game's aesthetic appeal but also play an important role in emphasizing its playful and fantastical aspects, fostering an understanding and appreciation of our cultural heritage through its design and gameplay mechanics.

To create a healthy game environment, we have consciously avoided incorporating combat or destructive behavior among characters. Thus, this game focuses on promoting positive interactions and problem-solving, emphasizing curiosity [Spielberger and Starr, 2012], courage [Campbell, 2008], and the thrill of the journey [Malone, 1981; Prensky, 2001], rather than conflict and aggression. Our game centers on the adventurous spirit of Caturama, a young member of an indigenous tribe from the Brazilian Amazon forest, driven by his thirst for proof that folkloric legends do not exist and his inherent bravery to confront any consequence. His age fuels this audacity, leading him into uncharted territories to pursue knowledge and understanding. Embarking on this hero's journey [Campbell, 2008], Caturama demonstrates the fundamental essence of interest and the joy of exploration. This way, our game aims to engage players through an original narrative that celebrates curiosity, courage, and the thrill of the journey.

Caturama VR is suitable for all ages, offering an immersive experience with simple controls and family-friendly content. With adjustable difficulty levels, it ensures fun and challenges for both beginners and experienced players, promoting educational entertainment for everyone.

Our game was developed using the Unity3D engine, incorporating established best practices in game design, development, and VR experience [de Oliveira and Rodrigues, 2023]. Throughout its development, specific attention was paid to the efficient use of the Meta Quest 2's resources. This included optimizing graphics, animations, 3D walkthroughs, and particle effects to ensure they are visually compelling yet light on processing demands. Memory usage was carefully managed to prevent overloading the system. Technical intricacies were considered to ensure a grounded gaming experience. This included fine-tuning the game's code to maintain a high frame rate and reducing latency, thereby ensuring a seamless and responsive VR experience. The development team employed various strategies such as code profiling, efficient algorithm implementation, and reducing computational

overhead wherever possible.

Supporting tools such as VisualStudio, Blender (a free 3D creation suite for modeling, rigging, and rendering), and Mixamo (an online database for character customization and motion capture animations) were employed. Sound design and effects were sourced from publicly available files on Freesound.

3.1 Narrative

Caturama VR is rooted in an original interactive narrative we crafted, centering around five sacred gems of a Brazilian Amazon forest indigenous tribe. These gems, symbolizing Brazilian indigenous beliefs and traditions, guide players through our cultural heritage, creating an educational and immersive experience within the gaming VR environment. It unfolds as follows.

In the past, in the heart of the Amazon region, there lived an indigenous tribe known for their profound connection to the forest and the spirits dwelling within it. At the center of their village stood a crafted altar, a tribute to these spirits. Legend told of five sacred gems that graced this altar: the Sapphire of Strength, the Emerald of Endurance, the Ruby of Resilience, the Citrine of Wisdom, and the Opal of Harmony (Figure 2). Each gem was believed to be a gift from the spirits of sea, forest, fire, air, and water, linking to the mystical beings of the Iara, Curupira, Pink Dolphin, Saci, and Victoria Regia.

The Sapphire of Strength, radiating a fierce blue, embodied the tribe's formidable strength and resilience, symbolizing their duty to protect. The Emerald of Endurance, with its deep green hue, represented the tribe's harmonious relationship with the rainforest, vital for sustaining life. The Ruby of Resilience, glowing with a fiery red, signified adaptability and prosperity, reflecting the tribe's ability to evolve and thrive amidst change. The Citrine of Wisdom with its warm yellow glow, embodied wisdom and cunning, emphasizing the importance of knowledge and astuteness. The Opal of Harmony, shimmering with a serene blend of pink colors, symbolized the balance and unity between humans and nature, a gift from the water spirit, representing the harmony of existence.

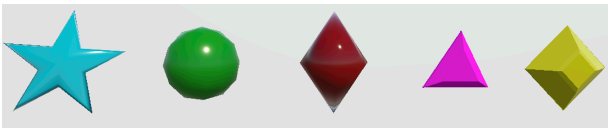


Figure 2. From left to right: the Sapphire of Strength, the Emerald of Endurance, the Ruby of Resilience, the Opal of Harmony, and the Citrine of Wisdom.

These five gems together formed the spiritual heart of the tribe, each an important pillar in their culture and belief system, guiding them in their daily lives and connecting them with the natural and the mystical world. However, as time passed, the younger generations began to question the ancient legends. Doubts about the tales and the mystical powers of these beings crept in, leading to a diminished belief in the sacred gems. Feeling their significance fading, the legendary creatures, pained by the loss of reverence, decided to reclaim all five gems, making a solemn vow to return them only when true belief and respect were rekindled.

Sensing the dwindling faith, Iara, Curupira, Pink Dolphin, Saci, and Victoria Regia, claimed the Sapphire of Strength, the Emerald of Endurance, the Ruby of Resilience, the Citrine of Wisdom, and the Opal of Harmony, respectively. Each of these actions was a call for a revival of respect and belief in the old ways and the deep connections they represented. The creatures awaited a time when the tribe's descendants would once again honor the legends and the wisdom they held, hoping that the gems' absence would remind them of the values and teachings they symbolized.

3.2 Characters

In the game design, careful adaptations were made to the characters (Figures 3, 4, and 5) from reputable 3D model repositories[1]. These adaptations involved modifying a female character to represent pregnancy through Blender's modeling capabilities, rigging, and animations for characters that lacked them, and adjusting the coloration of objects like the dolphin to achieve the desired visual aesthetics.

Figure 3. From left to right and top to bottom, respectively: Caturama, tribal Chief, and other tribe members.

Additionally, enhancements were made by creating a complete Saci's pipe 3D model, with dynamic smoke effects to create a more vivid legend representation. The Victoria Regia lilies were meticulously composed and positioned in the river waters, ensuring a natural distribution and interaction with the environment. Furthermore, the Victoria Regia, hanging from a tree, was uniquely customized to serve as a swing, adding a whimsical element to the scene. All these elements, along with the customizations of all special effects, were crafted to harmonically enrich the visual narrative and user experience. In particular, the Pink Dolphin and Victoria Regia characters are presented in the game in both forms: human and aquatic. More details are as follows:

[1] `https://sketchfab.com/3d-models/free`, `https://assetstore.unity.com/packages/3d/`, `https://sketchfab.com/3d-models/saci`, `https://www.freepik.com/free-vector/six-african-culture-icons`, and `https://sketchfab.com/3d-models/fantasy-elfscene`.

Caturama: A young Indian who serves as the protagonist, this character provides players with a firsthand experience of the indigenous tribe's culture and lifestyle (Figure 3). In most scenes, he is represented only by his 3D hands controlling the game from a first-person perspective. These 3D hands were designed to interact seamlessly with the virtual environment of the game, further immersing the player in the unique and rich world of the indigenous culture depicted. This design choice not only enhances the realism of the game but also allows for a more intuitive and engaging gameplay experience, as players navigate through the story and challenges using these hands as their primary interface. An example is shown in (a) of Figure 7.

Figure 4. The mythical beings, from top to bottom and left to right: Iara, Curupira, Pink Dolphin (in both forms, human and aquatic), Saci, and Victoria Regia (in both forms, human and aquatic).

Indigenous Tribal Chief: This character holds an important pivotal role in the tribe, offering guidance, wisdom, and crucial tasks to the protagonist (Figure 3).

Other Indigenous Tribe Members: These characters contribute to the social and cultural richness of the tribe, aiding in tasks, sharing knowledge, and adding to the narrative progression (Figure 3).

Iara, Curupira, Pink Dolphin, Saci, and Victoria Regia: These mythical beings from Brazilian folklore play significant roles as supernatural entities in the game, each tied to a sacred gem reflecting their essence, enriching the mystical ambient of the game world (Figure 4). Supplementary to these main characters, our game also features various non-playable characters (NPCs) that represent:

The Villagers: These characters add depth to the tribal community, each with their distinctive roles, personalities, and dialogues, including a pregnant woman, giving life to the village and emphasizing cultural diversity (Figure 5.a).

The Deforestation Workers: As antagonistic figures, these characters bring conflict into the game, symbolizing the threat to the indigenous lands and biodiversity, serving as catalysts for the protagonist's journey (Figure 5.b).

These characters have been conceived as agents in each moment of the game narrative. They collectively contribute to creating an engaging, culturally rich, and challenging gaming environment that draws players into the indigenous world and its struggles.

(a) Villagers.

(b) Deforestation workers.

Figure 5. Other NPCs of the VR game, most of them are animated.

3.3 Legends' Encounters

Five special encounters and challenges encourage players to learn more about the folklore legends and their cultural significance within the native Amazon forest tribe, as shown in Figure 6. These encounters enrich the game, emphasizing the importance of respecting and preserving cultural heritage.

More specifically, in these encounters, players have the freedom to chart their journeys through the game. They can explore and interact with various folklore legends in any sequence they prefer (see Figure 6), all within the immersive VR environment, with the ultimate goal of retrieving the five precious gems (Saphire of Strength, Emerald of Endurance, Rubi of Resilience, Citrine of Wisdom, and Opal of Harmony) that were originally taken from their tribe by these legendary characters (Figures 2 and 6). In our game, these precious gems not only add a layer of cultural depth to the game but also provide the protagonist with tangible symbols of the lessons learned and the virtues gained from each encounter with the legendary characters.

From now on, the images depicting interaction with the 3D environment and its game objects have been generated via screenshots taken with the right hand of one of the developers, so in these images, only the VR left hand is displayed.

Iara Encounter: Caturama meets the Iara [Cascudo, 2015], a mermaid-like creature with a rich backstory, near a river (Figure 7.a). Once a warrior betrayed by her siblings, she was transformed by gods into her current form and now seeks revenge. Known for her enchanting beauty and hypnotic singing, Iara lures her prey to their doom. In the game, the player assists Caturama in resisting Iara's song through a rhythm and memory-based mini-game (Figure 7.b). This challenge tests the player's problem-solving skills and cultural understanding, to emphasize empathy and the preservation of Amazonian tribal heritage. Should Caturama succeed in this visual and auditory memory challenge, he will

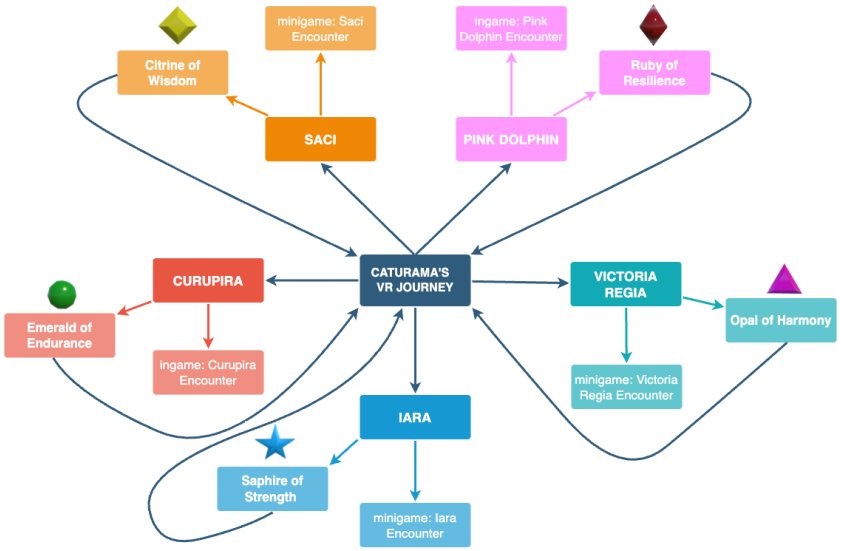


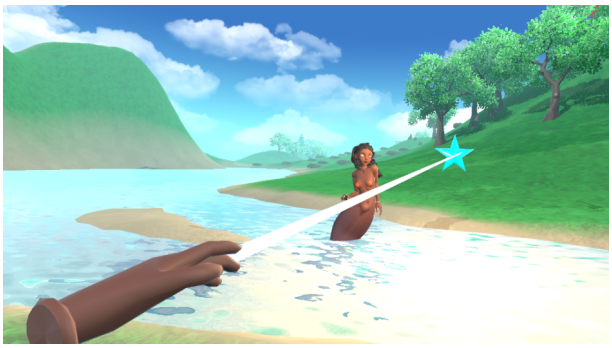
Figure 6. Caturama's VR Journey: Chart the paths through folklore legends in a virtual world for precious gems.

be rewarded with the Saphire of Strength, acknowledging his courage and respect for Iara. However, if the player fails to complete the mini-game, Iara will cast a spell of bright yellow light rays that illuminate the player's vision to an intimidating degree (Figure 7.c). In the legend, Iara is known to overpower and disorient those she encounters with her captivating presence and voice. The spell in the game symbolizes this overwhelming sensation, providing players with a direct, albeit temporary, experience of the mythological power Iara holds. This spell duration is designed to be impactful yet not overly hindering, allowing players to feel the intensity of Iara's legendary abilities while still maintaining an engaging gameplay experience.

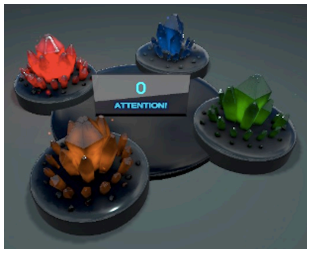
Curupira Encounter: Navigating the disorienting forest where Curupira [Cascudo, 2015] lives, this mythical creature with backward feet (Figure 8.a), known as a forest guardian, faces environmental tests. Witnessing illegal deforestation (Figure 8.b), Caturama's mission shifts towards forest protection. He gathers tools used for deforestation without confronting workers (Figure 8.b), proving his understanding of the ecosystem. The elusive Curupira, identified by echoing laughter, appears once these tools are confiscated. Caturama's courage and empathy for the forest earn him the Emerald of Endurance upon giving the tools to Curupira for destruction. According to the people living in the forest, the Curupira possesses the ability to create illusions and lead astray those who harm the forest, making them lose their way. If the player does not succeed in this mission, the Curupira will respond by surrounding the user with a vast cloud of brief but impactful smoke (Figure 8.c). The idea is to create an immersive experience without significantly hindering gameplay progress. This spell is intended to be an enlightening experience, aiming to impart upon Caturama the profound distress that the trees endure when destroyed by humans. It acts as a reminder of the critical importance of safeguarding the natural world.

Pink Dolphin Encounter: In this game encounter, Caturama delves into the enigmatic world of the shapeshifting Pink Dolphin [Cascudo, 2015], a being rooted in riverside village folklore. Known for its ability to transform into a human man and charm the villagers (Figures 9.a and b), the Pink Dolphin's tale unfolds through villagers, each harboring fragments of the story. Key insights emerge from the tale of a pregnant woman and the discovery of the Pink Dolphin's hat, used to conceal its blowhole. By collecting these clues and personal items scattered throughout the village, the player uncovers the Pink Dolphin's true identity and locates its hiding place for a final confrontation. At this moment, Caturama must use narrative choices to convince the Pink Dolphin to reconsider its actions, highlighting the risk of extinction due to its behaviors. If successful in persuading the creature about its misconduct, Caturama is granted the Ruby of Resilience, and the Pink Dolphin agrees to return to its original aquatic form (Figure 9.d). If the player's mission is unsuccessful, the Pink Dolphin, steeped in rich riverside folklore, responds with a display of its mythical nature. It casts a spell of radiant pink smoke, symbolizing its mystical essence and storied history (Figure 9.c). This spell is a manifestation of the dolphin's enigmatic powers, rooted in its legend of transformation and seduction. The spell's duration and intensity were calibrated to be impactful, reflecting the Pink Dolphin's significant role in local lore, while ensuring that it complements the game's overall flow and interactivity. This approach ensures that the spell serves as a memorable element of the story, enhancing the player's understanding of the Pink Dolphin's cultural and historical significance.

Saci Encounter: In the heart of the Brazilian forests, where the trees whisper ancient tales, dwells Saci-Pererê, a mythical being of remarkable agility and playful spirit (Figure 10.a). Known for his one leg, iconic red cap, and pipe, emitting mystical smoke, Saci embodies the essence of the forest's playful side. His legend [Lobato, 2008] speaks of his joy in challenging and interacting with those who venture into his domain. The encounter with Saci is both a test and a treat. Saci invites the player to control him in a dynamic race within a platform minigame, guiding Saci through a series of platforms and obstacles in the forest (see Figure 10.b). In this challenge, the player's speed and wit are put to the test as they maneuver Saci across the tricky terrain. If Saci falls during the game, the player experiences Saci's whimsi-



(a) The Iara character in the 3D environment of the VR game, set in the river of the forest.



(b) The Iara's mini-game.

(c) The Iara's spell.

Figure 7. Iara encounter.

cal pranks, a result of his magical trickery. Jumping over 12 platforms, successfully navigating Saci to the end of the race rewards the player with a precious gem "borrowed" from the Caturama's tribe, the Citrine of Wisdom. This gem is a symbol of the knowledge and cunning the player gains from skillfully guiding Saci, underlining the importance of using abilities with responsibility and respecting the forest and its mischievous denizens. If the child loses the challenge, Saci will cast his "Enchanted Smoke" spell. He will create a cloud of magical ghost smoke around the player, crafted using special effects and particle systems (Figure 10.c). This smoke will envelop the protagonist in a spectacle of mystical ghosts widespread everywhere. This spell not only marks the protagonist in the tribe as a part of Saci's trickery but also serves as a playful reminder of Saci's cunning and magical power. The ghost smoke will gradually disappear, leaving a lasting memory of the adventure and the encounter with this legendary figure of Brazilian folklore.

Victoria Regia Encounter: Amidst the tranquil waters of the Amazon, the presence of Victoria Regia is as serene as it is mystical (see Figures 11.a and b). She is the embodiment of the water's depth and secrets, often appearing as a beautiful woman with long hair. As described in [Franco and Lollo, 2014], her visage, reflecting the moon's luminescence, is a testament to her connection with this celestial body and her

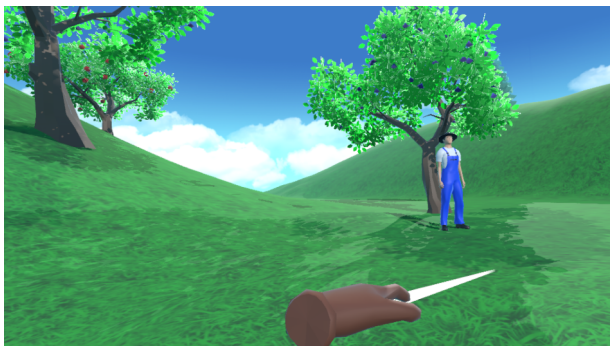
(a) The Curupira character in the 3D forest environment of the VR game.

(b) Curupira's in-game challenge.

(c) Curupira's spell.

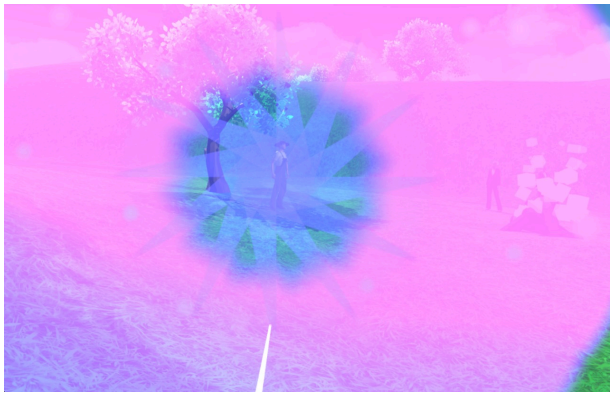
Figure 8. Curupira encounter.

role as the guardian of water's mysteries and the storyteller of its depths. In the tales, the Victoria Regia not only challenges the brave to comprehend the language of the waters but also embodies a deeper, symbolic journey of understanding and connection with nature. This profound symbolism is intricately mirrored in the VR game's mini-game. Here, players are entrusted with the task of throwing lilies flowers–-each representing the essence of the legend herself–- into a "cuia", the traditional Brazilian gourd (Figure 11.c). To accomplish the mission, players must score a minimum of 50 points. Flowers spawn in the minigame through a randomized loop of interactions, with an additional random delay of 0.5 to 0.7 seconds between each lily spawn. Successfully landing the lilies into the gourd symbolizes the player's attunement with the legend's wisdom and the harmony of nature. However, missing the target and letting the flowers lay on the floor serves as a poignant reminder of the balance between human actions and nature's grace. Those players who accept her challenge but fail are bestowed with the "Eyes of the River" spell (Figure 11.d). This enchantment produces a blue hue, reminiscent of the tranquil depths of the river, complete with the mesmerizing effect of gentle bubbles floating across the player's field of view. It is as if the player is

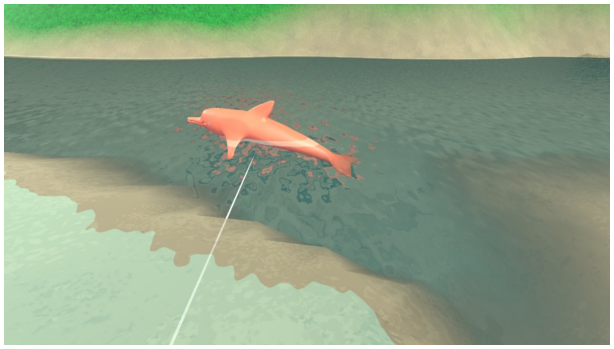


(a) The Pink Dolphin character in the 3D environment of the VR game.

(b) Pink Dolphin's in-game challenge.



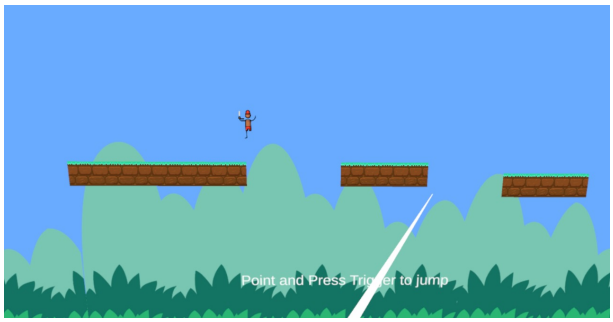
(c) Pink Dolphin's spell.



(d) The Pink Dolphin in its aquatic form illustrates the transformation of the same character from a human figure to a mystical aquatic creature.

Figure 9. Pink Dolphin encounter.

(a) The Saci character in the 3D forest environment of the VR game.



(b) Saci's minigame.

(c) Saci's spell.

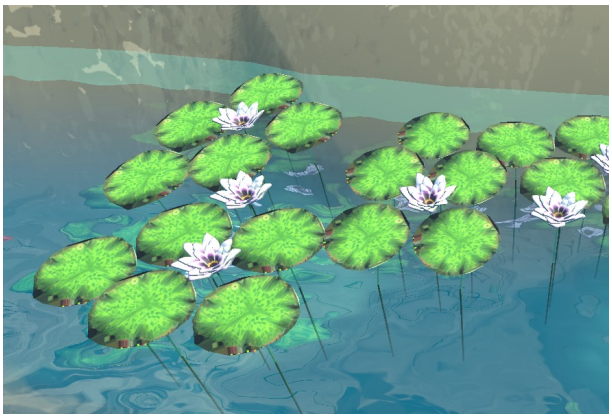
Figure 10. Saci encounter.

gazing through the river itself, enveloped in its serene and mystical essence. For those who succeed in her challenge, Victoria Regia grants the Opal of Harmony. This gem, symbolizing harmony and balance, is a testament to the player's deep understanding and respect for the Amazon's mysteries. The awarding of the Opal of Harmony goes beyond a mere triumph; it signifies the player's alignment with the essence of Victoria Regia's legend—a commitment to respecting and preserving the delicate equilibrium of nature.

3.4 Mechanics and Resources Management

Figure 12 displays the various components of the controller on the Meta Quest 2 platform, each of which has been mapped to specific mechanics in the Caturama VR game. This design approach enhances player immersion and presence, granting the users control over events and interactions within the game from a first-person perspective. In this viewpoint, only the hands of Caturama, the player's character, are visible, emphasizing the sense of personal engagement in the virtual environment.

In Figure 12.a, the (A) button on the front of the controller is enabled for the minigame's Simon-like memory sequence, specifically activated in the storyline of the Iara encounter.



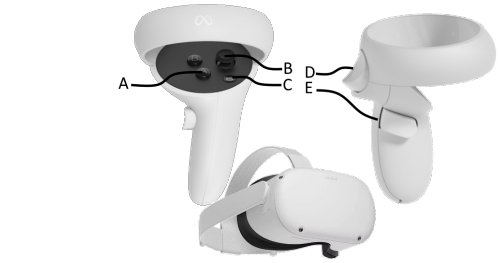
(a) The Victoria Regia as water lilies in the VR game's 3D river environment.

(b) The Victoria Regia character in the 3D environment of the VR game, depicted on a swing in a tree, illustrating her transformation from an aquatic plant to a mystical human figure.

(c) Victoria Regia's minigame.

(d) Victoria Regia's spell.

Figure 11. Victoria Regia encounter.



(a)

(b)

Figure 12. (a) Meta Quest 2 VR headset and controllers, and (b) Event control mechanics mapped for the VR game.

It involves pointing a beam at four crystals moving around a flat platform, where the player must interact with the crystals following the sequence of lights executed by the CPU. The thumbsticks (B), when moved left or right, rotate the player by 45° in the base game featuring the hands of Caturama. In the Victoria Regia minigame, these thumbsticks move a gourd object to the left or right to catch water lily flowers falling from the sky. In the Saci minigame, the player uses the left controller's trigger (D) to execute jumps between platforms in the forest to prevent Saci from falling through the gaps. The round button (C) at the center of the controller is reserved for accessing the Oculus system functions. Finally, the grip buttons (E), located on the side of the controller where the player's hand rests, simulate the action of grabbing virtual objects and moving within the scenario.

The character's hands were extracted from the original Caturama's 3D model using Blender's advanced editing tools. This process involved carefully separating the hands from the main 3D body model, ensuring a clean and precise detachment. Once isolated, the hands underwent a detailed rigging process. Rigging has involved the creation and placement of joints within the hands, enabling realistic and fluid motion. This step was fundamental for achieving lifelike movements and gestures in subsequent animations.

In detail, within Blender, four distinct 3D hand model states were crafted, mimicking the player's hand actions coordinated with the player's event control mechanics shown in (b) of Figure 12. These states include:

- **Relaxed:** A natural, restful position of the hands (open hand), suggesting ease and a lack of tension.
- **Thumbs-Up:** A universally recognized sign of approval or positivity, where the thumb is prominently raised.
- **Closed Fist:** A dynamic motion where the hand transitions into a closed fist, symbolizing determination or emphasis.
- **Pointing with the Index Finger:** A gesture where the index finger extends to direct attention or indicate an

object or direction.

We created these animated states to provide a range of expressive and responsive hand movements, enhancing the interaction within the VR environment. Both of Caturama's hands, controlled via mechanical actions through Meta Quest 2, are displayed in the game for enhanced player immersion. Finally, the player's perspective has been customized to match that of a child's viewpoint, aligning with Caturama's perspective and narrative, and thereby contributing to a more immersive and realistic user experience.

3.5 Animations and Special Effects

Most humanoid characters have associated animations. Those have been rigged using Blender and animated with Mixamo. Other game objects, such as river water, tree leaves, village bonfires, Victoria Regia personified as a woman, and the Pink Dolphin as an aquatic mammal, are also animated. Shaders were also applied to many objects to create realistic textures, lighting effects, and dynamic shadows, significantly enhancing the visual appeal and immersion of the game environment by adding depth and a sense of realism.

In the VR game design, a special white trailing effect (Figure 13) has been added in the form of a fading curved line, serving as a clue to guide players toward the legends' locations within the VR environment for exploration via walkthrough.

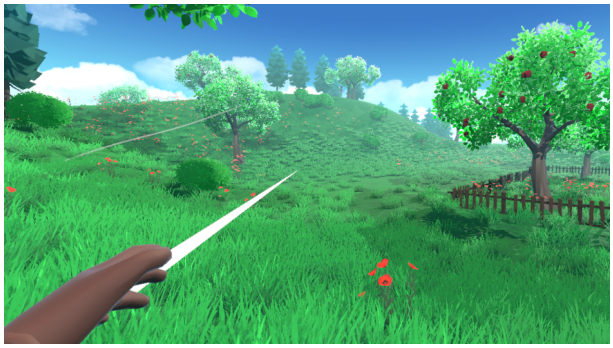


Figure 13. Visualization of the dynamic trailing effect, for guiding players to legend locations in the VR game environment. The white trail effect is depicted in the background, ascending the hill on the left, in a thin white curve.

In detail, as previously mentioned, if a player fails to master the Simon-like minigame presented by the legend Iara, a unique spell is cast upon the player, which features yellowish light particles with a white-fading tail with a duration of 20 seconds (Figure 7.c). Moreover, the system is configured to manage up to 200 particles, emitting 50 per second. The lifespan of each particle varies from 1.5 to 2.5 seconds, with the tail enduring for 0.5 seconds. This design not only ensures a dynamic and "magic" display but also maintains efficiency in the VR game, with parameters calibrated for optimal visual appeal and performance.

The inability to meet Curupira's challenges activates a special effect that features fiery and smoky particle systems (Figure 8.c). More specifically, two-particle systems are activated, and positioned on the left and right sides of the player's VR screen. These systems have a duration of 20 seconds, with each particle's lifetime varying between 0.6 to 0.75 milliseconds and a size range of 1.5 to 2 times the original scale. Both systems release particles to simulate fire and smoke. Although oriented towards the screen's center from the edges, the particle effects are influenced by gravity, causing them to rise and simulate the appearance of fire followed by smoke. The maximum capacity for each particle system was customized to 30 particles, with a maximum emission rate of 25 particles per second. The color of these particles shifts over time, beginning with a light orange hue and transitioning to darker shades of brown as they progress through their lifecycle. The size variation of the particles starts at 0 and rapidly expands to near size 1 as they approach the end of their lifecycle.

Upon failing Pink Dolphin's tasks, players witness a scene where a large pink sphere and swirling particles envelop the VR screen for 20 seconds (Figure 9.c), representing the lost chance to win Pink Dolphin's gem. It consists of particles swirling in a circular motion in front of the player, with a maximum limit of 50 particles.

Conversely, during the encounter with Saci, a particle system is activated, simulating the smoke from his pipe (see Saci in Figure 4). This system limits to 50 particles to maintain hardware performance, emitting them in soft shades of gray at a 20°. Another special visual effect is activated when Saci challenges players with a mini-game. Failure to succeed in his challenges triggers some special effects, where ghostly apparitions emerge (Figure 10.c), signifying the player's missed opportunity to claim the gem guarded by Saci. These apparitions were customized to emerge from the bottom of the screen, ascending towards the top over 20 seconds. Each apparition has a variable lifespan ranging from 1.8 to 2.2 seconds. The maximum number of simultaneous particles displayed is 15. This visual spectacle, created by a dynamic particle system, adds a layer of enchantment to the game.

When players falter in Victoria Regia's minigame, her special effect unfolds–a mesmerizing display of blue-translucent planes and bubble particles. This effect not only enhances the visual experience but also encapsulates the essence of her watery realm. More in detail, it involves the integration of a plane with blue transparency, followed by a particle effect simulating bubbles (Figure 11.d). These bubbles persist for a duration of 20 seconds, with each bubble's lifetime varying from 1 to 1.5 seconds. Bubbles initially appear at a size constituting 20% of their original dimension and gradually expand to 40% of the original size by the end of their lifecycle. The maximum number of simultaneous particles for this effect was set at 28, with the bubble particles moving unidirectionally from the bottom to the top of the screen.

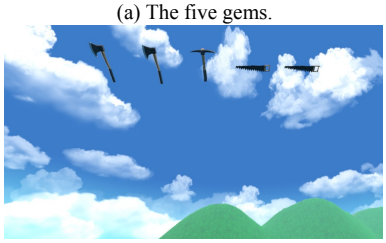
These custom animations and visual effects, created using the particle system [Moreno, 2023] and activated in Unity3D [Unity, 2020], are conceived to enhance the user's experience with vivid, engaging, and interactive visuals.

3.6 Inventory System

In Caturama VR, the inventory plays an important role, especially for an adventure game. It not only includes the five precious gems to be collected (Figure 14.a) but also features

various tools from deforestation workers (two pickaxes, two hacksaws, and one hatchet) shown in (Figure 14.b), and the personal collectible items from the Pink Dolphin character (pants, shirt, sneakers, and hat), shown in Figure 14.c. This diverse range of items adds depth to the game, encouraging exploration and interaction. It helps players understand the narrative's environmental themes and the impact of human activities on nature, while also providing a sense of achievement as they gather and utilize these items throughout their adventure.

(a) The five gems.



(b) The five deforestation workers' tools.

(c) The four Pink Dolphin's items.

Figure 14. The collectibles in the game's inventory.

In particular, to improve the VR player experience, we created a dynamic implementation that enables objects to follow the position and orientation of a camera in running time, while also setting a specific constraint on the maximum tilt angle upwards. It employs linear interpolation to smoothly transition the object's position to match the camera's current location [de Oliveira and Rodrigues, 2023]. This creates a tracking effect that is not instantaneous but slightly delayed, adding a natural feel to the movement.

Furthermore, the system introduces the following design for inventory visualization: shadows of the inventory items float above the level of normal player view when no item collection mission is active. Once a mission-requiring item collection starts, these are replaced with the required items, reverting to the items overview upon mission completion. This approach offers a flexible inventory view without the need for manual button inputs, enhancing user experience in virtual reality gaming. This way, we introduce a VR game feature where inventory items are retrieved through a floating menu. This floating menu is only activated when the player looks up at the 3D scene, instead of toward the horizon. As each inventory item is recovered, it is sequentially added to this panel, as shown in Figure 14. Successfully rescuing all inventory items (and the five gems in particular), prepares the protagonist to return to the sacred altar of his tribe, advancing toward the end of the game.

3.7 Game Over

The VR game's ending scene showcases two outcomes. In one, Caturama triumphantly returns the five sacred gems-the Emerald of Endurance, Sapphire of Strength, Ruby of Resilience, Opal of Harmony, and Citrine of Wisdom-to the tribe's primary altar (Figure 15.a). Upon placing all five gems, special magical effects also manifest in this scene, affirming the legends and revitalizing cultural heritage values through regional folklore appreciation (Figure 15.b).

(a) Victory: "Win!"

(b) A special "magical" effect reinforces the moment of reclaiming the five precious stones, emphasizing the player's achievement and the game's climax.

(c) Defeat: "Try Again!"

Figure 15. Game over scenes.

In the alternate ending, the player faces challenges in collecting and returning the sacred gems, with the scene offering motivational encouragement for the protagonist to persevere and potentially revisit the game to complete the mission (Figure 15.c).

4 Pre-user Testing Phase

This pre-user testing phase is essential for identifying and resolving major issues that could hinder player enjoyment or immersion, thereby setting a foundation for user feedback in the next phase of development.

Initially, we conducted functional tests to detect inconsistencies and failures, identify areas for improvement, and refine the implementation to minimize execution risks and optimize the gaming experience. This comprehensive Functional Testing was divided into three key areas: Unit Testing, Integration Testing, and System Testing. In the Unit Testing phase, we examined game components like interactive objects, animations, and audio cues to ensure they worked properly. Next, during Integration Testing, we focused on ensuring compatibility and synchronization between audio-visual elements and the interaction of game physics with VR controllers for immersion. Finally, System Testing targeted frame rate consistency and computational resource usage (CPU, RAM, and GPU) in key 3D scenes to optimize performance and maintain seamless gameplay.

To enhance the testing process, mock components were integrated with the *Unity Test Framework* to simulate real game scenarios. These mocks, representing both simple and complex game interactions, enabled the development team to manipulate and control game inputs and outputs without relying on actual game components. Examples of mock components include simulated user inputs, simplified animations, and placeholder audio files, all triggered by gameplay events. This approach isolated specific functions within the game, ensuring that each component functioned as expected under various conditions. Alongside automated testing, the team also conducted manual tests to assess aspects like user interface and overall player experience, which are challenging to evaluate thoroughly through automation alone. By combining mock components and manual testing with the automated capabilities of the testing framework as an early evaluation step, we could achieve more accurate results, thereby improving the game's quality and stability. Building upon these tests, we progressed to VR-specific Usability Testing by the three team members. More details are given in section 4.2.

4.1 Resource Utilization

The 3D environment of the game encompasses a multitude of objects with intricate geometry and visual attributes, such as the geometric mesh surface of the river and specular shading effects. Numerous objects, such as the leaves on trees throughout the forest, are animated and cast dynamic shadows, placing substantial demands on rendering resources.

On the computer used for development, equipped with an Intel Core i5 12500H processor, an RTX 3050 GPU with 4GB VRAM, 32GB of RAM, and a 1TB NVMe SSD, frame rates ranged from 35 to 70 FPS, depending on the view frustum in outdoor environments. On the Meta Quest 2, the frame rate remains around 60 FPS.

We optimized the game's performance by implementing measures such as adding occlusion culling and reconfiguring the shadow cascade, a rendering technique that generates realistic shadows at various distances by dividing the scene into shadow maps with varying resolutions. More specifically, in our game with shadow distance set to 50 and using four cascades, these settings optimized the rendering of shadows in Unity by dividing the view frustum into multiple cascades based on distance. This approach allowed for more accurate and efficient shadow rendering, with higher resolution and detail closer to the camera and lower resolution further away. These measures reduced polygon counts by up to 50% in certain scenes.

Additionally, the average CPU, RAM, and GPU consumption were measured when starting the game outside the Unity development environment, *i.e.*, from the game executable, from the perspective of the following scenarios: encounters with the Curupira, Victoria Regia, Pink Dolphin, Iara, Saci, and the Tribal Village. The results are shown in Table 1.

Table 1. Computational resource consumption per environment

3D Environment	CPU (%)	RAM (MB)	GPU (%)
Curupira	8.8	530	49.0
Victoria Regia	29.8	537	69.0
Pink Dolphin	16.0	541	96.0
Iara	7.9	544	53.9
Saci	26.0	547	50.8
Tribal Village	22.6	410	61.4

Based on these results, to optimize frame rates (FPS) to enhance the gaming experience, one can note that:

- **Curupira:** Moderately uses CPU, RAM, and GPU, indicating a scene with sufficient detail without overloading the system.
- **Iara:** Moderately to highly uses CPU, RAM, and GPU, suggesting additional visual detail while maintaining satisfactory frame rates.
- **Pink Dolphin:** Moderately to highly uses CPU, RAM, and GPU, providing an immersive experience with more elaborate visuals while maintaining good frame rates.
- **Tribal Village:** High CPU and GPU usage, but lower RAM, indicating a complex scene that may require additional optimization for smooth frame rates.
- **Saci:** High CPU and GPU usage, with significant RAM, suggesting a detailed and dynamic scene that may need adjustments for stable frame rates.
- **Victoria Regia:** Highest CPU, RAM, and GPU usage among the listed environments, indicating a highly detailed scene that may require further optimization for consistent frame rates and smooth gameplay.

Following, we sorted these results in ascending order based on CPU, RAM, and GPU consumption, as follows:

- **CPU:** Curupira < Iara < Pink Dolphin < Tribal Village < Saci < Victoria Regia
- **RAM:** Tribal Village < Curupira < Victoria Regia < Pink Dolphin < Iara < Saci
- **GPU:** Curupira < Saci < Iara < Tribal Village < Victoria Regia < Pink Dolphin

More in detail, the Vitoria Regia scene features intricate geometric details with textures and a wide view frustum, as the Tribal Village. However, the Tribal Village scene has fewer animated game objects. The Iara scene includes the river and its specular reflections. The Saci encounter, located at one of the highest points in the 3D environment, has a far plane of the view frustum that encompasses a significant number of triangles. In the Pink Dolphin scene, there are many humanoid game objects saturated with triangles.

Given the importance of maintaining a high FPS rate in the game, along with the critical role of GPU performance in ensuring a smooth player experience, we based our analysis on these three measures simultaneously: CPU, RAM, and GPU values for each environment, to determine their impact on FPS, ordering the results from higher to lower FPS rates: Tribal Village > Curupira > Iara > Saci > Victoria Regia > Pink Dolphin.

4.2 Early VR-Specific Usability Testing by Team Members

As the developers of the game and authors of this paper, we dedicate this section to discussing the usability testing undertaken by our team of three members. We engaged in early testing of the game through an opinion survey, allowing us to gather preliminary feedback and refine our game without the immediate need for Ethics Review Board submission. This initial phase focused on functionality checks and debugging, primarily to collect informal feedback on usability from our team. This approach not only aligns with best practices for initial usability testing but also prepares us for later stages that will require more structured user testing, comprehensive data collection, and ethical review.

This way, we conducted tests to assess the user experience (UX) of our VR game, focusing on *Comfort and Ergonomics*, *Interaction Fidelity*, *VR Navigation and Orientation*, *Content and Narrative Evaluation*, *Accessibility and Inclusion*, *UI Navigation*, *Inventory, Management, and Minigame Functionality*, *Prototype Feedback Loop*, *Graphics, Aesthetics, and Special Effects*, *Immersion and Presence*, and overall player feedback.

We evaluated motion sickness, eye strain, and physical fatigue, ensuring a comfortable experience, while also assessing the responsiveness and accuracy of VR controls, interaction with NPCs and the environment, and effectiveness of navigational cues. Our evaluation included narrative coherence, character integration, special effects, and language accessibility. Feedback on UI navigation, inventory management, and minigames' functionalities have been gathered, along with suggestions for improvement from internal playtesting sessions, guiding us in refining the game for optimal player engagement and enjoyment. We also assessed the intuitiveness and accuracy of VR controls which are paramount for a seamless immersive experience. Testing involved evaluating players' ability to navigate and interact with in-game elements using VR controllers. We focused on responsiveness and ease of mastering the control layout.

We adopted a free walkthrough approach, allowing the three team members (one developer at a time) who developed this game to freely navigate and interact within the game environment. By systematically exploring scenarios, especially those involving folkloric legends, our goal was to uncover potential usability issues impacting the player experience. Each team member conducted tests with a developer's eye, refining code and anticipating opportunities to enhance user experience. This method provided insights into the player's perspective and anticipated challenges in navigation, interaction, and comprehension within the game.

Upon completion of the game, each participant was asked to fill out a questionnaire with 30 questions seasoned by a UX specialist (one of the team members). This questionnaire, hosted on Google Forms, employed eighteen questions with a 5-point Likert scale based on the sentiment of the feedback (1-Strongly Disagree, 5-Strongly Agree) and twelve subjective questions regarding potential improvements.

Based on the testers' responses, the key findings are synthesized as follows:

Comfort and Ergonomics: All testers reported positive experiences regarding motion sickness, eye strain, and physical fatigue, indicating no significant issues in these areas. Suggestions for improvement include adjusting the Oculus headset's fit for users with prescription glasses, as two team members who wear glasses did not feel very comfortable with the headset overlapping the frames of their prescription glasses, and activating the responsiveness of the right-hand controller in navigating scenes.

Interaction Fidelity: Testers rated the responsiveness and accuracy of VR controls highly. Positive feedback was given for the implementation of first-person 3D animated hands. Suggestions for improvement include refining virtual hand positions and animations and enhancing interactions with NPCs, particularly in triggering events and interactions with certain characters, such as Iara and Saci.

VR Navigation and Orientation: Testers found particle systems effective for navigation cues but suggested making them more prominent. Recommendations include adding a tutorial for the game map and implementing a confirmation button before starting missions and minigames.

Content and Narrative Evaluation: Testers rated narrative coherence, character integration, and special effects positively. Suggestions include adjusting the difficulty level of certain mini-games.

Accessibility and Inclusion: Testers rated accessibility and the initiative for internationalization of the game, running not only the Portuguese version but also the tested English version, positively.

UI Navigation, Inventory Management, and Minigame Functionality: Testers provided positive ratings for UI navigation, inventory management, and minigame functionality. Suggestions include investigating errors and minutely lowering the inventory height placement to enhance the user's neck comfort.

Prototype Feedback Loop: Testers offered valuable feedback for improving game mechanics, narrative coherence, and navigation. Suggestions include clearer instructions for minigames and enhancing navigation guidance.

Graphics, Aesthetics, and Special Effects: Consistency in visual style and vibrant colors were praised, though some NPCs may need adjustment. Suggestions include triggering special effects slightly ahead of the player's vision for en-

hanced immersion.

Immersion and Presence: Immersion was enhanced through sound effects, storytelling, and interactive elements. Suggestions include integrating gameplay mechanics with 3D navigation for a more immersive experience, for example, by enhancing navigation guidance (perhaps by thickening the white trail lines of the special effects or making them longer in the forest environment) and activating the right-hand laser pointing (which was experimentally deactivated during the team members' test). Overall, focusing on NPC interaction and immersion can further elevate the player experience and prepare Caturama VR for future User Testing [Scheibler and Rodrigues, 2018].

In summary, testers had generally positive experiences, with some noted limitations and areas for improvement. These include refining NPC interactions, adjusting difficulty levels for the Saci and Victoria Regia minigames, optimizing minigame launches with an "OK" button to ensure player readiness, and enhancing navigation guidance. Additionally, while the gameplay is already smooth, further optimizing the environments of legend encounters to reduce computational resource consumption could make it even smoother, significantly enhancing the FPS experience. By focusing on these aspects, particularly NPC interaction and immersive elements, *Caturama VR* can be further refined for an enriched player experience in preparation for future User Testing.

5 Conclusions and Future Work

Caturama VR immerses players in Brazilian folklore, emphasizing the legends' cultural importance and the need for their preservation in indigenous heritage. This rich and immersive setting provides players with opportunities for exploration, discovery, and adventure as they navigate through the intricate landscape, unraveling its secrets and uncovering its hidden treasures.

Through VR game testing, rigorous functional testing stages were performed by the authors of this work. This way, we were able to refine our game to a predefined standard of quality, ensuring both reliability and an engaging player experience. Key enhancements focused on refining NPC interactions, adjusting minigame difficulties, improving navigation, and optimizing computational efficiency for smoother gameplay. Extensive testing targeted presence, immersion, navigation, control accuracy, graphics, and computational resource consumption, ensuring the game not only entertains but also immerses players fully in its virtual environment.

Thus, the pre-user testing phase effort was instrumental in fine-tuning the game's immersive qualities, ensuring an engaging, intuitive, and realistic experience. Specifically, the interactive scenes with the Pink Dolphin, Victoria Regia, and Saci were identified as the most computationally demanding. By addressing and resolving major issues early on, especially in these resource-intensive scenes, this phase helps prepare a more polished VR experience for User Testing. This lays a solid foundation for valuable feedback in the next development phase, enhancing player enjoyment and immersion.

Future work for *Caturama VR* could significantly benefit from incorporating real-user UX testing, providing essential insights to refine the game experience. In addition, system enhancements will involve implementing advanced spatial data structures to manage scene visibility more effectively [Serpa and Rodrigues, 2019] These hierarchical structures divide scenes into manageable sections, facilitating efficient rendering optimizations. By incorporating visibility algorithms with these spatial structures, we aim to enhance the culling process to render only visible elements, thereby significantly reducing computational load, particularly in complex scenes with numerous static and dynamic objects [Silva and Rodrigues, 2009]. Moving forward, we are aware of the limitations posed by the use of generic assets in our project. To address this, we plan to enhance cultural authenticity by securing financial resources and collaborating with artists who can offer culturally accurate representations. This commitment outlines our roadmap for future improvements that will resolve ethical concerns and elevate the quality of our cultural portrayals. In addition, enhancing NPC artificial intelligence will enable more dynamic interactions, bringing the virtual world to life, with every NPC in our game playing a pivotal role. Expanding the game with additional narratives, minigames, and legend encounters will further enrich the content. Additionally, exploring voice interaction with NPCs could introduce a new layer of immersion and interactivity.

Declarations

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Authors' Contributions

All authors collectively conceptualized the project, curated data, conducted formal analysis, and engaged in software development, art, and design, ensuring a robust and aesthetically appealing outcome. Thiago Narak C. de Oliveira contributed more significantly to the VR project's implementation, and Denise Q. M. Teixeira and Maria Andréia F. Rodrigues in the curated data and game conceptualization. The development, testing, and validation processes were collaboratively undertaken, reflecting a shared commitment to excellence. Maria Andréia F. Rodrigues and Thiago Narak C. de Oliveira concentrated also on writing, drafting, and revising content, ensuring clarity and coherence. Finally, Maria Andréia F. Rodrigues was also responsible for securing funding, crafting the narrative, designing gameplay, and establishing the project's methodology, laying the foundation for its thematic and interactive elements. All authors read and approved the final version of the manuscript.

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