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EMANUEL BANDEIRA FARIAS

A VIRTUAL REALITY APPLICATION FOR THE REHABILITATION OF CHILDREN WITH CEREBRAL PALSY - EXTENDED VERSION

FORTALEZA
2025

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Trabalho de Conclusão de Curso, na modalidade Artigo com Produto, a ser apresentado ao Curso de Bacharelado em Sistemas e Mídias Digitais do Instituto Universidade Virtual da Universidade Federal do Ceará.

Orientador: Prof. Dr. Antônio José Melo Leite Júnior.

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A Deus.

Aos meus pais, Carlos Alberto Menezes De Farias e Helena Lucia Bandeira Farias

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“Existe felicidade após o sangue e os machucados.” - Taylor Swift, Happiness, 2020.

APRESENTAÇÃO

Este trabalho constitui uma versão estendida do artigo intitulado *“A VIRTUAL REALITY APPLICATION FOR THE REHABILITATION OF CHILDREN WITH CEREBRAL PALSY”*, apresentado no Simpósio de Realidade Virtual e Aumentada - SVR 2025, que ocorre no SENAI CIMATEC, Salvador, entre 30 de setembro e 3 de outubro de 2025. O artigo foi aprovado no evento e atualmente encontra-se em processo de revisão para submissão final (Ver apêndice A).

A versão estendida expande o original, destacando o envolvimento do presente autor nos detalhes em relação à criação e execução da pipeline de desenvolvimento para a solução criada no projeto, com modificações pontuais da versão original em todo o seu decorrer, mas de todo modo, a autoria do trabalho se mantém entre todos seus autores.

O vídeo com a demonstração da aplicação desenvolvida está disponível em: https://tinyurl.com/mr37m7e7

A Virtual Reality Application for the Rehabilitation of Children with Cerebral Palsy - Extended Version

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***Abstract*—The development of virtual environments to support rehabilitation for various diseases and special needs has gained significant attention in recent years. These environments offer numerous advantages for patients and healthcare professionals, including increased motivation and engagement among patients and the possibility of objective and personalized monitoring of the rehabilitation process for professionals. These benefits become even more relevant when the target audience is children, considering the difficulties related to concentration and understanding of the situation by such young patients, as well as the psychological and emotional burden that clinical environments often impose on minors. This paper presents the development and evaluation of an immersive VR application designed to support physical therapy in pediatric patients. Built in collaboration with physiotherapists, the system employs a "slideshow" metaphor to guide children through interactive narratives within a tropical forest environment. In addition, the definition of a development pipeline for the process of making virtual reality applications of the same nature. The solution prioritizes simplicity of use for professionals and engagement for young users while enabling therapists to observe and stimulate cervical and cognitive functions. Initial testing with children aged 3 to 17 revealed positive responses, particularly in cervical movement stimulation and interaction quality, although cognitive abilities significantly influenced engagement. The results demonstrate the potential of VR as an effective and adaptable therapeutic aid, paving the way for future expansions, allowing flexible creation of different narratives, and also targeting other diverse neuropsychomotor conditions. The implementation of the proposed development pipeline significantly contributed to the efficiency and organization of the project. Due to its effectiveness, the proposed pipeline is currently being adopted in the development of additional applications within similar contexts.**

***Index Terms*—Virtual Reality, Rehabilitation, Physical Therapy, Cerebral Palsy**

I. Introduction

Cerebral palsy refers to a group of permanent movement and posture disorders attributed to a non-progressive disturbance that occurs during fetal or infant brain development, as defined by the Brazilian Ministry of Health. These disorders often result in significant limitations in an individual's functional abilities. The motor disorder in cerebral palsy may be accompanied by sensory, perceptual, cognitive, communicative, and behavioral impairments, as well as epilepsy and secondary musculoskeletal problems [1].

Epidemiological data presented by Prieto *et al.* [2] indicate that the incidence of cerebral palsy ranges from 1.5 to 5.9 cases per 1,000 live births in developed countries. In contrast, in underdeveloped regions, the rate can reach up to 7 cases per 1,000 live births. These figures highlight the need for accessible, engaging, and scalable rehabilitation strategies, such as virtual reality-based therapies, to meet the increasing global demand for effective interventions.

Rehabilitation for individuals with cerebral palsy aims to maximize functional independence, improve quality of life, and promote participation in daily activities. Among the various interventions, physiotherapy plays a central role, offering benefits such as improvements in gait patterns, muscle strength, range of motion, modulation of muscle tone, and balance. These physiotherapeutic approaches are diverse and must be continuously adapted to address secondary complications, biomechanical alterations, and neurological damage resulting from brain injury. These interventions are typically conducted through a multidisciplinary and individualized process, with therapeutic strategies emphasizing functionality, the development of motor skills, and the execution of movements that have not been acquired or are absent [3]. It ensures support for physical results and broader objectives, such as autonomy, social inclusion, and emotional well-being.

To enhance the effectiveness of rehabilitation and optimize patient outcomes, the use of virtual reality (VR) environments has been proposed to assist in the rehabilitation process. VR-based systems offer the possibility of creating controlled scenarios tailored to each patient's specific needs, limitations, and interests. However, in several cases, the patient's adaptation process to the therapy is exhausting and time-consuming, which increases the chances of abandonment, especially with children. The extended duration of treatment and the low motivation generated by traditional methods are frequently cited as reasons that lead to therapeutic failure [4]. Therefore, VR emerges as a promising solution to sustain patient commitment in this specific context [5], [6].

VR is an advanced user interface that incorporates visualization, immersion, and three-dimensional movement, allowing users to interact directly with the virtual environment. Instead, they can perform actions directly on three-dimensional elements — such as opening doors, pulling drawers, activating levers, or turning knobs.

Furthermore, human perception and capabilities can be extended in VR environments in intensity, time, and space. It becomes possible to see, hear, feel, act, and move far beyond the limits of human capacity: extremely far or close, strong or weak, fast or slow. Users can virtually become as large as galaxies or as small as atomic structures, travel at speeds beyond that of light, and exert forces far beyond physical human limits [7].

It should also be noted that, due to the high level of immersion and the ability to capture detailed interaction data within virtual environments, VR-based applications offer therapists the opportunity to conduct more precise and individualized monitoring of each patient's progress.

However, existing systems often lack intuitive interaction models that simplify therapist-patient engagement [8]. In addition, a project that involves multiple sectors such as developers, designers, and healthcare specialists needs to establish a production pipeline to better synchronize the project's requirements and goals.

Considering the above features, this work introduces a novel slideshow metaphor that prioritizes therapist control and patient engagement [9], addressing these limitations while leveraging VR's immersive capabilities, while also focusing on the project design process [10], by proposing a development pipeline that defines a step-by-step process for the project, optimizing the communication and workflow between developers, designers, and specialists.

Additionally, this work details the practical use of the proposed pipeline within the project, demonstrating how each stage contributed to the final outcome and emphasizing the collaborative effort across design, development, and clinical expertise teams.

The application proposed in this work places the patient in an immersive, child-friendly virtual environment with a forest theme, where the objective is to follow the movements of a monkey to promote the direct interaction between patient and therapist.

The video available at https://tinyurl.com/mr37m7e7 presents the solution developed in this work, which establishes an interaction model that simplifies operating the system and adopts a narrative solution that prioritizes human interaction over automatism, valuing the therapist's work and the patient's well-being.

The remainder of this paper is organized as follows. Section II presents the theoretical framework that supports the project. Section III discusses related work on VR-based rehabilitation systems. Section IV outlines the methodology and the proposed pipeline. Section V describes the implementation process. Section VI offers conclusions from the project. Section VII and discusses directions for future research. Section VII presents acknowledgments to contributors. Finally, Section VIII discusses directions for future work.

II. Theoretical Framework

A. Slideshow Metaphor

The slideshow metaphor (Figure 1) was designed around two fundamental concepts: the "template" and the "slides". The template defines the fixed environment in which the user is situated. Templates are static 3D environments that serve as the foundation for all interactions and narrative elements. The slides, however, represent the dynamic components within this template, including 3D models, animations, and sound effects triggered in a specific sequence. Slides are displayed one at a time, allowing the therapist to control the narrative to ensure a coherent flow of interaction with the pediatric patient.

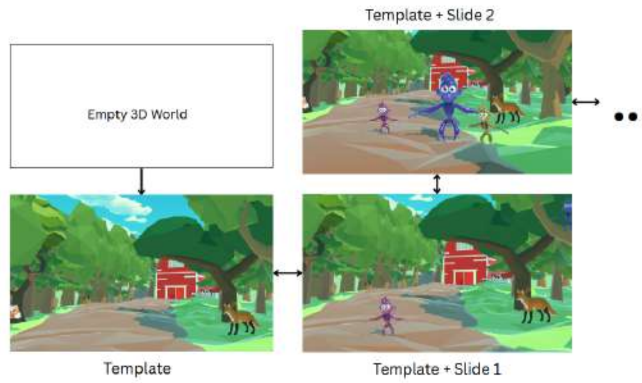

Fig. 1: The slideshow metaphor proposed to simplify therapist-patient interaction

The slideshow metaphor significantly differs from traditional VR interaction models, which often rely on automated or pre-programmed sequences. By allowing therapists to control the pacing and content of the narrative in real time, the system ensures greater adaptability to patient responses and cognitive levels. This approach not only humanizes the rehabilitation process but also enhances the therapist's ability to monitor and guide the patient effectively.

This concept is implemented using some devices: a head-mounted display (HMD), its controller, and a separate screen (usually a smartphone for portability and convenience). Then, the therapist follows a script (shown on the separate screen) and controls (using the HMD controller) the slideshow, alternating between slides that follow the template, that is, different visual and sound elements presented in the virtual world. Meanwhile, the patient watches the slideshow results through the HMD, interacting directly with the therapist, who monitors the results simultaneously on the separate screen - that, in addition to presenting the script, also replicates what is seen in the HMD.

The therapist continually encourages the patient to deal with the specific situations shown. For example, the therapist can ask the patient to look for something in the virtual environment to assess possible restrictions on movement in their neck. Similarly, the therapist can ask the child to call a character to check their cognitive abilities or motor and verbal responses. If it is necessary to repeat an activity, the therapist simply "goes back a slide"; otherwise, they continue with the slideshow to experience a new situation.

In the following, it is discussed the proposed narrative structure, the respective asset creation processes, the system architecture, and underlying implementation strategies adopted during the development, replacing traditional VR engines.

B. Game Engine

A game engine refers to the software development platform on which the applications are built, providing the necessary tools for the creation and execution of interactive virtual environments. Given it's flexibility, VR applications are being created using game engines.

C. Assets

Assets, in the context of this project, was a term the designer and development team settled on to refer to all, curated or produced, elements that constitute the experience. This includes 3D models along with their corresponding textures, animations, and rigging systems, as well as all sound elements that contribute to the construction of scenes and support the narrative flow. These assets are fundamental for shaping both the environment and the interactions within the virtual experience.

1) Visual Assets: Visual assets are all the resources used for the environment, characters, and overall visual aspects of the application, including three-dimensional(3D) models, textures, texts, and scenarios used in it.

These models are composed of interconnected polygons that form a 3D mesh which defines the geometry and structure of each object. It is essential that the models maintain a balanced polygon count, high enough to preserve visual quality for the user, yet optimized to avoid compromising performance of the application (Figure 2).

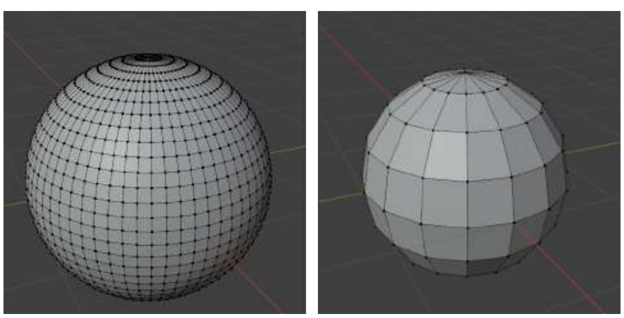

Fig. 2: Comparison between two spherical models. The left model has approximately 2,000 polygons, while the right has around 100. (Source: Authors)

The models may also include rigging: a skeleton-like armature connected to the 3D model, which defines its bones and joints. This structure enables the implementation of model animations.

Animations are defined as a sequence of changes applied to the rig and the position of the model over instances, creating the illusion of movement [11]. Each snapshot of movement is referred to as a frame, and the number of frames displayed over one second is referred to as Frames Per Second (FPS). The choice of FPS depends both on the intended visual style of the application and the performance constraints of the application.

Textures are also an essential part of a 3D model. They are two-dimensional images mapped onto the surface of the mesh, providing color and visual detail to the object. In addition to basic color maps, textures may include normal maps (Figure 3), images that indicate how light interacts with the object, creating the illusion of depth and detail without increasing the actual polygon count of the mesh.

Fig. 3: On the left: stone wall texture, on the right: its corresponding normal map texture. (Source: docs.unity3d.com)

2) Sound Assets: All sounds used in the application, from background music to character and object sounds, were selected to enhance the user's immersion in the virtual environment.

Much like polygon optimization for 3D models, it is important to manage audio data to ensure smooth performance. One of the ways the performance can be assured is by managing the bitrate [12], which refers to the amount of data processed per second and directly affects the sound quality. For this project, compressed formats such as MP3 were considered most suitable for balancing quality and performance.

Given the tridimensional nature of the virtual environment, sounds were placed at specific points within the scene to simulate spatial audio. This technique allows for the perception of direction and distance of sounds in three-dimensional space, significantly contributing to immersion.

Another important concept regarding the sound assets is diegetic sound. Diegetic sounds are those that originate from elements within the virtual environment and are perceived as part of the scene by the user, for instance, footsteps on grass. In contrast, non-diegetic sounds, such as background music, are not naturally part of the environment but are used strategically to influence the emotional tone or direct user attention [13].

D. Moodboard

The moodboard is a compilation of visual references developed to guide the aesthetic identity of the application (Figure 4). This tool supports the definition of the visual language of all the assets of the experience, helping ensure coherence in their designs by being the initial guideline of the visual identity, serving as a basis for analyzing colors, shapes, and common traits between media that shares the same target audience [14].

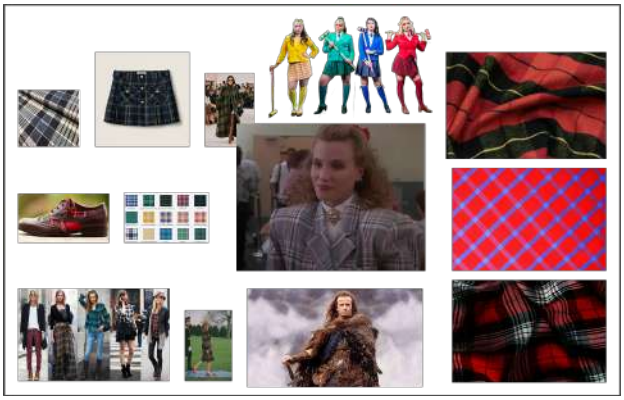

Fig. 4: Example of a Moodboard for a presentation about the tartan texture

1) Visual Identity: Visual identity refers to the set of aesthetic elements and design guidelines that provide visual coherence to the application, ensuring consistency in the presentation of environments and characters. It defines the parameters for selecting and creating the visual style of assets and also helps to establish the tone conveyed throughout the experience.

Visual identity encompasses multiple components, such as the color palette and contrast.

The color palette is the set of main colors chosen to represent the application visually. It extends across scenarios, characters, and all visual assets overall, contributing to the cohesiveness of the visual identity.

Contrast refers to the degree of difference between elements in terms of luminance, hue, and saturation. It is essential to maintain good visual clarity, support readability, and emphasize key elements within the environment.

III. Related Works

This section presents research on the advantages of adopting VR in rehabilitation processes and the main applications designed to support this process. The objective of this section is to provide a basis for a comparative analysis between the application proposed in this work and other research efforts that involve the use of VR as a supportive tool for rehabilitating patients with neuromotor and neurological disabilities in general. It should be highlight that this broader approach was chosen due to the still small number of studies that specifically refer to the use of VR for the rehabilitation of children with cerebral palsy.

A. Intensification of Brain Activation

The research presented by Brandão *et al.* [15] discusses solutions being developed and tested within the BRAINN_VR Initiative. This initiative is a research and development line of the Brazilian Institute for Neuroscience and Neurotechnology – BRAINN.

The work encompasses several research fronts, ranging from the design of VR environments to the development of hardware devices to be used by patients undergoing neurofunctional recovery and benefit from these immersive systems.

The study presents data highlighting the potential of VR in the rehabilitation process. Then, it indicates, for example, that functional magnetic resonance imaging (fMRI) could show increased activation primarily in the precentral gyrus (top view), which is associated with the primary motor area of the brain, following virtual rehabilitation that involves 12 intervention sessions held twice a week.

The findings are particularly relevant in cerebral palsy, characterized by motor impairments often linked to underactivation or dysfunction in motor-related brain regions. By stimulating these areas through engaging, repetitive, and goal-directed VR activities, there is potential to promote neuroplasticity and functional improvements in children affected by this condition.

B. Puzzle Game for Post-Stroke Patients

The work proposed by Araújo *et al.* [16] presents a VR application developed as an immersive puzzle game to support the rehabilitation of post-stroke patients. This application uses an HMD headset and an arm motion tracker through which the patient is required to perform 90º movements to solve the puzzle.

The application also allows for different configurations and supports data collection through movement recording, enabling detailed analysis of the rehabilitation process.

One significant feature that enhances immersion and increases patient engagement is the ability to dynamically insert an image during runtime, which is then used as the target image for the puzzle. These images generally represented the patients' daily lives or expressed affection for them.

Although initially developed for post-stroke patients, this type of application is particularly relevant for individuals with cerebral palsy, given the similarities in neuromotor challenges faced by both groups. In both cases, patients often experience impairments in motor control, muscle coordination, and range of motion, which directly impact their ability to perform daily activities.

C. VR for the Treatment of Autism

Strickland *et al.* [17] propose using VR as a learning aid to support children with various disorders, including autism.

The referenced work has shown considerable success in adopting VR in two phases. In the first phase, a child with autism must recognize and track an object within a virtual environment, for example, a moving car in a street scene. In the second phase, they must locate an object within the environment, walk toward it, and stop.

This application is particularly interesting, as it seeks to simulate and teach a real-world activity, such as crossing the street, while also stimulating cognitive skills by requiring the identification of objects and colors and decision-making. The application is also notable for its thoughtful design, featuring simplified textures and environments to reduce sensory overload, allowing a smoother and less stressful immersive experience for the child.

Although designed for children with autism, the strategies employed in this work are also promising for children with cerebral palsy, given the overlapping challenges in sensory processing, cognitive engagement, and motor coordination.

D. Serious Game for Rehabilitation of Upper Limb Amputees

The serious game proposed by Cavalcante *et al.* [18] serves as a virtual training environment for amputees of the upper limb to reduce their time to adapt to a real prosthesis.

The study describes not only the development of the virtual interface but also the creation of the interactive technology used (tethers and sensors). The virtual environment and the hardware were specifically designed for upper limb amputees, making the system robust and sophisticated.

The results were promising, with patients reporting that the game significantly aided their rehabilitation process. However, some challenges were identified, particularly regarding motion tracking and analysis accuracy and precision. Considering the motor limitations of the users, even slight inaccuracies can lead to considerable difficulty during the interaction, which remains one of the main problems in using virtual environments to rehabilitate individuals with neuromotor disabilities.

E. VR Compared to Conventional Home Exercise in Children with Cerebral Palsy

The work by Bryanton *et al.* [19] investigated the effects of a video-capture-based VR system on rehabilitation outcomes in children with cerebral palsy, comparing it to conventional physiotherapy exercises. The employed system, IREX (Interactive Rehabilitation and Exercise Systems), comprised a large TV monitor, a motion-capture camera, and a computer that integrated the patient's real-time movements into interactive virtual environments.

This solution presents games designed to elicit ankle dorsiflexion, a critical movement for gait in children with cerebral palsy. The joint range of motion was precisely measured using an electrogoniometer, while subjective perceptions of motivation and engagement were assessed by adopting the Visual Analog Scales (VAS) [20].

The results demonstrated that although the number of repetitions was higher in conventional exercises, the VR intervention led to a significantly greater increase in ankle dorsiflexion range of motion, attributed to the engaging and goal-oriented nature of the virtual tasks presented. Furthermore, both children and their caregivers reported higher levels of enjoyment and perceived adherence to home-based therapy when VR was utilized, underscoring the role of motivation in rehabilitation compliance.

These findings support the hypothesis that VR enhances therapeutic efficacy by improving biomechanical outcomes and addressing behavioral barriers such as monotony and low engagement associated with traditional protocols.

F. Virtual Reality for Cerebral Palsy Management

The research presented by Weiss *et al.* [21] provides an overview of the clinical use of VR, with a particular emphasis on cerebral palsy management. It presents encouraging perspectives regarding the importance of using VR for rehabilitation, addressing both physical and psychological aspects of patient care.

G. Synthesis of Related Works and Positioning of This Study

As can be seen, previous studies consistently highlight the potential of VR as a transformative tool in rehabilitating various neuromotor conditions, targeting a wide range of patients, from children to adults.

Hence, the capacity of VR to address emotional and autonomic dimensions of rehabilitation provides a unique opportunity to simultaneously tap emotional adaptation through physiological (e.g., autonomic and hormonal) responses to different emotional provocations [21], thereby facilitating a broader view of intrinsic factors that influence the outcome of interest [22]. Particularly, emotions are considered to be processes involving simultaneous changes in peripheral and central autonomic functions, and they also affect behavior and cognitive processes, and decision-making capacity, facilitating a range of responses to challenges [23], [24].

Despite the promising results shown in previous works, none have specifically addressed the challenge of simplifying and broadening the interaction between healthcare professionals, patients, and virtual environments. Thus, this work addresses this limitation by implementing an interaction model, the slideshow metaphor, that simplifies system use. It emphasizes a narrative-based approach that enables therapists to actively and naturally engage children, adapting activities to individual patient needs and fostering a more personalized therapeutic experience.

H. Other Works

In addition to the clinical and rehabilitation-focused studies, the following works, while not directly related to cerebral palsy, offer valuable insights into VR interaction models, ethical considerations, and accessibility strategies relevant to this study's development context.

- **MotionBlocks: Modular Geometric Motion Remapping for More Accessible Upper Body Movement in Virtual Reality:** The paper is about an approach that improves VR accessibility for users with limited upper-body mobility by remapping small or simplified motions into larger, more complex virtual actions through geometric primitives. This way, allowing highly customized interaction, reducing physical effort and enabling more inclusive VR experiences. [25]
- **Juggling Extra Limbs: Identifying Control Strategies for Supernumerary Multi-Arms in Virtual Reality:** The study explores strategies for controlling virtual supernumerary limbs in VR object manipulation tasks, focusing on how varying autonomy influences user adaptation. Findings inform guidelines to improve multi-limb interaction design, enhancing coordination, task delegation, and user experience. [26]

- **Is Your Family Ready for VR? Ethical Concerns and Considerations in Children's VR Usage:** This study investigates ethical concerns and design considerations for VR use among children aged 7–13 through surveys and interviews with both children and parents. The findings provide insights to guide responsible VR practices that balance potential benefits and risks for young users. [27]
- **A Virtual Reality Scene Taxonomy: Identifying and Designing Accessible Scene-Viewing Techniques:** This work proposes a scene taxonomy for virtual environments, classifying scene-viewing techniques based on visual structure and task to guide design decisions. Its application to accessibility challenges, such as limited head mobility, demonstrated its potential to inform VR interaction design while balancing accessibility, realism, and spatial awareness. [28]
- **Rehabilitation Games in Real-World Clinical Settings: Practices, Challenges, and Opportunities:** This study investigates real-world practices, challenges, and impacts of game-assisted rehabilitation for stroke patients over a two-year partnership with a rehabilitation hospital. Findings highlight varying patient engagement patterns, the critical role and challenges faced by therapists, and the need for better support to deliver personalized, patient-centered therapy. [29]

IV. Methodology

The proposed development pipeline, designed specifically for projects using the slideshow metaphor, was initially derived from prior experience of the developers in similar VR-based applications [30] [31], initially thought as a way to better pace the progress of projects that involved the slideshow metaphor in their development, the proposed pipeline was subsequently refined and adapted to meet the general narrative and development requirements of present and future works that require the involvement of different parties (developers, designers and specialists) and the distinct interaction demands of the application's target audience.

The pipeline (Figure 5) is structured into two main stages. The pre-production stage encompasses the first four steps: the initial meeting, the script refinement process, the development of the moodboard, and the definition of the asset list. Following this phase, the production stage begins, comprising the development of the application, the testing process, the analysis of feedback, and concluding with the consolidation of the final version of the experience.

A. Initial Meeting

The first step in this methodological process involves an initial meeting between the project specialists and the designer. The purpose of this meeting is to discuss the application requirements, clarify the technical capabilities and limitations of the chosen game engine, and define scope, expectations, and functional constraints. At this stage, the specialists are also asked to draft an initial script for the experience, developed with consideration of the specific characteristics and needs of the target audience.

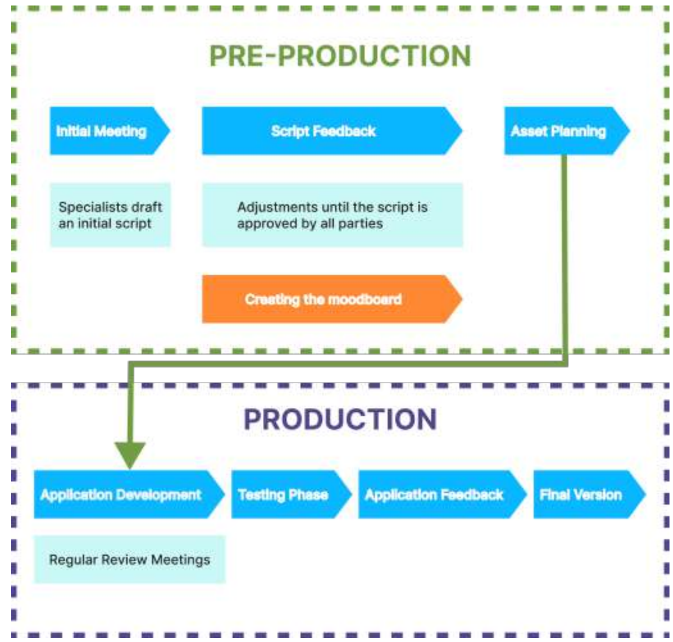

Fig. 5: The development pipeline for projects adopting the slideshow metaphor

B. Script Feedback

After the specialists submit the initial narrative script, it undergoes a detailed review by the designer, who may suggest revisions aimed at improving narrative clarity, feasibility, or alignment with requirement goals. The script is iteratively refined through collaborative feedback rounds until a final version is approved by all parties.

C. Creating the Moodboard

In parallel with the script's development, a visual moodboard is created to define the application's aesthetic guidelines. This visual reference board consolidates stylistic inspirations that inform both the creation and curation of visual assets.

D. Asset Planning

Prior to the production phase, a comprehensive asset list is compiled to define the requirements of the application. During this stage, decisions are made regarding which assets will be custom-developed and which will be sourced from external repositories, such as public 3D asset libraries.

E. Application Development

Once pre-production is complete, the development phase begins. This involves assembling the experience in the game engine based on the approved script and curated assets. The development process includes asset creation, configuration of scenes and integration of audiovisual elements. Regular review meetings between the designer and specialists ensure iterative refinement and alignment with the determined objectives.

F. Testing Phase

After the prototype is completed, it is submitted to the specialists, who conduct a testing phase with a group of participants representing the target audience for the application. This phase aims to evaluate the effectiveness of the script and identify any necessary adjustments to the content or other aspects of the experience.

G. Application Feedback

The results are consolidated and presented in a final feedback report at the end of the testing process, the format of the feedback, is defined by the availability and preference of the parties. The feedback can determine adjustments for future versions of the application, the effectiveness of the experience, and insights gathered by the specialists during the testing phase.

H. Final Version

Based on the feedback collected, it is decided if a final version of the application is needed, and if so, it will be produced incorporating the necessary adjustments to establish a cohesive and polished edition of the experience.

V. Development

The basis of the proposed solution came from a series of conversations between the authors of this paper and physiotherapists who specialized in treating children with cerebral palsy. During the discussions, it was realized that, despite the many processes involved in dealing with this type of patient, the system developed must be simple to operate. This requirement stems from the need to humanize the process, seeking to engage the child in several specific but rich situations while the therapist concentrates their efforts on guidance, observation, and diagnosis.

To address these needs, the use of the slideshow metaphor and the proposed pipeline was introduced, marking the beginning of the development, keeping in mind the target audience being children with cerebral palsy and physiotherapists guiding the experience.

A. Initial meeting

Following the described pipeline, the first step of the project was having a meeting with all parties involved, establishing the project's primary goal: creating a virtual reality experience to be used by physiotherapy sessions for children that had cerebral palsy.

The meeting began by defining the visual scope based on a target patient profile of children between 6 and 10 years old, a standard typically met by the physiotherapists consulted, who would conduct the therapeutic sessions needed to validate the solution. Common interests within this age group informed key design decisions (such as how to present the colors, their brightness and saturation, and the graphic style of the 3D models and virtual world) to ensure the virtual environment was engaging and suitable for the intended audience.

As the primary focus of the system should be stimulating the patient to facilitate the ability of the professional to monitor the child's progress, its respective narrative should provide opportunities aligned with the therapeutic purposes of the session.

Then, regarding the proposed slideshow metaphor, it was established a tropical forest as the template, and the main characters on the slides would be monkeys of different colors and sizes. The designer chose these simple elements to attract the child's attention [32], supporting their motor and cognitive engagement throughout the session in specific situations, allowing for more controlled progression and easier monitoring of patient performance.

At the end of the meeting, a script of the intended experience by the viewpoint of the specialists was requested.

B. Script Feedback

After the specialists returned with a complete script, the designer adapted it to align with the technical scope of the project and to improve clarity for the development team, reducing the script to only the changes that concern the template and slides. All changes were passed on and validated by the specialists before being confirmed in the script.

The adapted script would also be of use for the physiotherapists in the sessions, since it would serve them to guide the sessions and help contextualize and explain the changes in environment to the participants they would be accompanying.

For better use to the specialists, the final script (Figure 6) would also contain quotes between the different slides, giving narrative suggestions for them to help give the patient context to what is happening in the scene. The quotes are provided solely as suggestions to assist the physiotherapist in guiding the patient during the sessions. However, the professionals retained full autonomy to either follow these quotes or follow their own approach to the events of script.

Later, after receiving the initial script adaptations, the specialists played a key role in defining the ideal positions, movements, and pacing of the monkeys within the slides. These elements were carefully planned to gradually and safely challenge the patient's range of motion, considering the motor constraints typically associated with cerebral palsy. Particularly when it comes to the movement of the trunk and cervical spine, as patients tend to have little control over it. Accordingly, the monkeys perform actions such as jumping, climbing trees, and navigating both vertical and horizontal planes, prompting the patient to engage in various head motions, including upward, downward, and lateral movements.

The current version of the application does not support animations, as this feature is planned for future development. Consequently the intended actions would be represented through slight angular adjustments in the positioning of the models, for example, "cheer" would be represented by the character moving vertically, simulating a jump.

In another meeting with the physiotherapy specialists, the script included slower-paced moments within the narrative, implemented as sound-only slides. They were essential to

- Slide 1: Start of the virtual reality, only the environment(template), without the monkey
- Slide 2: Empty forest with a sphere in the middle

"Looks like there's a little animal over there!"

- Slide 3: Monkey sounds
- Slide 4: Monkey appears and greets the player, near the trees on the left side, then starts moving in low angles.

"Look! he appears to be happy to see you!"

- Slide 5: Monkey cheers when the player finds him.

"It seems that he's looking for something..." / "It seems he went to talk with his friend, the fox!"

- Slide 6: Monkey walks across the path to the right side of the forest in a slow pace

  "Look! a banana fell down from the tree, can you tell the monkey where it is?"

- Slide 7: A banana falling to the ground from the tree that's on the other side of the forest.

Fig. 6: Excerpt of the final script, the black lines were the changes made between each slide and the purple lines represented possible, but not required, quotes for assisting the physiotherapist (translated from Portuguese by the authors)

provide greater flexibility for the professional overseeing the session because these pauses could grant therapists complete control over the pacing between segments of the experience. In the same way, these additional slides could smooth the adaptation to the patient's needs and include intervals allowing more attentive monitoring of responses and posture.

The designer also included other elements in the narrative, like a banana and a fish, to justify the characters' actions and movement, making the narrative more plausible and diverse. These design choices resulted in a controlled, engaging, and suitable VR experience for the selected patient group.

Fig. 7: Example of a situation presented to a pediatric patient by the application

Finally, a script for use in the application was also finalized, with direct participation of the physiotherapists, resulting in 17 slides, this script briefly described each situation, indicating possible ways of exploring it with the patients.

Thus, for example, the child was encouraged to look for each monkey in the 3D environment in a given situation. Depending on the limitations imposed by cerebral palsy, the therapists, at this time, could also encourage the patient to call each of the monkeys verbally or through gestures. As the characters were in different positions, measuring the amplitudes of participants' cervical movements was possible.

After finding — and, if possible, calling — each monkey, they were lined up horizontally (Figure 7). The therapist could then, once again, depending on the cognitive abilities of the child, encourage them to answer questions about the quantities, colors, sizes, and other characteristics of the monkeys in the line.

C. Creating the Moodboard

Fig. 8: Forest moodboard

With the narrative defined, efforts were directed toward the visual development of the application. The next phase, following the proposed pipeline, consisted of gathering references from playful products from different media aimed at children. These findings were consolidated into a moodboard that oriented the development of the template needed to establish the virtual world (Figure 8).

Another specific moodboard (Figure 9) helped define a color scheme for the main character of the narrative, a monkey with purple fur. This color aimed to contrast the predominantly green forest environment, enhancing the character's visibility and prominence during interactions.

Both moodboards were created with the intent of establishing a visual identity that draws the interest of the participant, increasing the engagement in the session.

The visual identity was designed using a palette of vivid colors, including green, red, purple, and yellow, and geometric forms with minimal surface detail. Textures are limited to simple colors, supporting an almost toy-like aesthetic that is both stimulating and easy to interpret, especially for the target audience

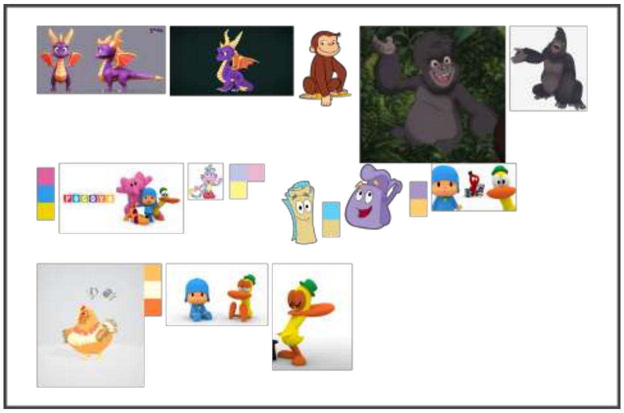

Fig. 9: Characters moodboard

D. Asset Planning

Using the script as a base, the designer made a list of every model needed to create the application, and decided, based on the deadline and availability, which assets were going to be outsourced to online repertoires and which were going to be custom made for the project.

Regarding the sound assets, the focus was placed on collecting diegetic audio elements, for instance, animal vocalizations and environmental sounds like rustling leaves and water movement, to enhance immersion and participant engagement. Non-diegetic elements were deliberately minimized to preserve immersion, with the sole exception being the inclusion of clapping sounds, incorporated to reinforce a sense of accomplishment during the session. [33]

E. Application Development

To implement the slideshow metaphor proposed, considering the narrative established and its respective assets, the system architecture shown in Figure 10 was defined, which illustrates how the two types of users (therapist and patient) interact with the system and how the main components of the architecture relate, as described below.

The Therapist externally controls the slideshow using an Input Device (the HMD controller) to establish the current slide. The Scene Manager retrieves the description of the current slide from the Slides Data. Then, the Scene Manager merges the Template Scene and the Dynamic Elements (of the current slide) to create the Scene displayed to the Patient via the Output Device. In parallel, the Therapists can also see the Scene on another screen.

Once the application's narrative, visual, and auditory aspects were defined, the project development phase began. The Unity 3D game engine was chosen to support development due to its extensive documentation, large developer community, and support for VR application development. Additionally, the implementation was based on a Meta Quest 2 HMD. This

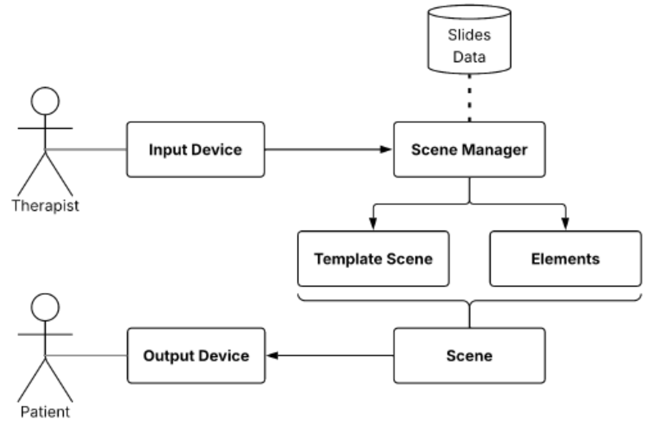

Fig. 10: The system architecture

device was chosen for its standalone functionality (i.e., it operates independently without requiring a connection to a PC), its solid integration with Unity, and the fact that the developers already had some units available for immediate use.

The first step was to build the forest environment, which composes the template needed. To better explore the performance of the Meta Quest 2, the scene was designed with a relatively small area to avoid overloading the device. However, the system can be easily extended to different HMDs, like Meta Quest 3 HMD or similar from other manufacturers.

This template comprises a vivid green forest with many trees and bright accents, like the blue lake on the right and the red barn on the back (Figure 11).

It was also included some static animals that could not be found in such an environment but that would help stimulate the children (Figure 12). All the 3D elements were obtained from free online repositories, used the glb format due to this format being supported by Unity, and followed the stylized and cartoon style that the moodboard represented.

The environment was populated with numerous objects, such as trees and rocks, to block the user's view of the infinite background beyond the scene's boundaries, thereby enhancing immersion.

The base of a pre-made model with a free license sourced from an online repository was used to create the main character. The model was also customized to fit the design proposals, generating the other monkeys needed. They adopted vibrant colors, such as blue, red, and yellow, further enriching the visual diversity of the application. This decision aligns with findings that bright and vivid colors tend to attract more attention and generate greater interest among children, contributing to a more engaging and stimulating experience. [33]

During development, due to the low number of sound assets and the absence of any noticeable impact on performance, it was not necessary to adjust the audio bitrate.

In addition to the visual elements, special attention was given to the implementation of the sound assets [34], particularly in light of the previously mentioned sound-only slides. The transitions between situations were accompanied by spe-

Fig. 11: Forest template - up view

Fig. 12: Forest template - front view

cific sound effects intended to anticipate changes and signal the patient what was about to occur. the preciously mentioned commemorative ”clapping” sounds were also incorporated to positively reinforce successful actions and clarify narrative contexts [35].

In parallel, the dynamic slide-loading system was developed based on the already presented architecture. The characteristics of each slide are stored in JSON files, containing attributes that define the user’s point of view (camera position in the virtual world) and the elements to be added to the scene. These elements also have their own attributes defined in the file, such as the 3D assets to be used and their characteristics (scale factor and position in the virtual world). It is also possible to associate a sound with each 3D asset, accompanying it in the virtual world. In addition, each 3D asset can also be moved in the slide, defining its initial and final positions, speed, and whether the movement will be cyclical. All this information is also stored in the respective slide JSON file.

When the application is initialized, the Unity script acting as the scene manager loads the slide’s JSON files and stores their contents in a list structure for later access (Slides Data). Then, the therapist can linearly control which slide is shown to the patient, being able to move forward or backward through the sequence.

The same script receives and processes input from the Meta Quest 2 controller, retrieves the corresponding JSON file from the list based on the selected slide, and consumes it. This slide consumption process involves applying the changes specified in the file, such as updating the displayed template, instantiating the respective static or animated elements, and repositioning the participant’s view of the world, among other actions.

F. Testing Phase

Once the application was finished, the developers delivered it, installed in one Meta Quest 2, to the specialists responsible for conducting the test. They carried out some initial tests to understand how the children would react. The results obtained during these sessions showed significant variation between participants. Some demonstrated aversion to using the equipment, refusing to put it on or removing it during activities (apparently due to not understanding the difference between the virtual environment and the real world). In contrast, others showed high levels of engagement with the experience.

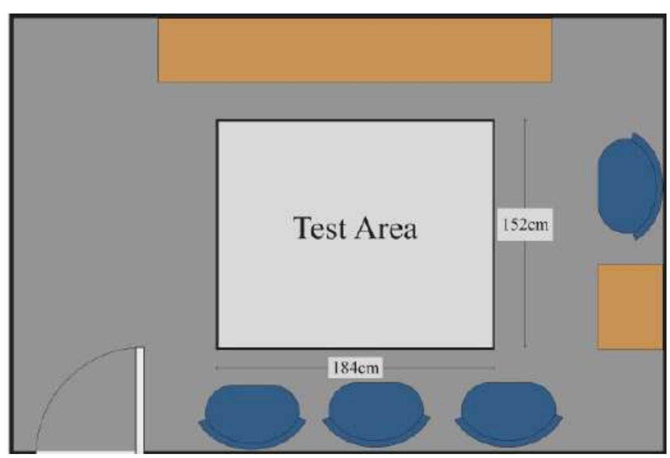

Fig. 13: Test environmet

Fig. 14: Physiotherapists attending pediatric patient

Subsequently, the therapists adjusted the early testing protocol. Then, the initial scope, which targeted participants between 6 and 10 years of age, had to be expanded, and patients were selected more carefully, considering their behaviors about the devices and the test environment used (Figure 13).

In four days, the therapists worked at [omitted for blind], an institution specialized in multidisciplinary health care. They attended to children with cerebral palsy classified as level V on the Gross Motor Function Classification System (GMFCS) [36], indicating the most severe level of motor impairment. They were all transported using wheelchairs and performed the tests on the same (Figure 14).

There were some restrictions in the selecting participants, particularly regarding psychological preparation to experience the temporary isolation provided by the VR environment and physical conditions to support the weight of the HMD, which, although light, can be significant for younger children or those with mobility problems. Therefore, it was also decided to include other types of neuropsychomotor impairment, like Down syndrome and myelomeningocele, to measure the impact of using the developed application in patients with related conditions. All participants, aged 3 to 17, had sessions of around 15 minutes to prevent fatigue from using the head-mounted display(Table I).

Although the target audience had been expanded, the physiotherapists reported that differences observed in participant responses were not determined by age but rather by cognitive comprehension. It was noted that a younger participant could display a more advanced level of cognition and, consequently, greater comprehension and interaction with the narrative and stimuli compared to an older participant who might have a lower cognition level related to the experience and not engage as much.

Furthermore, although some patients did not finish the entire narrative due to fatigue or lack of attention (which is common due to the neuropsychomotor impairment of the participants), the therapists considered the engagement the system promoted as a remarkable success, particularly when compared to traditional stimulation methods.

G. Application Feedback

During the test, the therapists identified that introducing a more extended initial familiarization phase with the virtual environment is essential to facilitate participant adaptation, especially considering many had never used a virtual reality device before. Participants could freely observe the virtual environment during this phase, understand their surroundings, and feel more comfortable and secure before the guided activities began.

The impact of the novelty effect of the device and the virtual environment was also highlighted as a significant factor contributing to participant engagement, especially among those experiencing the technology for the first time during the tests.

As the sessions progressed, it was observed that the narrative suggestions outlined in the original script were used more as a reference than as a strict guide, serving as a base for conducting the activities but not being followed precisely, since the primary focus was to adapt the narrative to the participants' responses.

It was also noted that the absence of continuous sounds in the virtual environment, such as forest noises or natural background sounds (like water flowing, birds chirping, and leaves rustling), resulted in prolonged periods of silence, especially when the pace of slide transitions varied between participants. This silence contrasted even more with the sound effects associated with scene changes, which sometimes confused the participants.

The specialists also pointed out that some of the animals depicted in the virtual environment (e.g., fox and moose) were not recognizable to the participants, suggesting their replacement with more familiar species, like dogs or horses, to increase recognition and facilitate understanding of the activities.

Regarding the application's content and duration of its use, the specialists assessed that the number of slides presented was sufficient for the sessions. However, some areas could be further detailed and improved, like when the monkey goes fishing and could get a beach ball to play with other animals or have a party, for example. And it was emphasized that even in cases where participants did not complete all slides, the primary objective of the experience — the activation of cervical movements — was effectively achieved during the tests.

The results align with prior studies showing higher motivation in VR therapy compared to conventional methods [19], [37], and they underscore the importance of designing VR systems that balance technical sophistication with user-centered simplicity. The slideshow metaphor proved effective in stimulating cervical movements and promoting therapeutic

TABLE I: Test participants

Participant	Age	Gender	Diagnosis	Functional Classification	Cognition	Result
A. L	9	Male	Cerebral palsy with GMFCS V	Very little control of the trunk and cervical spine.	Reduced cognitive, no verbal response.	Cooperative, accepted HMD, often smiled, limited cervical rotation, initial fright episodes, improved adaptation, and fewer frights during a second session, and followed commands reasonably.
E. S.	4	Female	Down syndrome	Excellent trunk and cervical spine control. Presents global hypotonia (reduced tone throughout the body).	Excellent cognitive and good verbal response.	Cooperative, followed commands, accepted HMD, and repeatedly removed it to check if virtual animals were present in real life, then resumed.
E. V.	17	Male	Cerebral palsy with GMFCS V	Little control of the trunk and cervical spine.	Excellent cognitive and verbal response.	Cooperative, enthusiastic, answered every question asked. Afterward, she said it was great and didn't feel dizzy.
M. L	10	Male	Cerebral palsy with GMFCS V	Very little control of the trunk and cervical spine.	Good cognitive, but no verbal response.	Cooperative, engaged, often smiled, followed therapist cues, was startled by sounds occasionally, and finished excited, wanting to use the HDM again.
R. V.	4	Female	Cerebral palsy with GMFCS V	Little control of the trunk and cervical spine.	Reduced cognitive, little verbal response.	There was a lot of resistance when putting on the HMD, and it was not possible to apply them even after many attempts.
V. H.	3	Male	Myelomeningocele	Excellent trunk and cervical spine control. Compromised functions below the knee (strength, sensitivity).	Excellent cognitive and verbal response.	Cooperative, engaged, described the scene, followed commands, enjoyed the experience, and wanted to continue even after the HMD battery discharged.

interaction, highlighting its potential as a foundational model for other possible future VR-based rehabilitation systems.

H. Final Version

After collecting the previous feedback, a new version of the experience is scheduled for future development. Additionally, new specific templates are expected to be developed to refine the application for future uses, which will use insights from the current version to better align with the target audience's interests and needs.

VI. Final Considerations

This work presented the development and testing of a virtual reality application to accompany the rehabilitation of children with cerebral palsy. The proposed solution was designed through direct collaboration with specialized physiotherapists, ensuring that design, narrative, and interaction decisions aligned with the clinical and cognitive needs of the target audience.

Adopting the slideshow metaphor proved effective in giving therapists greater control over the session's pacing and facilitating the adaptation of activities to each patient's performance. Creating a playful and visually engaging narrative by following the proposed pipeline demonstrated the potential for stimulating interaction with children, increasing their motivation and engagement — key factors for therapeutic success in this context.

The pipeline definition also had a huge impact on the project's streamlining, providing smoother operations that had set goals and objectives. It allowed all the parties involved to maintain a clear direction throughout all phases of development, enabling more efficient communication between the specialists, developers and designers involved, while consistently aiming to ensure an engaging and accessible interaction adapted to the target audience.

The testing protocol adopted was designed to evaluate the system's ability to engage children with varying cognitive levels and neuropsychomotor impairments. By expanding the target audience and adapting the narrative to individual responses, the results demonstrated the system's flexibility with positive reception from both healthcare professionals and patients, particularly in stimulating cervical movements and promoting therapeutic interaction. These findings align with the broader goals of VR-based rehabilitation research, which emphasize personalization and engagement as critical factors for therapeutic success.

At the same time, opportunities for improvement were identified, such as the need for a longer introductory phase to help users familiarize themselves with the virtual environment, incorporate continuous background sounds, and replace particular visual elements with figures more familiar to children.

Given the promising results achieved, including children who do not have cerebral palsy, it is essential to carry out more sessions with patients with different types of neuropsychomotor or people with autism spectrum disorder, for example.

In summary, the results reinforce the feasibility of using virtual reality as a complementary tool to conventional physiotherapy, especially when combined with a personalized and therapist-centered approach.

In particular, the slideshow metaphor and therapist-centered approach demonstrated practical feasibility, offering a scalable model for diverse therapeutic settings. Consequently, it can provide a solid foundation for future enhancements and validation in diverse therapeutic contexts. For that, an initial version of a parallel application is being developed to store patient performance data, including information about cervical movements, like angles and timestamps, related to each slide presented. It will allow a quantitative assessment of the rehabilitation processes.

In the same way, the developers are also developing a virtual world editor to be a flexible and intuitive tool designed to empower non-technical users — such as therapists or educators — to create personalized rehabilitation experiences without relying on programmers or designers. Built around the same customizable slide-based storytelling model proposed, this editor can allow users to configure both narrative content and virtual environments through a user-friendly interface, enabling rapid deployment even during live therapy sessions.

In parallel, the proposed pipeline will also be validated through its implementation in future projects that adopt the template metaphor.

In the future, the solution proposed in the present work can also incorporate AI-driven tools, such as large language models with text-to-mesh capabilities, allowing users to generate content by simply describing it in natural language.

Thus, this set of solutions (slideshow metaphor, pipeline, architecture, and the developed application) initiated with the present work could significantly reduce the barrier to creating and using therapeutic VR content, establishing an adaptable, accessible, and effective digital ecosystem to support a wide range of cognitive and motor rehabilitation needs.

Additionally, the findings of this work may also be extended to systems beyond the healthcare field, demonstrating potential for adaptation across a range of projects that adopt the slideshow metaphor.

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VIII. Future Work

This direction aligns with one of the core strengths of the application: its flexible and adaptable. The narrative, visual cues, and task objectives presented through the slide-based storytelling approach can be fully customized to suit the specific needs of different clinical profiles. This adaptability enables the application to serve as a versatile therapeutic tool, capable of addressing a wide range of cognitive and motor rehabilitation goals. Given the positive outcomes of the current implementation, additional projects employing the same development pipeline are already underway.

Ultimately, the long-term goal — and perhaps the most ambitious aspiration of this project — is the development of an intuitive game editor. This tool is envisioned to empower non-technical users, such as therapists and educators, to create custom rehabilitation experiences without requiring assistance from programmers or designers. Both the templates and the slide-based narratives would be easily configurable through a user-friendly interface, along with the inclusion of support for rigged animations, allowing for rapid implementation, even during live therapy sessions. By eliminating the need for programming in complex game engines or manual editing of JSON files, the editor would significantly lower the barrier to content creation, fostering a more accessible and flexible therapeutic platform.

To advance toward this broader vision, several intermediate goals have been established. One key objective is the integration of AI features, particularly the use of large language models (LLMs) with text-to-mesh capabilities, to enable real-time and user-friendly asset generation. With this approach, non-technical users could describe desired elements using natural language, and the system would automatically generate or configure these elements within the application. Another important step is allowing runtime adjustments to slide parameters, such as pacing or duration, to better adapt the experience to each session. Although the complete editor is still in development, this feature could be partially implemented in the short term using platforms like Unity PlayFab SDK [38].

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APÊNDICE

A: Mail de aceitação SVR - 2025

[SVR 2025] Notification for submission #13725 (A Virtual Reality Application for the Rehabilitation of Children with Cerebral Palsy) Caixa de entrada ×

jems3@sbc.org.br 24 de jul. de 2025, 10:51 (há 6 dias)

para diegocaracasmendes02, george, melojr, icarobarbosace, jpsml, joaquimb, thomas, cvidal, joaquim.bento, edson.coelho, mim

Dear Diego Mendes,

Congratulations, your submission #13725 entitled "A Virtual Reality Application for the Rehabilitation of Children with Cerebral Palsy" for Main Track (SVR 2025) has been accepted.

The reviews are bellow or can be found at
https://jems3.sbc.org.br/submissions/13725/

You will receive instructions for the camera-ready version soon.

Best regards,
SVR 2025
Technical Program Co-Chairs.