Mindscapes: Exploring EEG-Driven Emotional Expression in VR for Enhanced Emotional Relief and Mental Well-being

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Abstract

Existing VR emotional healing applications lack real-time adaptability and meaningful interaction with user emotions. This thesis explores an emotionally responsive VR system that visualizes brainwave data to create immersive and adaptive experiences. Using research through design (RTD) methodologies, through an iterative prototyping process this project investigates how real-time biofeedback can enhance user interaction and well-being in virtual environments. The system integrates EEG-based feedback with environmental dynamics, applying art therapy principles and meditation techniques to foster emotional engagement to enhance emotional regulation and self-awareness.

Keywords: EEG, Emotional Regulation, Art Therapy, Meditation, Biofeedback, Virtual Reality, Research Through Design, Human-Computer Interaction

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Table of Content

List of Figures

List of Tables

1. Introduction

1.1 Motivation

In contemporary society, individuals are facing an increasing array of problems that significantly impact mental health, including stress, anxiety, and depression. Following the COVID-19 pandemic, there has been a significant rise in the incidence of various mental diseases (WHO, 2022). In general, this is attributable to the post-pandemic era being driven by economic pressures, workplace demands, and the escalating cost of living. The proliferation of information overload, characterized by the swift influx of digital content and constant connectivity of social media, complicates emotional regulation. This can hinder attention and decision-making capabilities, resulting in stress and fatigue, which obstruct meaningful reflection and emotional processing, consequently diminishing opportunities for individuals to participate in restorative activities, thereby exacerbating the situation (Mindful Health Solutions, 2022). The ongoing influence of these elements on daily living underscores the necessity for accessible and effective emotional support systems.

An method to facilitate emotional control and mental health is necessary, considering the previously indicated context. Conventional therapy, including counseling and meditation, have proven successful in treating mental health concerns. Counseling provides individualized engagement and customized approaches; nonetheless, it can be expensive and may not be universally accessible (Cramer 2024). Meditation is typically accessible and economical; yet, it frequently lacks external feedback systems, which may constrain its efficacy for persons desiring immediate insights or adaptive emotional support (Brandmeyer and Delorme 2013). These constraints underscore the necessity for more flexible and interactive feedback systems. Emerging technologies, particularly virtual reality (VR) and electroencephalography (EEG)-based emotion identification, provide significant potential to bridge these gaps. Research demonstrates that EEG can proficiently and precisely detect emotional states (Calvo and Peters 2014), whereas VR enables captivating and interactive settings via immersive encounters (Müller and Malmström 2016). The amalgamation of these technologies presents an innovative pathway for improving emotion management and mental health assistance.

Research in environmental psychology highlights the substantial connection between an individual's emotional condition and their surroundings, indicating that conducive environments—be they physical or immersive digital—are essential for enhancing emotional stability (Müller & Malmström, 2016). Immersive digital environments can effectively duplicate simulated experiences, enabling users to get completely engrossed in the virtual realm. This profound sensation of immersion may aid in diverting attention from external stressors, augmenting focus on the virtual experience, and affecting emotional states. Moreover, immersive environments can be crafted to integrate systematic emotional engagement strategies, guaranteeing that users experience visual immersion while simultaneously receiving assistance in managing their emotions within the virtual realm. This highlights the significance of creating interactive, emotionally responsive settings that aid users in self-regulation and emotional equilibrium (Kazdin & Rabbitt, 2013).

These insights indicate that innovative approaches integrating technology, psychology, and therapeutic practices possess growing potential to address the evolving requirements of emotional well-being. Creating environments that promote self-awareness and emotional regulation enables individuals to navigate the complexities of modern life with enhanced resilience and balance.

1.2 Research Summary

1.2.1 Problem Statement

This study initiates an analysis of traditional emotional therapy frameworks, including psychotherapy, positive thinking meditation training, emotion-focused interventions in mobile and virtual reality applications, and art therapy. The analysis of these approaches reveals significant advancements in therapeutic interventions and digital applications, highlighting the potential for technology integration in emotional therapy. Nevertheless, a substantial gap remains in the creation of a unified system that incorporates these achievements into a holistic framework. There appears to be a lack of systems that meaningfully integrate EEG-based emotion identification, immersive virtual reality, and art therapy to enhance therapeutic experiences and provide an emotionally responsive, immersive, and artistic meditation environment.

1.2.2 Hypothesis

Currently, immersive VR environments and EEG-based emotion recognition technologies have shown potential in enhancing emotional regulation and meditation practices. This study explores the integration of EEG-driven feedback, VR environments, and art therapy principles to create an interactive and emotionally supportive experience. By adapting to users' EEG input, a responsive virtual environment may deepen the sense of immersion, allowing users to engage more intuitively with their emotional states. By visualizing real-time emotional fluctuations as dynamic visual elements within the VR space, users may gain a deeper understanding of their emotional states, potentially improving self-awareness and regulation. The interaction is designed as a form of passive creation, where users' emotions organically shape the environment, transforming their mental states into evolving patterns of visual expression.

Additionally, art therapy and meditation principles are believed to enhance and structure the experience. Beyond active creation, passive creation, where art unfolds without direct user control, is also recognized as a therapeutic method for emotional relief. It involves engaging with art through observation or interaction rather than creation, providing a means to process emotions and a more accessible form of self-expression, particularly for those facing communication and decision-making challenges (Ferrara & Flammia, 2022; Psychology Today, 2022). By enabling individuals to reflect on artistic changes rather than shaping them, passive creation offers an alternative emotional engagement approach. In this study, emotional fluctuations drive passive creation in the VR environment, applying art therapy principles non-verbally and intuitively. Meanwhile, structured frameworks like Focused Attention (FA) and Open Monitoring (OM) meditation offer a systematic approach to emotional engagement (Lutz et al., 2008). By integrating these elements, this study explores a new framework for digital meditation and emotional support, providing an alternative path for emotional engagement and self-regulation through intuitive and creative interaction.

1.2.3 Research Question

1) Main Research Question:

How can EEG-driven real-time emotion recognition and VR environments address the limitations of traditional emotional healing applications to create a dynamic, interactive system that enhances emotional regulation and promotes healing through art therapy principles?

2) Sub Research Questions:

- In an emotionally responsive experience, what system interactions and visual elements contribute to emotional relief?
- How can EEG-driven emotion recognition be integrated into VR to support emotional regulation?
- How can immersive VR environments transform real-time EEG data into visually engaging and interactive elements to support emotional balance?
- How to apply art therapy principles in VR to visualize and engage with emotions?

1.2.4 Goals

This study aims to explore and develop a potential responsive system that integrates EEG-driven real-time emotion recognition with immersive VR environments to enhance emotional regulation and therapeutic engagement. The system dynamically responds to emotional data input while incorporating principles of art therapy and meditation. By leveraging biofeedback mechanisms and adaptive virtual interactions, it seeks to enhance self-awareness, emotional expression, and overall well-being, providing real-time, personalized feedback within an immersive experience. The operation of the potential responsive system can be summarized and separated into three parts (Figure 1).

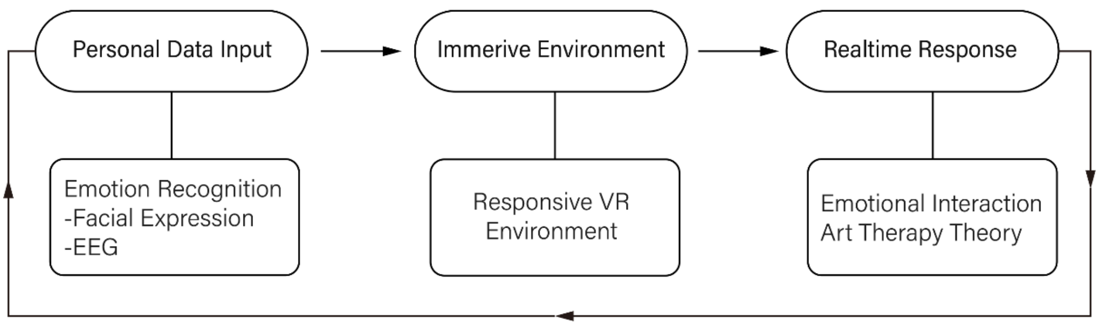

Figure 1- Potential Emotional Responsive VR Responsive System (By author, 2024)

1. Emotional data input and real-time feedback: Emotion identification technology, including facial expression analysis and EEG-based feedback, evaluate real-time emotional states to modify the VR experience. Contemporary VR systems struggle with continuous sensor integration, limiting the accuracy and responsiveness of real-time emotional feedback. This system integrates several technologies to dynamically monitor emotional fluctuations and modify the VR experience accordingly.

2. Emotionally Responsive VR Environments: Create VR environments that adapt to and reflect user emotions. Although virtual reality provides immersion and interactivity, its capacity for dynamic adaptation informed by real-time emotional input remains underutilized.

3. Integration of Art Therapy and Meditation Principles: Integrate art therapy and meditation principles into virtual reality experiences. This encompasses enabling users to articulate emotions via creative therapeutic activities, while fostering positive thinking and emotional equilibrium through meditation approaches such as Open Monitoring (OM) and Focused Attention (FA) (Lutz et al., 2008).

1.2.5 Outcomes & Contributions

This research contributes to the field by integrating background literature on emotional therapy, environmental psychology, and art therapy principles to inform the design of immersive, EEG-driven VR experiences. Addressing the core research question—how EEG-driven real-time emotion recognition and VR environments can enhance emotional regulation—this study explores spatial composition and color theory as essential design elements that influence emotional well-being. By examining how these principles can be applied to virtual environments, the study proposes new directions for creating emotionally supportive digital spaces. These theoretical insights are then implemented through scene design prototypes in VR, incorporating real-time interactions with Muse[1] EEG signals to visualize emotional states dynamically. This process allows for the direct representation of emotional fluctuations within an immersive setting, enabling a more engaging and responsive experience.

Furthermore, this research investigates how art therapy principles, including Focused Attention (FA) and Open Monitoring (OM) meditation techniques, can be integrated into EEG-VR interactions to refine meditation experiences. By designing prototypes that merge these therapeutic frameworks with EEG-driven digital environments, the study provides an alternative approach to emotional regulation that extends beyond conventional therapy methods. The iterative development of these VR prototypes contributes to a refined understanding of how interactive, biofeedback-driven systems can facilitate immersive meditation experiences. Ultimately, this work offers new perspectives on the design of interactive and emotionally adaptive VR spaces, demonstrating the potential of EEG-driven environments to enhance self-awareness, relaxation, and emotional support.

[1] https://choosemuse.com/pages/how-it-works

1.2.6 Methodologies and Approach

This study adopts Research through Design (RtD) as its primary methodology (Zimmerman et al. , 2010), utilizing iterative prototyping to explore the integration of EEG-driven real-time emotion recognition within immersive VR environments. Through this approach, the research investigates how spatial design, color theory, and interactive biofeedback can support emotional regulation and meditation experiences. The design process involves multiple iterations of VR scene development, integrating Muse EEG signals to create real-time responsive interactions. Additionally, to evaluate the effectiveness of the prototypes, self-evaluation and self-reflection methods are employed. These assessments focus on the system's ability to provide meaningful emotional feedback, the coherence of visual and spatial elements, and the overall immersive experience. Through structured reflection on each prototype iteration, insights are gathered to refine the interaction design, ensuring a more engaging and emotionally supportive digital environment.

1.2.7 Scopes and Limitations

This study investigates the design and development of an immersive EEG-driven meditation experience, incorporating principles from meditation and art therapy to develop a dynamic and interactive virtual environment. The research examines how real-time emotional data visualization, spatial design, and color theory might improve emotional engagement, providing a novel viewpoint on digital meditation experiences. This research investigates how users' emotional states might be mirrored and communicated through passive artistic creation in virtual reality by integrating art therapy principles with Focused Attention (FA) and Open Monitoring (OM) meditation techniques.

Nonetheless, due to the interdisciplinary character of this subject, several aspects remain outside the purview of this study. The quality of EEG data depends on the existing hardware and SDK constraints, indicating that the research does not seek to enhance EEG accuracy but instead investigates how the existent data can be represented in a virtual environment. This study does not aim to assess emotional changes or validate psychological effects; rather, it concentrates on the visual and interactive depiction of emotional states. The system presents an interactive meditation notion, not as a game, but as an artistic experience focused on emotional discovery. Owing to temporal and scope limitations, formal usability studies and extensive participant assessments have not been undertaken; the research instead seeks to offer a conceptual framework and illustrate its practicality.

There are still several places require additional refining in the future. The virtual reality experience could be improved with more sophisticated EEG feedback analysis and more interactive components to promote user engagement. Investigating supplementary multi-sensory feedback and adaptive contextual reactions may enhance emotional immersion. Furthermore, incorporating more structured guidance rooted in meditation and art therapy principles may augment the therapeutic efficacy, while subsequent research might concentrate on assessing the system's influence on emotional regulation via user testing.

1.2.8 Chapter Overview

This thesis is structured into six main chapters, beginning with an introduction. **Chapter 1** outlines the motivation, problem statement, and an overview of the research. **Chapter 2** presents a comprehensive literature review, examining mainstream emotion relief methods, VR emotional healing applications, the integration of art therapy with VR, and the role of EEG and facial expression recognition in emotional response assessment. It also includes a related work study to position this research within existing efforts. **Chapter 3** details the methodological framework, introducing Research Through Design (RTD) and evaluation methods, including self-evaluation and reflection. **Chapter 4** describes the iterative development of prototypes, highlighting the ideation, design, and reflective processes for each version. **Chapter 5** discusses key findings from the evaluation process, including insights from exhibitions, reflections on the research questions, personal challenges, and directions for future work. Finally, **Chapter 6** concludes the thesis by revisiting the research objectives, summarizing the contributions, acknowledging limitations, and proposing future development pathways.

2. Literature Review

This literature study analyzes current emotional relief techniques and their implementations across various technological platforms, concentrating on five principal themes. Initially, it examines conventional emotional healing methodologies, such as psychological counseling, meditation treatment, and mobile emotional healing applications, assessing their efficacy and constraints. Secondly, it examines the application of virtual reality in emotional rehabilitation, emphasizing its capacity to improve immersion and involvement while mitigating some limitations of conventional approaches. Third, it examines the incorporation of art therapy in digital contexts, specifically how creative expression in virtual reality might enhance emotional well-being. Fourth, it assesses emotion recognition and responding methodologies, analyzing EEG and facial expression recognition as instruments for obtaining real-time emotional data and improving interactive emotional feedback. Finally, it examines pertinent research, particularly the Sink in Sync project, which amalgamates EEG and VR to provide a collective brain experience, providing insights into the technical viability and design of EEG-based interactions. These discussions establish the basis for creating a VR-based emotional rehabilitation system that incorporates EEG-driven interactions with immersive, tailored experiences.

2.1 The Study on Main Stream Emotion Relief Methods

2.1.1 Psychological Counseling Therapy

A common method for addressing emotional distress is to engage with licensed therapists or psychologists. These professionals offer personalized, one-on-one support, leveraging specialized training to help clients understand and manage their emotions effectively (Norcross & Wampold, 2011). Therapeutic conversations enable individuals to articulate complex feelings, develop coping strategies, and benefit from the stabilizing nature of the therapeutic relationship itself (Wampold, 2015). This individualized care not only alleviates emotional distress but also fosters deeper cognitive clarity, reducing the tendency to exaggerate negative emotions.

Despite its effectiveness, traditional therapy faces several notable limitations. Cost remains a significant barrier, as professional therapy often involves high fees per session, making it inaccessible for many individuals. For instance, the average cost of therapy sessions varies widely but is generally expensive (Cramer 2024). Additionally, therapy is often geographically restricted, requiring individuals to meet practitioners in person, which presents accessibility challenges for those in remote areas. Despite the gradual emergence of mental telemedicine measures, including tele-mental health services that utilize videoconferencing or telephony (BMJ, 2023), these approaches continue to exhibit limitations. High dropout rates are one of the concerns. Dropout rates for online trauma interventions range from 15% to 41% in clinical trials, indicating difficulties in sustaining participant engagement (Young and Campbell, 2018). Furthermore, time constraints and busy schedules limit individuals' ability to regularly attend therapy. Beyond logistical barriers, psychological resistance—such as stigma or discomfort in discussing deeply personal emotions—can deter people from seeking professional help.

2.1.2 Meditation Therapy

In addition to therapy, meditation has emerged as a widely recognized method for promoting emotional stability, particularly in recent years. As a more economical and flexible alternative, meditation has gained popularity for its accessibility and potential to support mental well-being without the logistical or financial barriers often associated with traditional therapy. Rooted in Buddhist practice, meditation techniques such as Mindfulness-Based Stress Reduction (MBSR) have been integrated into therapeutic approaches to alleviate stress and improve emotional regulation (Wallace, 2003). Consistent practice has demonstrated long-term benefits, such as enhanced emotional resilience and improved attentional control. Meditation techniques are typically categorized into two main styles: Focused Attention (FA) and Open Monitoring (OM) (Lutz et al., 2008). FA meditation involves concentrating on a single object, such as the breath, and redirecting attention whenever distractions arise. Over time, this practice fosters selective attention and enhances focus, engaging areas of the brain such as the prefrontal cortex. OM meditation, on the other hand, emphasizes a nonjudgmental awareness of the present moment, allowing practitioners to observe thoughts and emotions without attachment. This style promotes emotional regulation and self-awareness. (Zeidan et al., 2010).

It is also important to recognize that these two types of meditation are not independent; rather, focused attention (FA) and open monitoring (OM) are interrelated and exhibit a hierarchical relationship (Travis and Shear, 2010). For instance, FA meditation can enhance an individual's positive thinking and improve mood, whereas OM meditation can further elevate positive thinking and sustain a positive mood. The fluctuations in positive thinking and mood during the training process are dynamic (Zhang et al., 2019). Chiesa (2011) concluded that the initial phases of positive thought training are linked to the enhancement of focus attention (FA), selective attention, and attentional performance. In contrast, the subsequent phases emphasize open monitoring (OM) meditation, which fosters heightened alertness and sustained attention. The current study indicates that the design of the meditation-based experience must adhere to a systematic step-by-step process of mindfulness training, following a specific sequence to guarantee its effectiveness.

Despite its accessibility and cost-effectiveness, meditation has notable limitations. For instance, practicing meditation without professional guidance can make it difficult for individuals to maintain focus, particularly when facing complex or overwhelming emotions. As noted by Lomas et al. (2015), participants without prior meditation experience reported difficulties in sustaining attention and managing distressing thoughts during unguided meditation sessions. Additionally, meditation lacks external feedback mechanisms, which may reduce its effectiveness for those seeking real-time insights or dynamic emotional support. The effectiveness of external feedback lies in its ability to enhance participants' understanding of their meditation practice while simultaneously deepening their experience. Combining neurofeedback with meditation helps sustain optimal brainwave patterns, enhancing mindfulness and nonjudgmental awareness (Brandmeyer & Delorme, 2013). However, the lack of structured interaction or personalization may hinder long-term engagement.

2.1.3 Mobile Emotional Healing Applications

Building on the limitations of traditional meditation practices, numerous mobile meditation applications have emerged to provide accessible and cost-effective alternatives. Designed primarily for smartphones and tablets, these apps address challenges such as the lack of feedback and difficulty in maintaining focus. For instance, applications like Headspace and Calm provide tailored guided meditation sessions that cater to individual requirements, aimed at enhancing user engagement and consistency in practice (McCormick and Owens, 2024). These applications generally provide breathing training for 10 to 20 minutes of daily guided meditation, which can address specific conditions such as stress, anxiety, or depression. Numerous randomized controlled trials (RCTs) have demonstrated the efficacy of Headspace in alleviating anxiety and depression, among other outcomes (Lahtinen et al., 2023). In these applications, features like daily tracking, reward mechanisms, and guided meditation sessions enhance user engagement and make meditation more structured and approachable. One significant advantage of mobile meditation apps is their accessibility and time flexibility, allowing users to practice meditation anywhere and at any time, fitting seamlessly into busy schedules. Additionally, these apps are relatively affordable, often offering free versions or low subscription costs, making mental wellness support more broadly available. A recent report by Grand View Research, Inc. indicates that the global mental health apps market is projected to attain a size of USD 17.52 billion by 2030, with a compound annual growth rate (CAGR) of 15.2% from 2024 to 2030. This indicates the increasing adoption and popularity of mental health apps, their benefits in enhancing awareness of mental health among users, and their potential for future growth (Grand View Research, 2024). Additionally, certain applications have begun to incorporate real-time monitoring capabilities utilizing devices such as Apple Watches or Muse headbands to track heart rate, EEG, and other physiological data, offering limited yet valuable feedback on physical conditions during meditation. The Muse headband, along with its meditation app, measures brain activity, heart rate, and physical activity through an EEG-monitoring device. This headband connects to a mobile application that facilitates the meditation process for the user (Muse, 2023). The app enables users to visualize changes in their brain waves, enhancing their understanding of brain activity.

However, mobile meditation apps also face notable limitations. For instance, Headspace and Calm are prominent meditation applications that primarily offer FA-style meditations, including guided breathing exercises and mindfulness practices through software platforms. FA-style meditation is accessible for beginners and enhances the controllability and quantifiability of the meditation experience. However, the extended concentration required may result in fatigue and subsequent challenges in maintaining focus (Lutz et al., 2008). Furthermore, FA meditation may not be suitable for contexts that necessitate flexibility in emotional response adjustment, particularly when an individual's mood varies. An excessive focus on a singular goal may inhibit the ability to address and manage complex emotional responses effectively (Zeidan et al., 2010). Without immersive or interactive elements, users may find it difficult to sustain focus during sessions, especially in environments with distractions. Many apps rely on basic reward systems or static guided practices, which may not be sufficient to maintain long-term user engagement or address deeper emotional needs. Furthermore, the external emotional feedback, such as the response that can be provided to a change in mood, provided by these apps is limited, often relying on generic insights or subjective user input rather than real-time responses to dynamic emotional states. This lack of personalized interaction reduces the potential therapeutic impact of mobile meditation tools, especially for users seeking more tailored support.

2.2 VR Emotional Healing Applications

2.2.1 The Definition of VR

The emergence of Extended Reality (XR) as a significant component of emerging technologies creates new opportunities for the advancement of emotional healing applications. Extended Reality refers to a comprehensive concept that includes all hybrid environments where real and virtual elements coexist within a system, with the integration of these realms occurring along a continuum. XR encompasses a spectrum from entirely virtual environments (VR) to real environments enhanced by virtual elements that interact with or alter reality, including Mixed Reality and Augmented Reality, culminating in fully realistic environments (Milgram and Kishino, 1994). In this continuum, the defining characteristic of Virtual Reality (VR) is a fully synthetic or fully virtual view, which can also be described as an entirely constructed reality. Participants are engaged in and capable of interacting with this completely synthesized environment (Speicher, Hall, and Nebeling, 2019). A virtual world can replicate certain characteristics of real-world environments while simultaneously transcending the limitations of physical reality, allowing for a realm where conventional laws of physics, such as those governing space, time, mechanics, and material properties, do not apply (Milgram and Kishino, 1994). The fully immersive virtual environment of virtual reality (VR), in contrast to mixed reality (MR) and augmented reality (AR), provides distinct advantages for psychotherapy. A significant element of virtual reality in psychotherapy is its capacity to provide users with a sense of "presence" within the computer-generated environment (Hacmun, Regev, & Salomon, 2018). The sense of presence serves as an effective therapeutic instrument for personal transformation and self-reflection, offering individuals the chance to engage in an experience that appears genuine. Furthermore, VR is commonly described as a "advanced imagery system," representing a type of experiential imagery that effectively elicits emotional responses (Riva et al., 2016).

2.2.2 Research of VR Emotional Healing Applications

Thus, Virtual Reality (VR) has emerged as a promising platform in recent years, providing a more immersive alternative to mobile meditation applications to tackle certain challenges encountered by emotional healing applications on mobile devices. Enhancing immersion in virtual reality improves the quality of the meditation experience and significantly increases user engagement and focus, leading to a deeper connection to the practice. Tripp exemplifies the use of VR technology to integrate visualization, auditory experiences, and guided meditation along with mindfulness training. This experience may provide greater relief from stress and anxiety compared to standard mobile meditation applications, as sensory engagement improves emotional clarity and focus (Amazon Science, 2022). Tripp employs AI to assess the user's emotional state at the start of the session, subsequently assigning a tailored session and selecting a suitable preset environment based on the analysis. In addition to Tripp, VR meditation applications like Liminal VR provide customizable "altered mood" experiences, enabling users to choose settings that align with their emotional requirements (Geraets et al., 2021). These applications increasingly personalize emotional healing to meet diverse needs while integrating interactive content for greater appeal and effectiveness.

Despite the increased immersion and interactivity of VR meditation applications compared to earlier mobile apps, they continue to exhibit certain limitations. Many mainstream VR applications, such as Tripp and Liminal VR, continue to depend on manual emotional input from users due to hardware limitations. This reliance may not accurately represent the user's true emotional state or needs, as the evaluation of emotions is inherently complex. Users may struggle to accurately assess their own emotions, particularly during periods of instability (Berrios, 2019). The absence of real-time mood monitoring during sessions restricts the capacity to adapt dynamically to mood fluctuations and diminishes the personalized feedback anticipated by users in a therapeutic context. Moreover, although the immersive nature of VR can enhance engagement, it does not ensure the efficacy of emotional therapy, as these tools do not possess the strong, scientifically validated therapeutic outcomes associated with conventional counseling or therapy. The effectiveness of VR applications in delivering long-term emotional relief requires further investigation.

2.2.3 Current Problems

According to previous researches, in the field of emotional relief, existing solutions face several key problems that limit their effectiveness in providing meaningful and immersive support for users. One significant issue is the inability to achieve real-time response and immersive experience simultaneously. While wearable devices, such as smartwatches, can incorporate sensors to monitor physiological data, this technology has not been effectively integrated into mobile or VR platforms. The absence of seamless real-time feedback in these tools restricts their capacity to dynamically respond to users' emotional states, reducing their therapeutic impact.

Another critical problem lies in the lack of personalization. Most meditation and emotional relief applications rely on generic, pre-designed content or self-reported user inputs, which often fail to capture the nuances of individual emotional states. Without personalized data, these tools struggle to deliver tailored experiences that address users' unique needs, limiting their ability to foster meaningful emotional connections and provide targeted relief.

In addition, there is insufficient interaction between users' emotional states and their external environments. Psychological theories, such as Lewin's Field Theory, highlight that emotional regulation is influenced by the interaction between internal consciousness and external stimuli (Lewin, 1936). However, many current applications overlook this dynamic interplay, offering static and generalized environments that fail to adapt to users' changing emotional and environmental contexts. This lack of responsiveness undermines the potential for immersive experiences that could effectively regulate emotions through both internal and external adjustments.

Lastly, the static or non-adaptive nature of content in many existing tools reduces their interactivity and engagement. Without adaptive mechanisms that respond to users' real-time emotions, these applications often feel monotonous and fail to maintain long-term user interest. The absence of dynamic, interactive features diminishes the immersive quality of the experience, making it less appealing and potentially less effective for emotional relief.

Addressing these problems requires a shift toward solutions that integrate real-time biofeedback, personalized emotional responses, and dynamic environmental interaction. By doing so, future tools can create immersive and adaptive experiences that align with users' emotional needs, offering more effective and engaging pathways to emotional relief.

2.3 Art Therapy & VR

2.3.1 Art Therapy Fundamentals and Applications

Art therapy is a therapeutic approach that employs the creation of art to enhance mental health and well-being. The British Association of Art Therapists characterizes art therapy as a psychotherapy modality that employs art media as the principal means of expression and communication (British Association of Art Therapists, 2015). Art media serves as the primary communication method to facilitate patients' health and well-being, allowing them to engage with art materials that promote their creative resources within a safe and enriching environment (Deshmukh et al., 2018). The increase in the use of art therapy can be attributed to its ability to facilitate emotional expression, enhance self-awareness, and support emotional regulation (Rubin, 2009). It is also gaining recognition as a significant form of spiritual support and complementary therapy (Faller and Schmidt, 2004; Nainis et al., 2006). Art therapy seeks to establish an environment in which the therapeutic process is manifested, enabling users to articulate their emotions nonverbally through creative activities that facilitate insight and emotional clarity (Rubin, 2009). By expressing themselves in a culturally acceptable manner, both internally and externally, patients experience a reduction in symptoms of depression and anxiety (Hu et al., 2021).

Art therapy is categorized into five primary domains: performing arts, which include music, dance, theater, singing, and film activities; visual arts, encompassing crafts, design, painting, photography, sculpture, and textiles; literature, involving writing, reading, and engagement in literary festivals; culture, represented by visits to museums, galleries, art exhibitions, concerts, plays, community events, cultural festivals, and fairs; and digital arts, which cover animation, film production, computer graphics, and online art outcomes (Fancourt and Finn, 2019). Art therapy can be categorized into active and passive approaches. Active engagement entails the direct creation of art forms, including painting, sculpting, writing, or performing, allowing individuals to tangibly express their emotions and experiences. Passive creation involves engaging with art through observation or interaction with existing artworks, rather than through active creation. This method provides therapeutic advantages by enabling individuals to process their emotions and experiences through the art they engage with (Ferrara & Flammia, 2022). Passive creation offers a more accessible and less intimidating means of self-expression for individuals who encounter difficulties in communication and decision-making

(Psychology Today, 2022).

Active and passive engagement with art are both effective methods of art therapy (Joschko et al., 2022). These approaches may include imagination, aesthetic engagement, sensory activation, cognitive stimulation, emotional arousal, and, in some instances, increased physical activity and social interaction (Fancourt and Finn, 2019). Patients may be advised to cultivate nonverbal communication skills to mitigate emotional, cognitive, linguistic, or motor deficits. This study investigates passive creation in digital art therapy within virtual reality environments to promote inclusivity and universal accessibility. This approach facilitates user engagement with a personalized VR environment, promoting relaxation and emotional healing without necessitating active artistic creation, thereby ensuring accessibility for diverse user groups.

2.3.2 The Integration of VR and Art Therapy

The research on art therapy indicates that it offers a framework for patients to explore their emotions and inner experiences through creative activities. It is important to note that the therapeutic environment plays a crucial role in emotional processing and healing, warranting emphasis (Hu et al., 2021).Virtual reality offers a coherent interface for the development of such an environment. The distinctive features of the VR experience, along with the innovative avenues for artistic expression in VR, enhance these therapeutic opportunities (Lohrius and Malchiodi, 2018). Artistic expression in VR psychotherapy significantly contributes to fostering a sense of familiarity and safety for patients, while also enhancing self-reflection and meditation. The establishment of a "safe space" is a prevalent practice, designed by the client based on individual preferences, functioning as an emotional refuge (Hadjipanayi, et al., 2023). Safe spaces, typically represented as houses or caves, have been utilized in psychotherapeutic practice long before the introduction of virtual reality. However, the capacity to enter into artworks is a distinctive feature of VR technology, thereby broadening the scope of this practice (Frewen et al., 2020). The integration of VR technology with art therapy transforms user interaction with art, enabling not only observation and appreciation but also active participation in the creative process and engagement in the art experience.

Furthermore, creation in virtual reality integrates aspects of painting, including lines, facets, shapes, and colors in two dimensions, alongside three-dimensional elements from sculpture, as well as innovative components introduced by digital media. This unique combination resembles traditional media such as painting, drawing, and sculpture, yet it is fundamentally distinct. The VR headset interface offers enhanced interaction methods; for instance, the incorporation of emotion-monitoring recognition technologies can facilitate an emotionally responsive environment in virtual reality (Gupta et al., 2024). A notable distinction is that, unlike traditional mediums such as painting and sculpture, the creation of art in virtual reality is fundamentally digital. Consequently, VR paintings lack substance and haptic feedback from both the material and the canvas (Hacmun, Regev, and Salomon, 2018). This virtualization enables VR creations to be realized without the limitations imposed by the natural laws of physics. Objects generated in three dimensions can be suspended in mid-air, remaining unaffected by the physical world's gravity, thereby facilitating a more flexible creative environment. This VR environment offers an innovative and effective platform for art therapy by integrating aspects of non-creative process reality with immersive sensory experiences, facilitating a dreamlike experience within a secure and controlled setting (Leclaire, 2003).

The visualization of mood swings in virtual reality possesses supplementary therapeutic benefits. A significant number of individuals struggle to comprehend or articulate their emotions, often as a result of restricted imagination or introspective capacity. The real-time visualization of brain activity or emotional states within a VR environment offers users an immediate and intuitive method for comprehending their emotions and cognitive processes. Immersive environments can visually and interactively enhance the emotional processing of abstract feelings, offering advantages for individuals with limited introspective abilities (Lohrius and Malchiodi, 2018). The integration of real-time feedback in virtual reality systems enables users to externalize and visualize their emotional states through dynamic, artistic creations, effectively connecting abstract emotional concepts with tangible representations (Hacmun, Regev, and Salomon, 2018).

However, currently the lack of integrated emotional sensors in mainstream VR headset hardware limits the popularization of emotionally-responsive healing application software that utilizes VR headsets as an interface. This technical limitation can be addressed or resolved. Users may enhance their VR headset experience by incorporating additional devices for emotional recognition, such as consumer-grade EEG devices, which can evaluate emotional responses in conjunction with the VR system (Horvat et al., 2018). The aforementioned research highlights the potential for integrating art therapy with real-time emotional responses in virtual reality. However, further investigation is required to develop concrete technical methods for achieving emotionally responsive spatial interactions in future studies.

2.4 Emotion Response Using EEG & Facial Expression Recognition

In terms of emotion responsive techniques, emotion recognition is essential for facilitating personalized and responsive feedback. This field primarily employs two techniques: facial expression recognition and electroencephalography (EEG). Facial expression recognition involves the analysis of emotional cues via AI-driven image processing of facial data (Calvo & D'Mello, 2010). Mollahosseini et al. (2016) demonstrate that this technique effectively tracks real-time emotional changes, offering adaptive feedback to users. However, this approach has notable limitations, particularly in immersive environments like virtual reality. Facial recognition exhibits inaccuracies stemming from variations in expression or occlusion resulting from VR headsets, leading to low reliability for high-precision applications. Furthermore, users' expressions do not always align with their precise mood states. Individuals often smile in response to happiness, frown when experiencing sadness, and exhibit frowning when feeling anger. These occurrences are even more common than one might occasionally anticipate (Barrett et al., 2021).

Under this circumstance, EEG technology offers a more direct and objective approach to capturing emotional states through the analysis of brainwave activity. Shemesh et al. (2016) demonstrated that EEG can detect subtle emotional changes in real time, offering important insights into user responses to external stimuli. Griffith et al. (2015) demonstrated that EEG-based tools can improve emotion regulation systems through accurate and real-time monitoring of brain activity. While consumer-grade EEGs currently do not reach the performance levels of professional laboratory equipment, devices like the EMOTIV EPOC+[2] EEG and Muse headset are regarded as appropriate for student experiments. They are particularly effective in detecting emotion-related phenomena, where exact electrode placement is not essential (Horvat et al., 2018).

Furthermore, similar to facial expression recognition, the current development of EEG and VR technologies entails a notable degree of conflict. Effective immersion in virtual reality necessitates a substantial display that encompasses the upper facial region and forehead. Additionally, the elastic straps required to secure the thick screen will cover a significant portion of the scalp, potentially impacting EEG recognition to some degree. In instances where the experiment does not necessitate high accuracy in the signals and data captured by EEG, a simpler headset with fewer electrodes may suffice for conducting a power spectral analysis of EEG activity. This device offers improved manageability and compatibility with VR headsets, thereby streamlining the integration of EEG and VR technologies. In comparison to the EMOTIV EEG device, the Muse 2[3] headband features only 4 electrodes (Figure 2), resulting in a more compact design that enhances compatibility with VR headsets (Horvat et al., 2018). Thus, this study will utilize EEG due to its accuracy relative to facial recognition and its compatibility with VR systems, enabling the integration of individual emotional data into immersive VR environments.

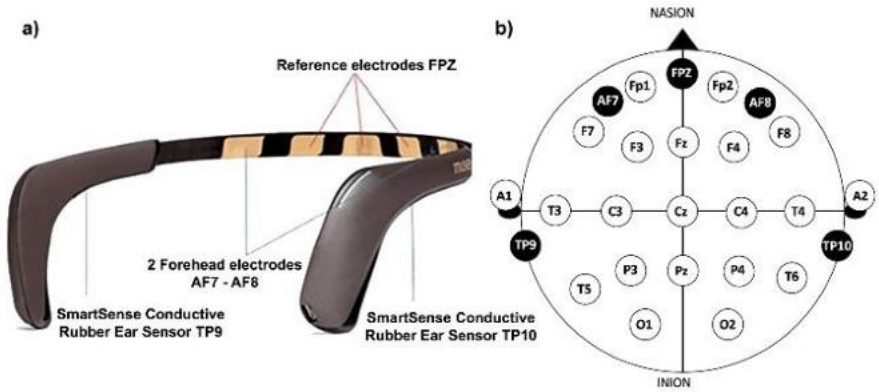

Figure 2- MUSE 2 headband sensors overview & Top-down view of the EEG electrode positions (Mansi et al. 2021)

IoT-driven responsive space has also introduced in the study to enhance the integration of EEG in VR and improve interactivity with the virtual environment. This system is designed to operate efficiently. This system enhances VR's capacity to recognize user emotions and facilitates real-time environmental adjustments based on EEG data, resulting in a more dynamic and personalized emotion regulation experience.

The Internet of Things (IoT) is a connected ecosystem that integrates technologies including sensor hardware, cloud computing, and data modeling to facilitate seamless communication

[2] https://www.emotiv.com/?srsltid=AfmBOormnPhsd9xQl7DBRiY9zpYfaEX1mJyqxpQq9CH7R0A0Xabzuo2W

[3] https://ca.choosemuse.com/products/muse-2

among smart objects (Perera et al., 2013). The dynamic sensing capabilities enable continuous collection and analysis of environmental data, forming the foundation for context-aware applications (Bandyopadhyay et al., 2011). Context-aware computing enables systems to deliver more intelligent responses to environmental stimuli through the analysis of sensor data (Abowd et al., 1999). This capability facilitates the integration of IoT and virtual reality, resulting in immersive and interactive environments (Müller & Malmström, 2016). This combination allows virtual reality to adapt in real time to user behavior and physiological states, resulting in more adaptive and context-aware digital experiences (Speicher, Hall, & Nebeling, 2019).

The design of Responsive Spaces is based on a four-stage context management model, which includes context acquisition, context modeling, context inference, and context distribution (Figure 3). The system efficiently manages situational context using this framework. This framework enables the system to efficiently process multimodal sensor data and optimize the VR environment to dynamically synchronize with the user's emotional state based on inference results (Gupta et al., 2024). This mechanism enhances the potential of VR applications for emotion regulation and promotes the integration of IoT with immersive interaction technologies.

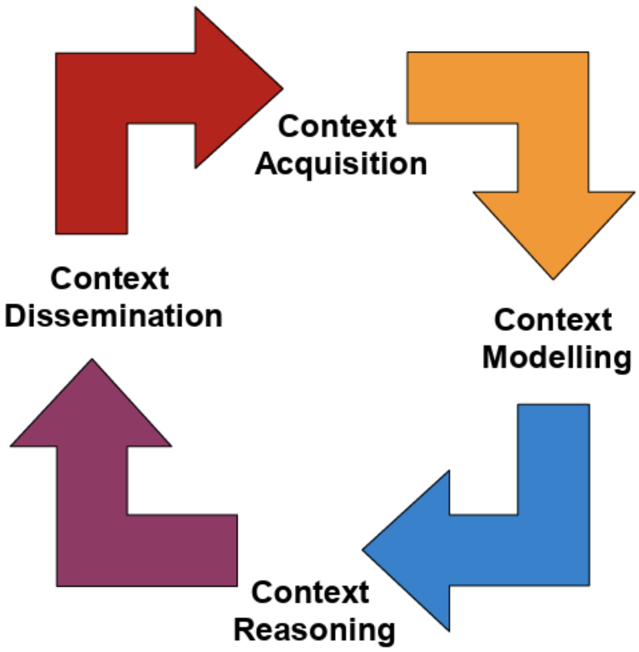

Figure 3- A Simplest Form of a Context Life Cycle (Perera et al., 2013)

Additionally, Virtual Reality (VR) serves as a potent medium for developing immersive environments that augment emotional engagement. The user-friendly nature of VR headsets, along with their capacity to deliver multi-sensory stimulation—including dynamic vision, spatial audio, and haptic feedback — renders them particularly effective for fostering immersive emotional experiences. Sternberg (2009) asserts that the environment significantly influences emotional states, and the capacity to simulate and adapt to environmental factors in virtual reality aligns with the tenets of environmental psychology. Dynamic features, including light, sound, and movement in virtual reality environments, can effectively regulate emotional responses by engaging internal awareness and external sensory input (Müller & Malmström, 2016). The immersive nature of VR enhances user focus and engagement in emotional relief exercises, effectively addressing the limitations associated with traditional meditation tools. Virtual reality enhances the meditation experience by immersing users in fully interactive and personalized environments, leading to improved emotional regulation. However, it is worth noting that long-term use of VR for emotional regulation may result in decreased engagement and interest, subsequently leading to lower arousal and dominance scores in the SAM. It is essential to evaluate the suitable duration of VR usage for mood regulation to sustain user engagement and interest (Gu et al. 2024).

2.5 Related Work Study: Sink in Sync

The integration of EEG headsets with VR environments has garnered significant interest in artistic and scientific domains, especially in the investigation of emotional and social connectedness. The project Sink in Sync investigates inter-brain synchronization as a means to enhance social bonding and engagement via a VR-based EEG neurofeedback experience (Wang and Feng 2023). Inspired by physiological synchronization, which involves the alignment of heart rates, breathing patterns, and neural rhythms during social interactions, Sink in Sync converts real-time EEG data from Muse 2 headsets into an immersive and interactive virtual environment, providing a novel method for individuals to connect beyond conventional verbal communication.

The virtual reality environment responds to variations in brainwave activity by modifying elements like ambient fog, glowing orbs, and pulsating lanterns to visually depict the mental states of two users. When the brainwave frequencies of both participants synchronize, environmental changes occur—shooting stars traverse the sky, or flowers bloom at their feet, visually reinforcing their neural alignment (Wang and Feng 2023; Vega Awards, 2024). This approach enables Sink in Sync to create a shared sensory experience that enhances interpersonal connections by rendering the process of brainwave synchronization perceptible.

In addition to its conceptual and experiential framework, Sink in Sync establishes a significant precedent for the integration of EEG and VR. The project establishes the technical feasibility of integrating Muse 2 EEG headsets with virtual reality, confirming the stability and responsiveness of this configuration in a real-time interactive application. This success highlights the potential of EEG-driven interaction in immersive environments, serving as a significant reference for future research aimed at integrating neurofeedback into digital experiences. Sink in Sync also establishes a serene and introspective environment, influenced by celestial elements including nebulas, floating energy trails, and dynamic atmospheric lighting (Wang and Feng 2023). The experience is crafted to be transient and immersive, employing nuanced, responsive design elements to augment emotional awareness and engagement. The application of subtle and organic visual effects emphasizes the sensitivity of brainwave interactions, providing important insights for the design of EEG-responsive virtual reality environments. The aesthetic choices, specifically the implementation of soft, fluctuating forms and ambient visual feedback, are critical factors in the development of emotionally engaging virtual environments.

The project Sink in Sync provides several key takeaways that inform this research. Unlike its focus on social connectedness through inter-brain synchronization, this study prioritizes individual self-exploration and emotional awareness. Instead of emphasizing shared neural states, this research investigates how a single user's EEG data can shape a responsive virtual environment, facilitating introspection and mindfulness. By drawing from *Sink in Sync*'s technical and aesthetic approaches, this project establishes a clear direction for integrating EEG-driven feedback into VR, using these inspirations to explore the relationship between cognitive states, emotional regulation, and interactive digital spaces.

2.6 Summary

The literature analysis explores the advantages and drawbacks of current emotional healing techniques and examines how innovative technology can improve user experience and participation. Conventional methods, such psychiatric counseling and meditation therapy, provide established advantages but encounter obstacles concerning accessibility, engagement, and immediate response. Mobile applications have sought to resolve these challenges via guided meditation and biofeedback functionalities; nonetheless, they still exhibit constraints in personalization and immersion. The evaluation of VR applications reveals their capacity to facilitate more immersive and engaging emotional healing experiences, especially when integrated with art therapy principles to promote self-expression and reflection. Furthermore, studies on emotion identification algorithms highlight EEG as a promising instrument for real-time emotional feedback, notwithstanding hardware constraints that impact signal precision. The Sink in Sync project demonstrates the viability of EEG-driven virtual reality experiences, offering significant insights into the design of emotionally adaptive virtual environments. These ideas collectively guide the creation of a VR-based emotional healing system that incorporates EEG-driven interactions, immersive spatial design, and creative expression to provide a more engaging and adaptive meditation experience.

3. Methodology

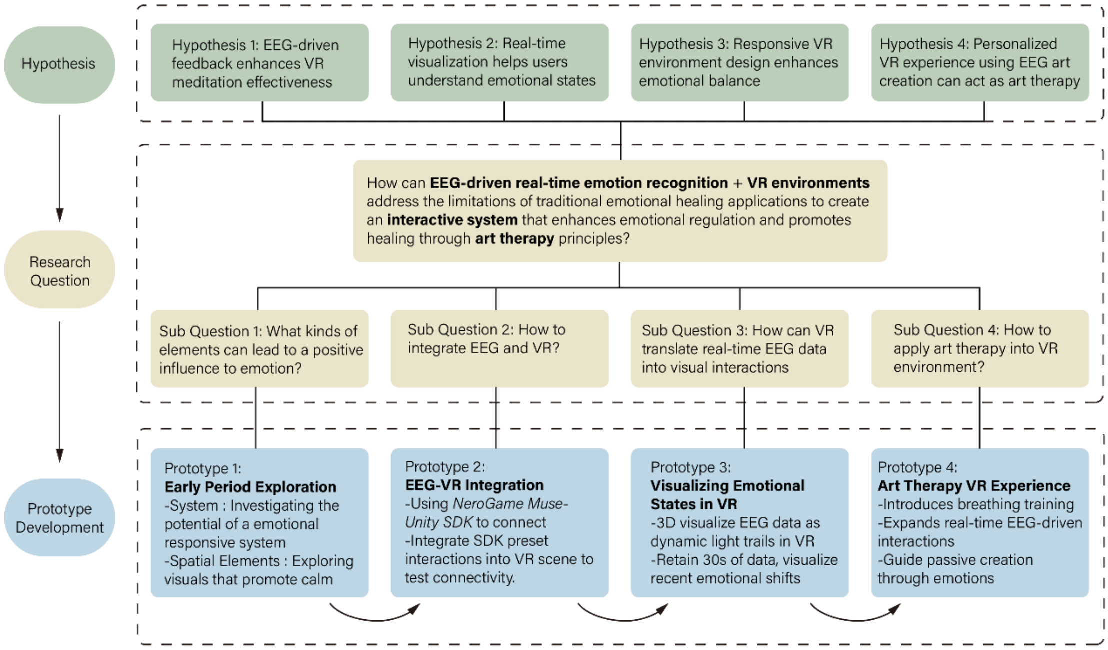

Figure 4- Thesis Program Diagram

Figure 4 outlines the comprehensive framework of this thesis, demonstrating the transition from the initial hypothesis to the research questions and their categorization into four principal sub-topics. Each sub-question corresponds to a particular prototype, directing the iterative development process. This framework elucidates the systematic examination of EEG-VR integration, with each prototype targeting a certain facet of emotional engagement and system responsiveness. By segmenting the research into distinct stages, the framework guarantees a coherent and systematic methodology for examining and enhancing the EEG-driven immersive experience.

3.1 Research Through Design

This study employed a research design (RtD) approach for the development of the prototype, incorporating its iterative framework in the creation and refinement of the EEG-VR Emotion Alleviation System (Fig. 4). RtD is especially appropriate for this study as it enables an iterative, practice-led methodology to investigate emerging design challenges that may not be sufficiently addressed by conventional empirical or theoretical methods. Through ongoing iterations, RtD facilitates an adaptive research process that permits incremental enhancements to EEG-driven VR interactions, ensuring that both technical feasibility and quality of experience progress in tandem with theoretical exploration.

Zimmerman et al. (2010) describe RtD as an approach that integrates interdisciplinary knowledge and enables the iterative reconfiguration of problem domains and solutions, thereby serving as an effective methodology for exploring complex, open-ended design challenges. The integration of EEG-driven feedback for emotion regulation in virtual reality environments presents a complex challenge that extends beyond technical implementation; it necessitates an examination of human perception, emotion, interaction, and immersion. The application of RtD methods facilitated a strong connection between the research and design processes.

The phases of this study corresponded with the essential stages of the RtD framework (Explore, Create, Evaluate, and Reflect), facilitating ongoing adaptation informed by the outcomes of prior iterations. Early prototypes aimed to investigate the feasibility of correlating emotional states with visual elements to evaluate the potential of an emotional response system. Subsequent prototypes incorporated a wider range of EEG interactions, immersive spatial components, and principles of art therapy, while the system was continuously refined through ongoing evaluation.

This iterative process did not aim to assess the system's effectiveness in a clinical or empirical context; instead, it focused on exploring its feasibility and potential as an EEG-driven, emotionally responsive virtual reality experience. Each prototype advances the understanding of how real-time biofeedback, immersive spatial elements, and interactive visuals can facilitate user engagement with emotional states in significant ways. Continuous iteration and reflection cycles facilitate incremental refinement of technology integration and experience design, ensuring the system evolves based on insights obtained through prototyping and evaluation (Figure 5).

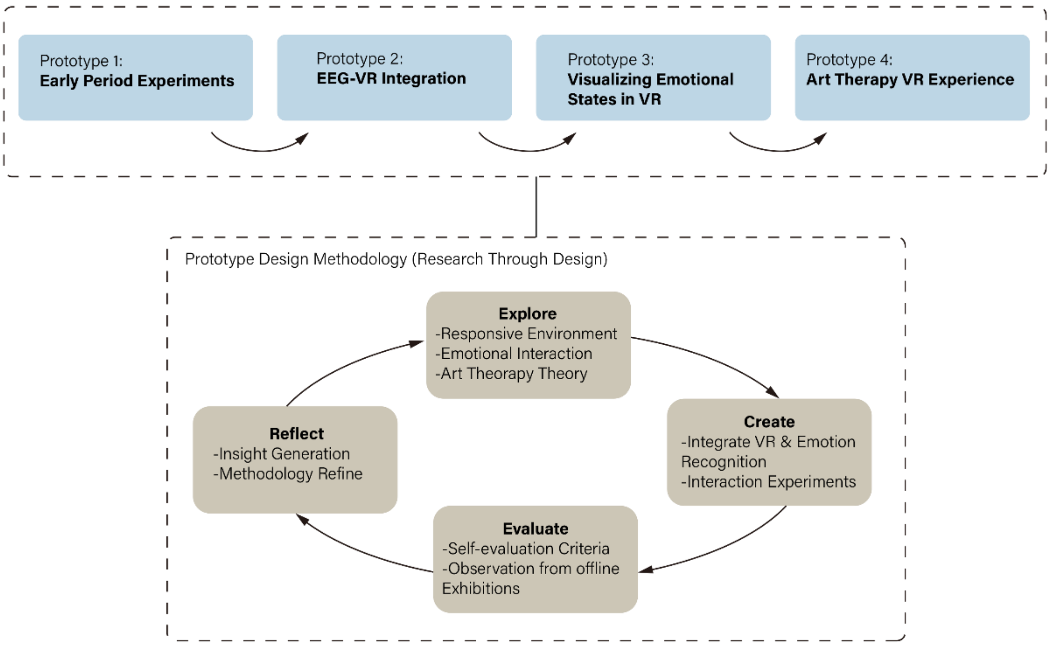

Figure 5- Research Through Design Method Diagram

3.2 Evaluation Methods

3.2.1 Self Evaluation

This study primarily investigates the conceptual viability of an EEG-driven emotionally responsive VR system, assessing its potential to augment emotional engagement, self-awareness, and interactive immersion. Thus, this research employs a self-evaluation methodology to systematically evaluate the efficacy of each prototype in enhancing the system's flexibility, emotion recognition, and environmental reactivity, rather than relying on extensive user testing. This methodology provides an analysis of the strengths, weaknesses, and prospective uses of emotionally interactive VR environments by evaluating system responsiveness and adherence to recognized design principles.

This self-evaluation criteria is structured on the Extended Reality and Internet of Things (XRI) Design Considerations (Tsang & Morris, 2021), a framework that amalgamates immersive technologies (VR, AR, MR) with IoT-enabled adaptive systems to generate responsive, data-driven experiences. This study specifically examines two main evaluation components: XRI Design Context and XRI System User Experience, which provide defined criteria for measuring the system's interaction, emotional feedback mechanisms, and overall efficacy in emotional regulation.

The XRI Design Context dimension evaluates the alignment of the system's aims, user interactions, and emotional response mechanisms with its intended purpose of facilitating emotional regulation. This entails assessing the system's capacity to detect, process, and visualize EEG data in real time, guaranteeing that feedback is coherent and effectively integrated into the VR environment (Tsang & Morris, 2021). The XRI System User Experience prioritizes usability, immersion, and emotional resonance, guaranteeing that the system promotes engagement, emotional connection, and intuitive interaction inside the virtual reality environment. These aspects establish the basis for a systematic self-assessment process, evaluating the system's adaptability and its capacity for emotional reaction.

Furthermore, this evaluation approach incorporates Nielsen's usability guidelines (Nielsen, 1994), which are extensively utilized in VR settings (Kendrick, 2021). These heuristics offer a pragmatic foundation for evaluating elements such as system status visibility, consistency in interaction design, user autonomy, adaptability, and error mitigation—all essential for crafting an intuitive and emotionally responsive VR experience. This study integrates XRI considerations with usability criteria to create a thorough self-evaluation approach, guaranteeing that the VR system accurately visualizes and responds to emotional states while preserving an immersive and user-friendly interface. The self-evaluation table can be concluded below:

Evaluation Criteria	Corresponding XRI Framework	Description	Nielsen's Usability Heuristic
System Connection	XRI Design Context	Evaluates how effectively the system detects and visualizes emotion/ EEG signals in real-time. This includes responsiveness to different EEG states and whether these responses are meaningfully represented in the VR environment.	- Visibility of System Status
Immersive Emotional Interactivity	XRI System User Experience	Evaluates how the system enhances immersion by dynamically adapting the VR environment to EEG signals, ensuring interactive responses that foster user engagement and emotional connection.	- Match Between System and the Real World - Aesthetic and Minimalist Design:
Art Therapy Principles Application	XRI System User Experience	Assesses whether the VR system incorporates meditation principles to foster mindfulness and emotional balance while integrating guided creative elements that encourage artistic exploration and structured creative engagement with potential applications in art therapy.	-Recognition Over Recall - Flexibility and Efficiency of Use input
Visual Emotional Consistency	XRI System User Experience	Examines the system's ability to maintain consistency in translating EEG data into visual and interactive elements, ensuring clear emotional representation.	- Consistency and Standards
Personalization Interactions	XRI System User Experience	Evaluates how well the VR environment adapts to user-specific emotional responses and personal engagement patterns, ensuring a tailored experience.	- Flexibility and Efficiency of Use input.

Table 1- Self-evaluation Criteria Table

A radar chart was created based on the criteria outlined in the evaluation table to analyze the performance and overall quality of each prototype (Figure 6).

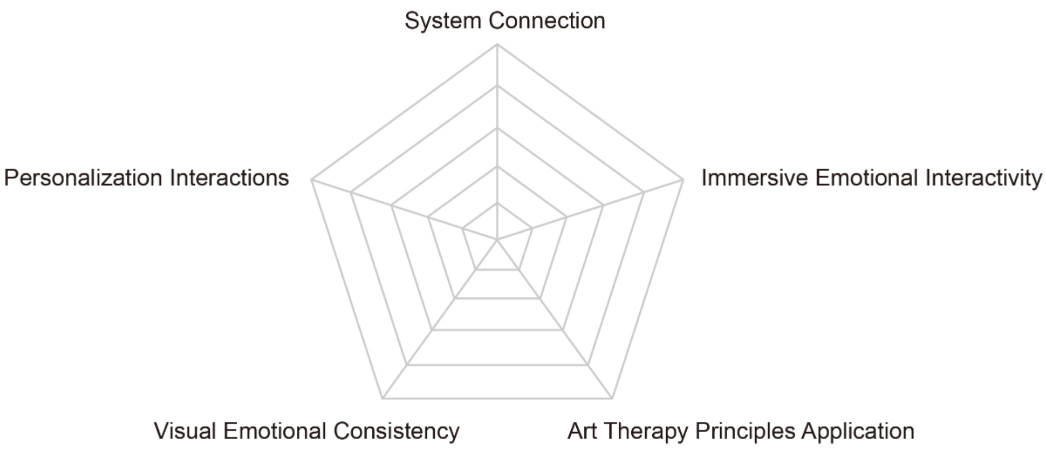

Figure 6- Prototype Evaluation Radar Chart Template

To complement the radar chart visualization, the following five-point scale was used to standardize evaluation across key dimensions. Each score from 1 to 5 reflects the degree to which the prototype fulfills its intended design and experiential criteria:

Self-Evaluation Scoring Scale

1. System Connection

Assesses how accurately and reliably the system detects and visualizes EEG signals.

1 – EEG input is unstable or not connected; no meaningful visual feedback.
2 – Signals are occasionally captured but visuals are inconsistent.
3 – Real-time data is captured, but its translation into visual feedback is unclear or not intuitive.
4 – EEG data is mostly stable and consistently visualized.
5 – EEG input is smooth, responsive, and accurately reflected in real-time visual elements.

2. Immersive Emotional Interactivity

Evaluates how well the VR environment responds to EEG input to create emotional engagement.

1 – Environment does not respond to emotional input.
2 – Limited interactivity with weak emotional connection.
3 – Some visual changes occur, but not immersive.
4 – VR adapts noticeably to emotion signals; supports engagement.
5 – Strong immersive feedback loop enhancing emotional connection.

3. Art Therapy Principles Application

Measures how effectively the system applies creative therapeutic frameworks.

1 – No application of art therapy concepts.
2 – Basic aesthetic presence but no emotional or reflective intent.
3 – Includes visual metaphors with light guided elements.
4 – Integrates passive creativity and meditation-inspired structure.
5 – Strong alignment with art therapy; fosters self-reflection and expression.

4. Visual Emotional Consistency
Assesses clarity and coherence in how emotional states are represented visually.
1 – Visual feedback is unrelated or misleading.
2 – Visuals respond occasionally but inconsistently.
3 – Visuals reflect state changes, but with occasional mismatches.
4 – Mostly consistent and aligned visual feedback.
5 – Highly intuitive and emotionally coherent visual representation.

5. Personalization Interactions
Evaluates adaptability to user-specific input and emotional patterns.
1 – One-size-fits-all experience.
2 – Very limited responsiveness to individual differences.
3 – Some personalization based on EEG data.
4 – Environment adjusts meaningfully to user state.
5 – Strong tailored feedback; feels personalized and adaptive.

3.2.2 Self Reflection

This study employs self-reflection as a key evaluation method to assess the completion level and areas for improvement of the developed prototype. Self-reflection, or introspection, refers to the self-observation and reporting of one's thoughts, desires, and feelings (Gläser-Zikuda 2012). It is a conscious mental process that involves thinking, reasoning, and examining one's own ideas and emotions, providing a structured way to evaluate the design and functionality of the system.

Throughout the research process, self-reflection is used to analyze how the prototype integrates EEG-driven emotional visualization, immersive VR interactions, and art therapy principles. This method helps identify technical limitations, interaction inconsistencies, and areas where the meditation experience could be further refined. Additionally, reflections conducted after two public exhibitions, provide an opportunity to critically reassess the prototype's effectiveness in achieving its intended goals. By systematically documenting these observations and insights, this approach ensures a continuous iterative refinement process, improving both conceptual and technical aspects of the system.

4. Prototype Development

The prototype system for this project is designed to integrate EEG-driven feedback with VR environments, enabling a dynamic interaction loop where emotional data is captured, processed, and visualized in real time to influence both the user's emotional state and their engagement with the virtual environment. The design evolves iteratively, progressing from a simplified system in Prototype 1 to a more detailed and refined workflow in Prototypes 2 through 4, ensuring each iteration builds upon the insights gained from the previous one (Figure 7).

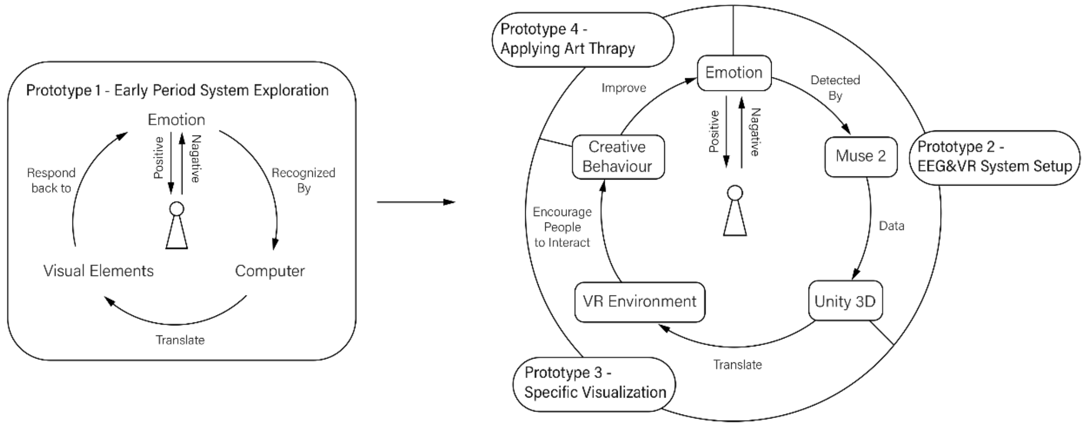

Figure 7- Detailed Prototype Development Diagram

Prototype 1 is an early exploration into emotional response systems to assess their capacity to provide emotional relief. This phase concentrated on developing a simple fundamental system for capturing and analyzing emotional data and converting it into visual feedback. The prototype additionally examined how various color schemes and spatial arrangements could enhance emotional well-being, establishing a foundational design framework for subsequent prototype development. The prototype, although not yet deployed in VR, establishes a foundation for enhanced incorporation of emotional responses within immersive settings.

Prototypes 2 to 4 enhance and broaden the system's functionalities, incrementally improving its interactivity and immersive capacity. The system is enhanced by the use of the Muse 2 EEG equipment, facilitating more accurate identification of emotional states. Emotional data is conveyed to Unity 3D, where it dynamically affects the VR experience, beyond mere visual representation to establish an adaptive, responsive space. Users' emotions influence aspects such as color variations, motion, and object interactions, guaranteeing that the environment responds instantaneously to their interior conditions. As the iterations advance, the incorporation of art therapy concepts enhances the system's capacity for emotional alleviation. Emotional data is manifested not just in environmental sights but also integrated into interactive experiences that promote creative involvement. Users actively influence their environment, producing dynamic visual compositions through passive creation, wherein their emotions imprint upon the area. This iterative process enhances self-awareness and emotional regulation, converting the VR world into a medium for reflection and expression.

This iterative method ensures that each prototype improves upon its predecessor, progressively augmenting the system's capacity for emotional awareness and self-regulation. Through continuous reflection and enhancement, the project transformed from an abstract inquiry into a systematic, immersive emotional relief instrument that captivates users in a tailored and adaptive virtual reality experience.

4.1 Prototype 1

4.1.1 Ideation & Motivation

Prototype 1 established the foundational framework for this project by examining two key aspects: the feasibility of an emotion-responsive system utilizing visual representation and the influence of spatial visual elements on emotional states. This prototype was developed during an initial experimental phase to explore the capture, processing, and reflection of emotional data within a digital environment.

The initial exploration concentrated on the feasibility of system connectivity and interaction. A web-based system employing p5.js and AI-driven facial expression recognition was developed, facilitating the rapid prototyping of a fundamental emotion-feedback loop. This setup facilitated an exploration of emotion-driven color feedback, aiming to evaluate the system's capacity to convert user emotions into real-time visual elements and to assess the effectiveness of color, as an abstract medium, in influencing perception and engagement.

The second exploration analyzed spatial visual elements and their psychological effects on emotional states. Utilizing principles from environmental psychology, initial spatial concept designs were developed to investigate the impact of various spatial structures, lighting conditions, and compositions on emotional relief. Preliminary spatial experiments examined the efficacy of enclosed versus open layouts, dynamic lighting, and fluid visual compositions in fostering immersive and emotionally supportive environments.

The objective of Prototype 1 was to investigate the system interactions and visual elements that facilitate emotional relief in an emotionally responsive experience. This prototype established a foundation for comprehending the dynamic response of digital spaces to user emotions through the integration of color-driven emotional feedback and spatial environmental factors. Initial testing during this phase revealed particular interactive system responses and visual and spatial design elements that may improve emotional well-being and user engagement in responsive environments, serving as a reference for future VR system implementation.

4.1.2 Design & Method

Early Stage Responsive System and Color Concept Exploration

An initial exploration was conducted to investigate the relationship between emotional states and visual representation, utilizing a web-based application in P5.js[4] and integrating MorphCast Facial Emotion AI[5] for real-time emotion recognition. Although previous studies have identified the shortcomings of facial recognition in comparison to EEG, it was selected at this phase for its accessibility and ease of implementation, as accurate emotion detection was not the main objective. The objective was to investigate the translation of emotional states into dynamic, color-based visualizations within an interactive digital environment.

The system correlated emotions with color schemes according to principles of color psychology, indicating that warm colors are associated with energy and positivity, whereas cool colors promote relaxation and stability (Elliot & Maier, 2014). Happiness and excitement were associated with yellow and orange, while neutrality and calmness were linked to cooler shades such as blue and green. The MorphCast Facial Emotion AI was employed to analyze facial expressions, enabling the extraction of primary emotional states including anger, disgust, fear, sadness, neutrality, happiness, and surprise. Specific emotions, including happiness, surprise, neutrality, and calmness, were selected and mapped to colors for real-time interaction, integrating them into a P5.js[6] web-based environment (Figure 8).

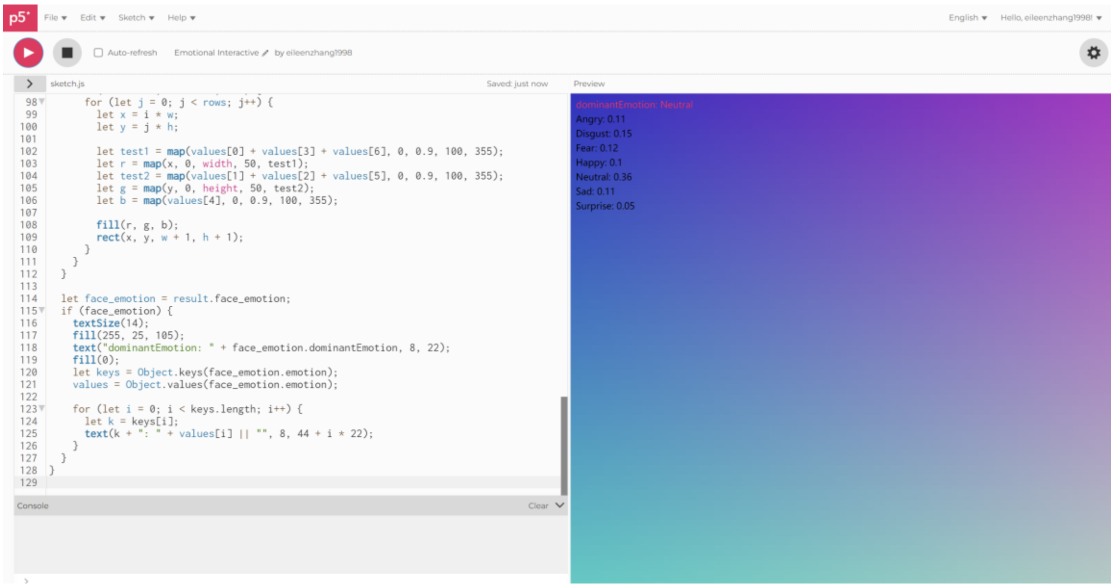

Figure 8- Initial Emotion-Color Responsive Exploration (By Author)

In terms of the detailed coding development, the P5.js script integrates the MorphCast AI SDK, initializes the required AI modules, and activates facial emotion detection to analyze real-time expressions captured through a webcam. The detected emotional data is stored and updated dynamically, with the dominant emotion reflecting the most intense emotional state at any moment.

[4] https://p5js.org/

[5] https://www.morphcast.com/

[6] https://editor.p5js.org/eileenzhang1998/sketches/mw4Y_ZskJ

The script visually represents emotional fluctuations by mapping detected emotions onto a 100x100 grid, with each cell dynamically adjusting its color in response to real-time inputs. A gradient-based approach reveals that warm colors, such as red, yellow, and orange, correspond to high-energy emotions like happiness and surprise, whereas cool colors, including blue and green, represent calmer, more neutral states. The transitions between these colors produce a fluid and evolving visual landscape that responds dynamically to emotional variations. Furthermore, real-time text feedback is presented on the screen, thereby improving user awareness of identified emotions.

Environment Design Concept Exploration

In addition to the color exploration system, Prototype1 includes a conceptual analysis of spatial structures, examining their ability to influence emotions and improve cognitive focus. Radial symmetry with a central focal point is a fundamental design principle that effectively directs visual attention inward, promoting mental consolidation and relaxation (Reber, Schwarz, and Winkielman 2004). This method corresponds with Le Corbusier's philosophy of geometric order, highlighting that organized spatial arrangements foster psychological balance and spatial harmony (Le Corbusier 1955). The design organizes space in a clear, symmetrical manner, establishing predictability and calm, which fosters an environment conducive to mental equilibrium and focus.

Alongside symmetry, spatial permeability significantly influences user perception. An atrium structure has been integrated at the center of the space to enhance openness and spatial connectivity. The atrium not only provides natural light but also enables a smooth transition between indoor and outdoor spaces, a design approach linked to psychological openness and tranquility (Ma et al. 2017). The visual linkage among various areas of the space fosters a perception of expansion, thereby alleviating emotional constriction and promoting a sense of freedom (Figure 9).

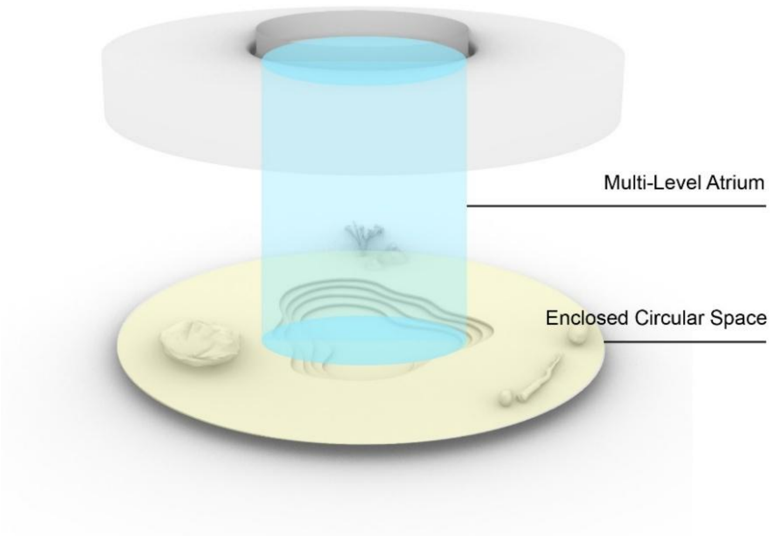

Figure 9- Main Spatial Design Concept Diagram

A spiral form has been introduced to enhance the spatial experience by evoking movement, fluidity, and transcendence. Studies in neuro-aesthetics indicate that curved and flowing geometries generate greater emotional engagement compared to rigid, angular structures, thereby enhancing immersive and meditative experiences (Vartanian et al. 2013). This design strategy is complemented by vertical spatial extension, drawing inspiration from Gothic cathedral architecture to evoke grandeur, reverence, and introspection (Berryman 2010). The tubular spiral structure above the atrium enhances verticality, reinforcing spatial depth and fostering a contemplative atmosphere that aids in emotional regulation (Figure 10).

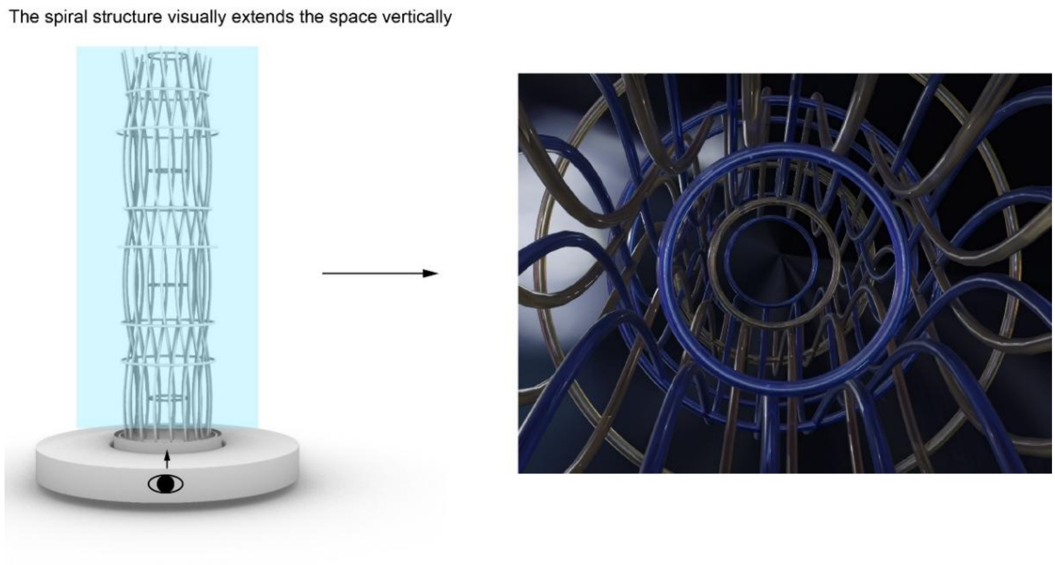

Figure 10- Spiral Structure Concept Diagram

In addition to spatial configuration, natural elements significantly impact emotional stability, affecting psychological comfort and physiological well-being. Biophilic design theory posits that incorporating water, natural textures, and vegetation into an environment can reduce stress levels, enhance cognitive function, and foster emotional resilience (Kellert and Calabrese 2015). A central water feature has been integrated into the design to harness these effects, with its gentle motion promoting emotional balance and creating a tranquil atmosphere. The presence of blue spaces, including freshwater bodies, has been associated with reduced psychological distress and enhanced mental well-being, emphasizing their restorative potential in designed environments (McDougall et al. 2022).

The integration of organic elements, including stones, wooden textures, and vegetation, has been systematically arranged to augment the meditative and restorative attributes of the space. The interaction of these materials establishes a visually and sensorially enriched environment, thereby enhancing the psychological advantages of nature-inspired design. Research indicates that the incorporation of naturalistic elements in architectural environments enhances emotional security and reinforces users' connection to their surroundings (Ma et al. 2017). The strategic application of these elements allows the space to transcend mere aesthetic value, serving as an active contributor to emotional restoration and cognitive ease (Figure 11).

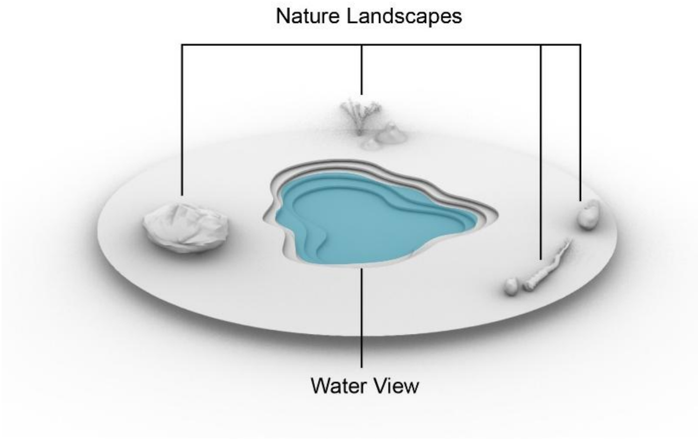

Figure 11- Natural Elements Concept Diagram

The conceptual scene in Prototype 1 also incorporates an interactive light effect that translates internal emotional states into dynamic visual feedback, thereby enhancing self-awareness and emotional engagement. The ability of environmental stimuli to shape mental states has been widely recognized, with visual and sensory exposure to natural or dynamic elements shown to promote cognitive restoration and stress reduction (White et al. 2021). The lighting system externalizes fluctuations intuitively, linking internal cognition with external spatial experience, thereby fostering introspection and emotional clarity.

The light effect functions not only as a reactive element but also facilitates fluidity and evolution within the space. The shifting and adapting light patterns render the environment dynamic and responsive, thereby preventing stagnation and maintaining engagement. This is consistent with experience design principles that highlight multi-sensory interaction as a crucial element in emotional immersion and psychological recalibration. The design fosters deeper and prolonged interaction with the environment by integrating light, movement, and spatial perception.

An initial spatial scene concept was then 3D modeled, developed and rendered in Blender[7], based on the color theory and comprehensive spatial design concepts outlined above. The following presents the preliminary scene concept (Figure 12).

[7] https://www.blender.org/

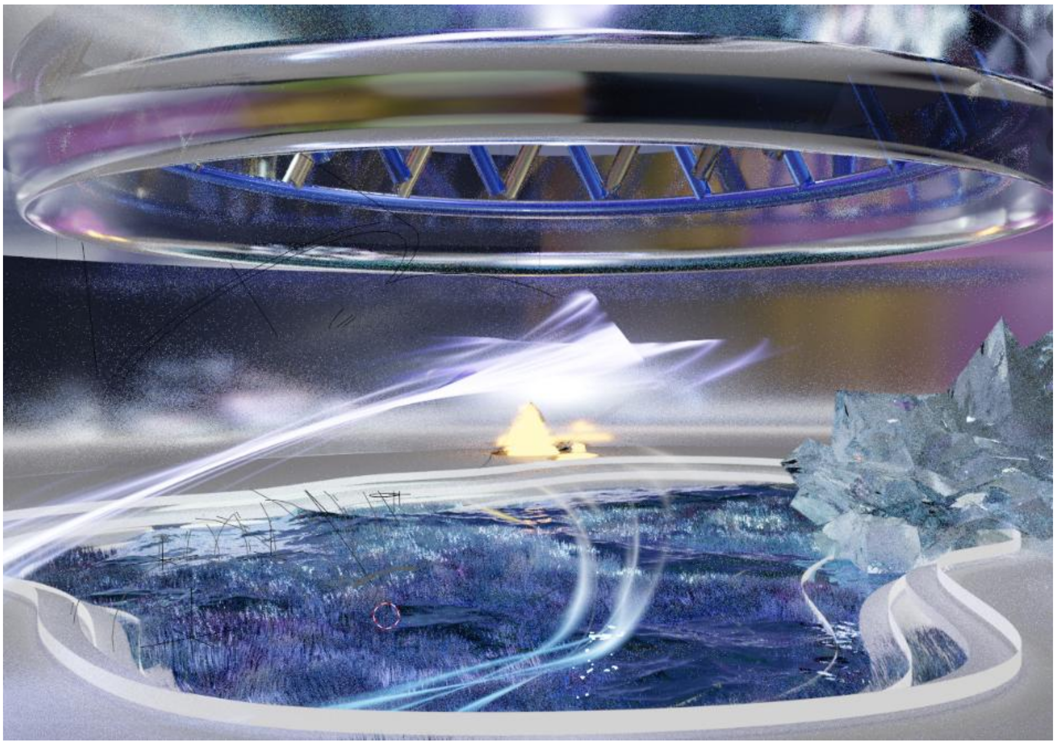

Figure 12- Overall Spatial Concept Rendering Built in Blender

4.1.3 Reflection

This study conducted an initial examination of system interactions and visual components associated with emotional relief in immersive environments. An initial code-based investigation into emotion-driven interaction was established, utilizing a web-based prototype developed with p5.js and AI-powered facial expression recognition. This phase evaluated the feasibility of converting emotional states into real-time visual feedback, establishing a foundation for subsequent iterations.

Beyond the technical framework, the study also examined visual elements associated with human emotions, such as color theory, spatial composition, and the incorporation of natural elements, in addition to the technical framework. The design decisions were informed by principles from environmental psychology and color psychology, which have been shown to influence emotional perception and mood regulation in physical and virtual spaces. These frameworks provided both theoretical grounding and practical direction for shaping the emotional tone of the environment, leading to the current spatial and aesthetic configuration. The study conducted an experimental analysis to investigate the effects of various spatial structures, lighting conditions, and organic design elements on emotional regulation. The findings informed the establishment of a foundational concept, providing initial guidance for future system architecture and immersive scene design in VR applications.

More specific assessments will be based on the following diagram based on previous self-evaluation criteria (Figure 13).

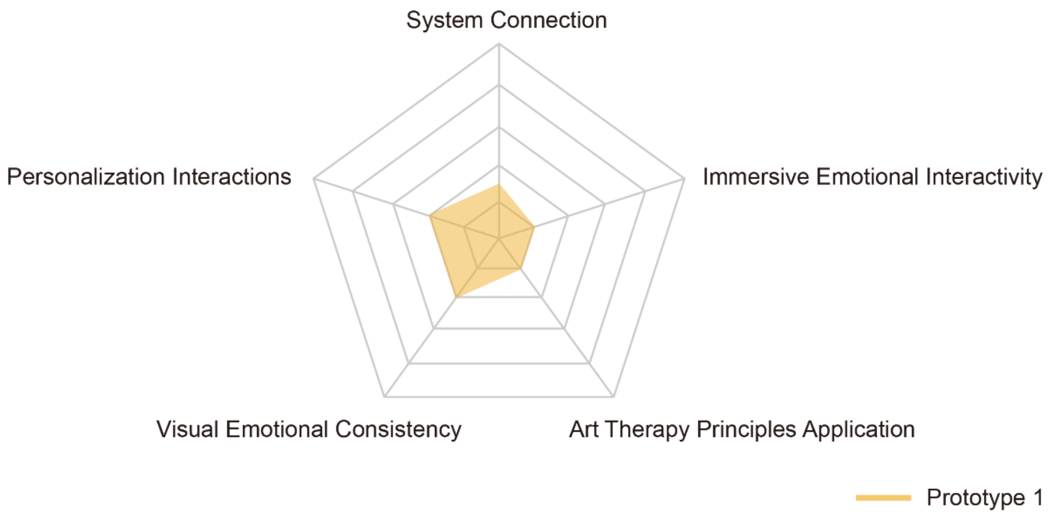

Figure 13- Radar Chart for Prototype 1

System Connection (1.5/5)

Prototype 1 implemented a web-based emotion-responsive system using facial expression recognition to generate real-time visual feedback. This initial exploration established a functional emotion-feedback loop, demonstrating the system's ability to react dynamically to user emotions. However, facial recognition poses significant challenges for VR integration, as head-mounted displays obscure facial expressions. While this prototype laid the groundwork for emotional detection, future iterations must explore alternative emotion-tracking methods, such as EEG signals or physiological data analysis, to ensure compatibility with immersive VR environments.

Immersive Emotional Interactivity (1/5)

The prototype introduced emotion-driven visual interactivity, dynamically adjusting color and brightness based on real-time emotional input. While this approach created a responsive experience, the lack of a fully immersive VR environment limited the depth of emotional engagement. As a web-based system, it did not provide spatial presence or embodied interaction, which are crucial for a truly immersive experience. Moving forward, integrating this system into a 3D VR space with multisensory feedback—such as haptic response, spatialized audio, and environmental adaptation — would significantly improve its effectiveness in fostering emotional immersion.

Art Therapy Principles Application (1/5)

Prototype 1 incorporated basic color psychology principles, mapping emotions to color changes to visually represent mood states. However, it did not fully utilize structured art therapy methodologies or integrate meditative practices. Established techniques, such as guided artistic expression, dynamic mandalas, or structured creative tasks, were not included. Future iterations could benefit from a more comprehensive application of art therapy principles, incorporating interactive painting, generative art elements, and mindfulness-driven visual compositions to enhance emotional relief and therapeutic engagement.

Visual Emotional Consistency (2/5)
The prototype maintained visual consistency in emotional representation by ensuring that each detected emotion corresponded to a distinct color output. This approach established a predictable and coherent visual feedback system, reinforcing user perception of their emotional states. However, color alone may not be sufficient to fully convey complex emotions, as human affective experiences are multidimensional. Enhancing this system with dynamic textures, motion-based feedback, and subtle lighting transitions could improve emotional clarity and depth, making the visual representation more nuanced and immersive.

Personalization Interactions (2/5)
Prototype 1 introduced a basic level of personalization, adapting color responses to individual users' emotional states in real-time. Each user experienced a unique visual reaction, offering an initial exploration of personalized interaction design. However, this customization was limited to color-based feedback, lacking deeper adaptive elements such as environmental modification, interactive spatial changes, or memory-based adaptation. To enhance personalization, future iterations could incorporate user-driven scene customization, adaptive spatial arrangements, and historical emotional tracking to create a more tailored and meaningful user experience.

This prototype served as an essential proof of concept, validating key interaction mechanisms and visual elements related to emotional relief. While limitations in immersion, emotion-tracking methods, and depth of personalization remain, the findings provide a critical foundation for advancing emotionally responsive VR environments. Future developments will focus on improving VR integration, expanding interaction modalities, and deepening the application of therapeutic principles to create a more comprehensive and effective emotion-responsive system.

4.2 Prototype 2

4.2.1 Ideation & Motivation

Prototype 2 builds upon the foundational framework of Prototype 1 by integrating its spatial design concepts into the Unity Engine, resulting in an immersive virtual reality environment. The integration of the Muse 2 EEG headset with the VR system, utilizing the NeuroGame Muse2Unity Template[8], marked a significant advancement by facilitating real-time brainwave data input and interaction. The integration established a functional connection between the EEG device and the VR environment, enabling the embedding of predefined interactions within the system.

The prototype also enabled an initial examination of the preset interaction scripts in the Muse2Unity Template, yielding important insights into the structure and functionality of EEG-driven interactions. This stage established a foundation for the future integration of customized interactive elements by analyzing and testing predefined mechanisms. The successful integration of all system components represents a crucial advancement in creating

[8] https://github.com/neurogamedev/MuseUnity-Windows-NeurogameTemplate

a dynamic and adaptive emotion-responsive experience, paving the way for more complex and personalized interactions in future prototypes.

4.2.2 Design & Method

Following the conceptual exploration, a VR environment was built in Unity 6[9], incorporating the color references and spatial design concepts established in the previous stage. The scene models were imported into Unity, where materials were adjusted, lighting was refined, and particle effects were added to enrich the environmental atmosphere. The prototype was then deployed and tested using the Meta Quest 3[10] VR headset, where initial self-testing was conducted to evaluate the visual and spatial effects of the scene. This stage focused on establishing a visually and spatially coherent setting, laying the groundwork for subsequent prototypes that would further enhance the system by integrating EEG-driven emotion detection and improving interactive responsiveness within the VR environment[11] (Figure 14).

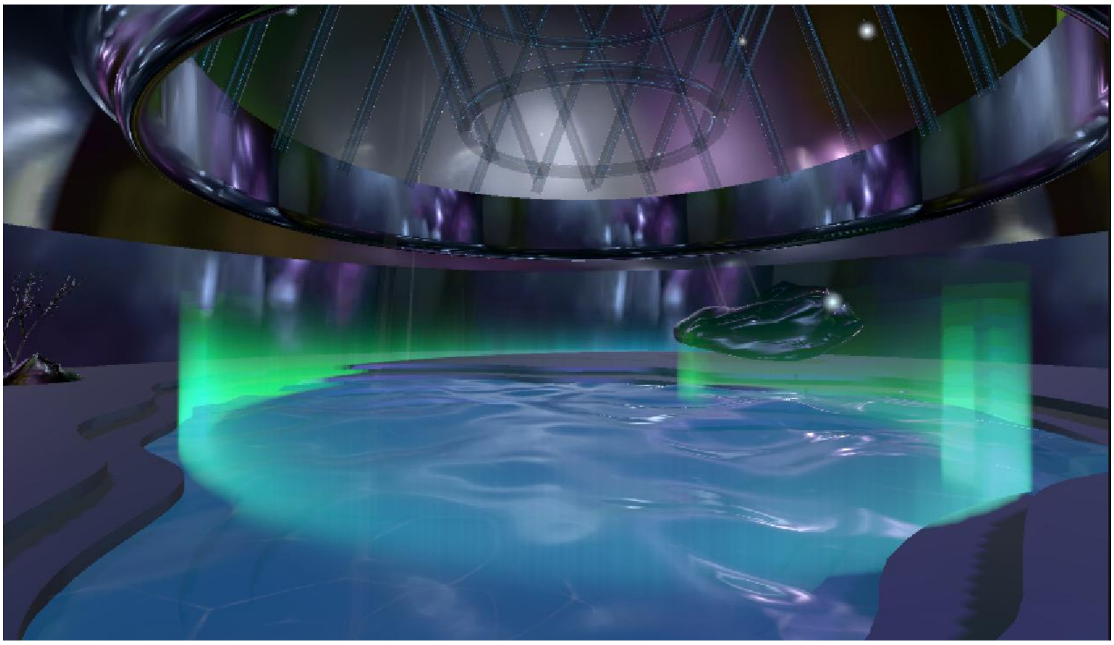

Figure 14- VR Environment Setup (By Author)

In the next step, to connect the Muse 2 device to Unity, the Muse Template for Unity, developed by the NeuroGame Development team (2024), was employed (Figure 15). This SDK provided a streamlined solution for processing EEG data, including metrics such as Calm, Focus, Flow, Eyeblink, and Heart Rate. The NeuroGame SDK enabled real-time EEG-driven interactions, allowing brainwave data to influence game objects dynamically:

- **Calm:** Represents the user's mental relaxation and emotional stability, typically indicating a lower level of stress or anxiety. In the system, it controlled the rolling speed of a sphere, with higher calm levels leading to a smoother and faster motion.
- **Flow:** Measures the degree of deep engagement and effortless immersion in an activity, often associated with heightened focus and enjoyment (Nakamura & Csikszentmihalyi,

[9] https://unity.com/blog/unity-6-features-announcement
[10] https://www.meta.com/ca/quest/quest-3/
[11] https://www.youtube.com/watch?v=aabo8rT_eRU

2002). In this template, the value adjusted the stretching and compression of a cylinder, visually representing the user's level of immersion.

- **Focus:** Reflects the user's cognitive concentration and attentional engagement, indicating how well they are directing mental resources toward a task. In the system, increased focus resulted in faster rotation of a cube, illustrating heightened mental effort.
- **Eye Blink:** Tracks involuntary neural responses and physiological relaxation, often linked to changes in attention or cognitive load. This value controlled the flickering of a sphere, translating eye movement activity into visible changes in the game environment.
- **Jaw Clenching:** Detects muscular tension in the jaw, which can be associated with stress, determination, or subconscious reactions. In the system, this value influenced the opening and closing of a frame, converting muscular activity into interactive motion within the game space.

These basic interactions validated EEG-Unity integration, establishing a foundation for expanded interactivity, including more dynamic environmental responses, multimodal feedback, and deeper emotional engagement in future iterations.

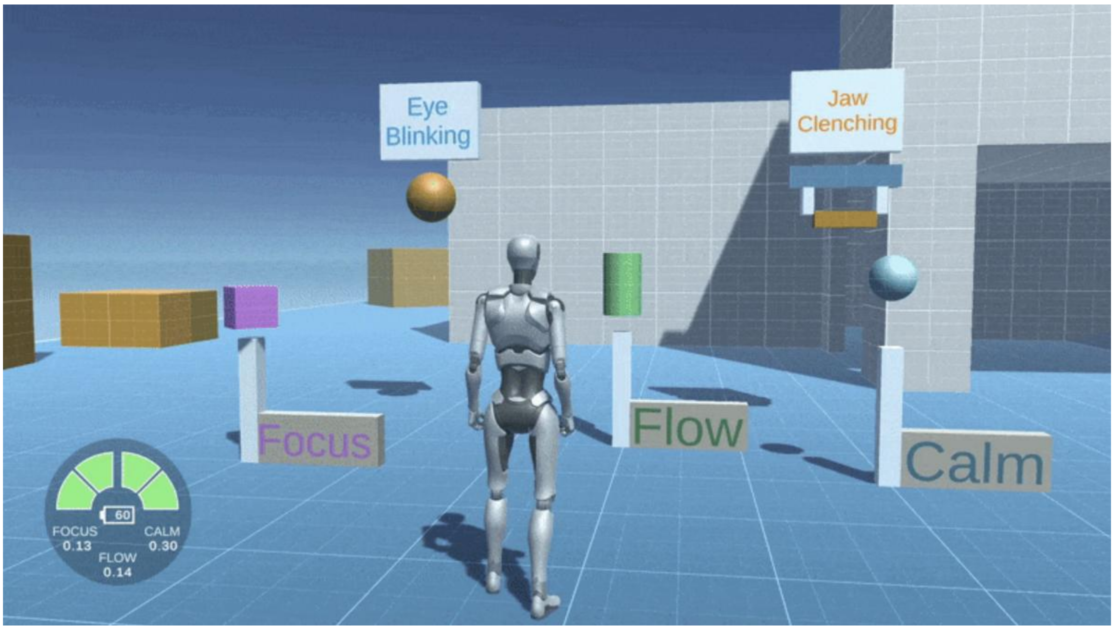

Figure 15- NeuroGame MuseUnity-Windows Template Scene (NeuroGame, 2025)

Furthermore, in the real-time connection preview panel of the NeuroGame MuseUnity-Windows Template (Figure 16), the system first establishes a Bluetooth connection between the Muse 2 headset and the computer, which allows seamless integration with Unity. Once the headset is powered on and the Unity program is running, the connection is automatically established without requiring additional configuration. During operation, the preview panel displays the connection status of the Muse 2 headset with its four electrodes and monitors the five key values. Among these, Calmness, Focus, and Flow continuously update in real-time, reflecting dynamic fluctuations in brain activity. In contrast, Eye Blink and Jaw Clench function as event-based triggers, activating only when a corresponding action is detected.

This distinction in data processing highlights how different neural and physiological responses influence interaction within the system.

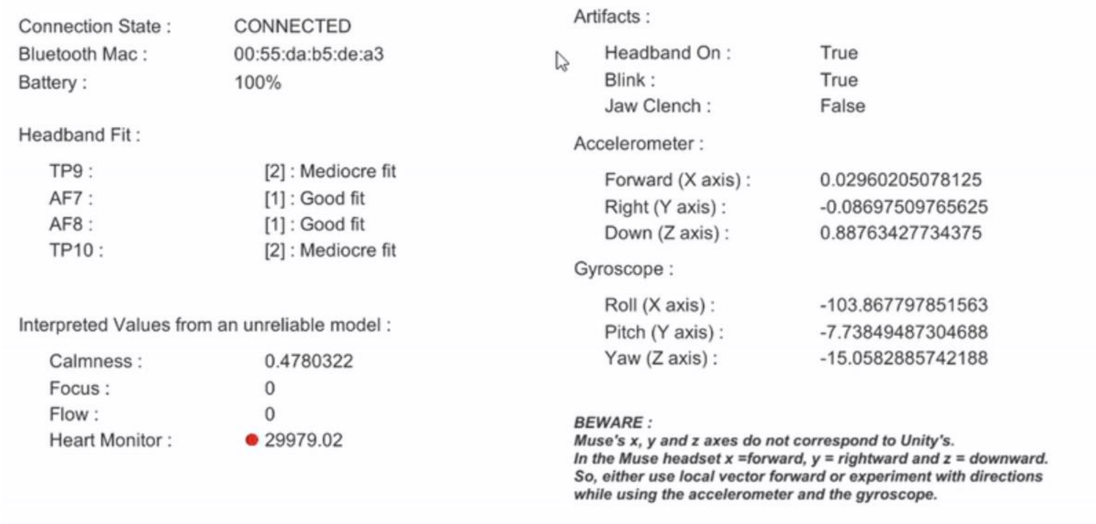

Figure 16- Review Interface for Muse 2 Four Electrodes Real-time Connection and Different Values Detection (NeuroGame, 2025)

With the EEG system integrated into the previously built Unity VR environment, the predefined interactions from the NeuroGame MuseUnity-Windows Template were implemented and tested. When both the Muse 2 EEG headset and the Meta Quest 3 VR headset were worn simultaneously, EEG data was transmitted and converted into visual elements within the VR space. This ensured that brainwave activity could dynamically influence the virtual environment in real-time, marking a crucial step in establishing an interactive feedback loop between the user's cognitive state and the VR system.

The fundamental interactions demonstrated the viability of EEG-driven real-time interaction in virtual reality, establishing a foundation for subsequent improvements (Figure 17).

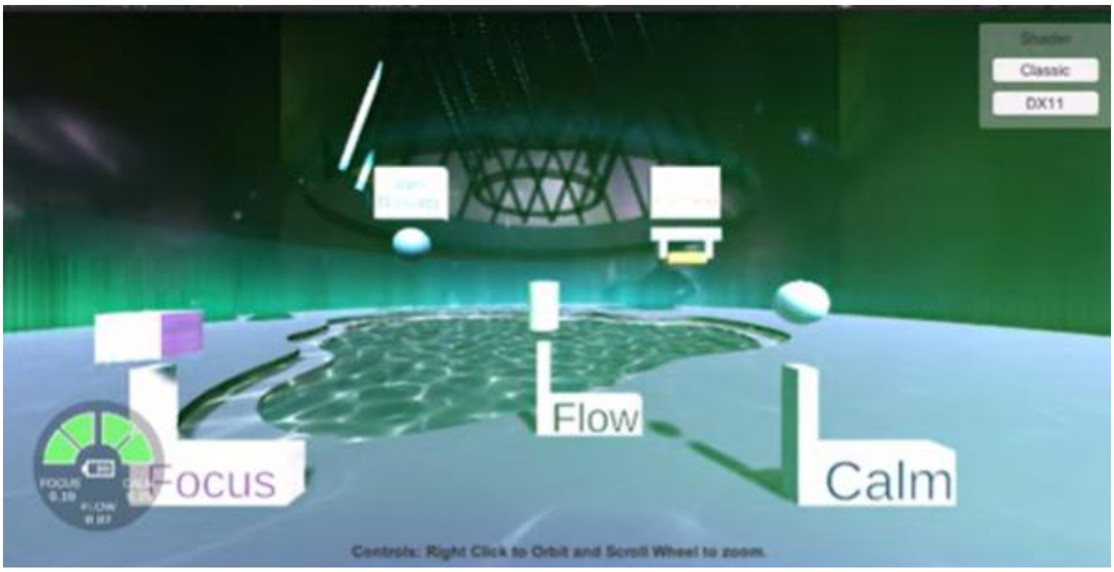

Figure 17- EEG Integrated VR Environment Setup

Additionally, testing confirmed that the Muse 2 EEG headset and the Meta Quest 3 VR headset can be worn simultaneously, ensuring compatibility between EEG data collection and immersive VR experiences. However, it was observed that proper positioning of the Muse 2 headset before wearing the VR device is crucial. If the Muse 2 is not securely fitted beforehand, the placement may shift when the VR headset is put on, potentially leading to weaker electrode contact and unstable data transmission. (Figure 18).

Figure 18- Example of the Correct Setup of Muse 2 and VR Headset

Beyond the construction of the VR environment, much of the EEG-VR integration in this phase relied on the NeuroGame MuseUnity-Windows Template, which provided the foundational connection and basic interactions, such as object rotation and floating movements in response to EEG input. This prototype primarily focused on establishing a stable connection, ensuring data transmission, and converting EEG signals into visual elements within the VR space. While the system enables real-time responsiveness, interactions remain relatively simple at this stage, with EEG data influencing only a few predefined object behaviors.

4.2.3 Reflection

The development of this prototype established a functional EEG-VR connection, ensuring the smooth transmission and basic visual translation of EEG data within the VR space. By leveraging the NeuroGame MuseUnity-Windows Template, the system was able to integrate real-time brainwave input with predefined object interactions, such as rotation and floating movements, demonstrating the feasibility of EEG-driven visual responsiveness. However, at this stage, the system remains limited to fundamental interactions, with brainwave signals primarily affecting a small set of preconfigured elements.

While the current implementation validates the technical integration, it also highlights areas for refinement. The interactions, though functional, lack depth and adaptability, as they do not yet fully utilize EEG signals to create a more immersive and emotionally responsive environment. Moving forward, the challenge lies in expanding the variety of interactions, allowing EEG input to dynamically influence environmental transformations, spatial adaptations, and more personalized visual elements. By enhancing the system's ability to interpret and translate cognitive and emotional states into richer, more nuanced feedback, future iterations will aim to create a truly interactive and immersive emotional experience that extends beyond basic EEG responsiveness.

To further assess the performance and impact of this prototype, a more detailed evaluation was conducted as the radar chart below (Figure 19).

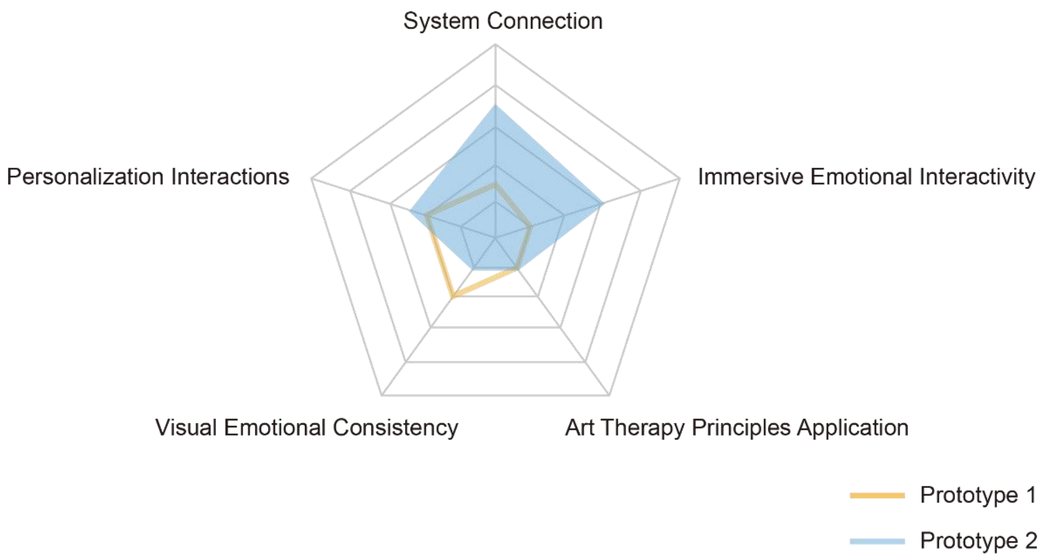

Figure 19- Radar Chart for Prototype 2

System Connection (3.5/5)

The prototype established a stable connection between the Muse 2 EEG headset and the VR environment, while also ensuring compatibility with the Meta Quest 3 headset when both were worn simultaneously. The connection quality proved to be smooth and reliable, allowing for real-time EEG data transmission without significant disruptions. The system's integration process was straightforward, demonstrating strong compatibility among the components.

Immersive Emotional Interactivity (3/5)

Compared to the previous prototype, this version introduced a fully built VR environment, significantly enhancing the sense of immersion. Emotional fluctuations influenced game object interactions within the VR space, making the environment more dynamic and responsive. Although the interactions remained relatively basic and predefined, they nonetheless introduced an initial layer of real-time emotional engagement, offering a foundational level of interactivity.

Art Therapy Principles Application (1/5)
While this prototype mapped emotional states to interactive responses, it did not introduce new art therapy principles or structured therapeutic approaches. The focus remained on technical integration rather than incorporating guided emotional expression, mindfulness-based interventions, or therapeutic visual elements. As a result, its application in the context of art therapy remains minimal.

Visual Emotional Consistency (1/5)
The previous prototype, though simple, used color as a direct visual representation of psychological states, aligning with basic human cognitive recognition. In contrast, this version added interactive elements influenced by EEG data, but these interactions were predefined within the NeuroGame template, making them feel disconnected from users' emotional experiences. Without a clear, intuitive relationship between brainwave activity and environmental changes, the consistency of emotional representation was weakened.

Personalization Interactions (2.5/5)
The EEG-based interactions in this system offered a more diverse range of responses compared to the facial expression recognition used in the previous prototype. Different EEG values could influence varied interactions within the VR space, making the system more dynamic than simple color-based feedback. However, since the interactions remained limited to predefined actions, personalization was still relatively constrained. Although a step forward in interaction complexity, it did not yet provide deeply personalized or adaptive responses tailored to individual users.

This evaluation highlights both the progress made in VR integration and EEG responsiveness, as well as the remaining challenges in deepening emotional interactivity, enhancing personalization, and improving the clarity of visual emotional representation. Future iterations will focus on expanding adaptive interactions, refining emotional coherence, and integrating structured therapeutic principles to create a more immersive and personalized emotion-responsive system.

4.3 Prototype 3

4.3.1 Ideation & Motivation

Prototype 3 investigates the potential of immersive VR environments to convert real-time EEG data into visually compelling and interactive elements, with the objective of improving emotional awareness and self-regulation. This prototype employs the Muse 2 EEG device to visualize Calm and Flow, two essential emotional and cognitive states, using dynamic, trailing light bands that encircle the user. The trails represent EEG fluctuations and function as a fundamental environmental concept, wherein users leave visual traces in the space corresponding to their fluctuating emotional states. This process exemplifies passive creation, wherein emotional fluctuations autonomously influence the developing virtual environment, transforming neural activity into a dynamic, artistic representation of cognitive rhythms. This is consistent with the principles of art therapy, which propose that non-directive creative engagement serves as a reflective and therapeutic instrument, enabling individuals to externalize subconscious emotional states (Moon 2010). Theories in embodied cognition highlight that engagement with sensory-based digital environments is crucial for self-perception and emotional processing, thereby underscoring the significance of passive visualization techniques (Shapiro 2019).

This mechanism also corresponds with Open Monitoring (OM) meditation techniques, which promote the observation of mental states without interference or judgment. The two light trails offer real-time visual feedback that adapts their movement and shape according to EEG input, thereby enhancing the visibility and intuitiveness of Calm and Flow fluctuations. As users traverse the VR environment, their neural activity consistently impacts the visual composition, resulting in a dynamic emotional landscape that mirrors their cognitive and emotional changes. This form of passive interaction has been examined in interactive digital environments, demonstrating that non-intrusive engagement with dynamically responsive systems can improve self-awareness and emotional regulation (McCarthy and Wright 2004). Visualizing emotional variations, as opposed to interpreting abstract numerical data, enhances one's connection to their internal state, thereby facilitating introspection and emotional clarity.

This prototype aims to create a stronger link between the user's mental state and their virtual environment through the integration of OM meditation principles and emotion-driven spatial imprinting. The patterns produced by EEG fluctuations provide a distinctive approach to engaging with emotions creatively and introspectively, thereby enhancing the immersive experience and promoting emotional reflection and self-regulation in a non-intrusive manner. This system's passive nature enables users to interact with their emotional states without the demands of active manipulation, consistent with theories of embodied cognition and intuitive interaction in immersive media (Shapiro 2019).

4.3.2 Design & Method

Prototype 3 advances the framework established by Prototype 2 by converting EEG data into dynamic visual components within the VR environment, focusing specifically on Calm and Flow—two values closely associated with emotional states. The primary visualization elements were selected to function as an interactive representation of emotions and a medium for passive creative expression within the space (Figure 20). The system is structured such that the user's position serves as the central point, with Calm and Flow dynamically orbiting around it as two concentric circles of varying radii. Initially, both values begin at a baseline of zero, with their respective curves varying upward or downward in response to real-time EEG input.

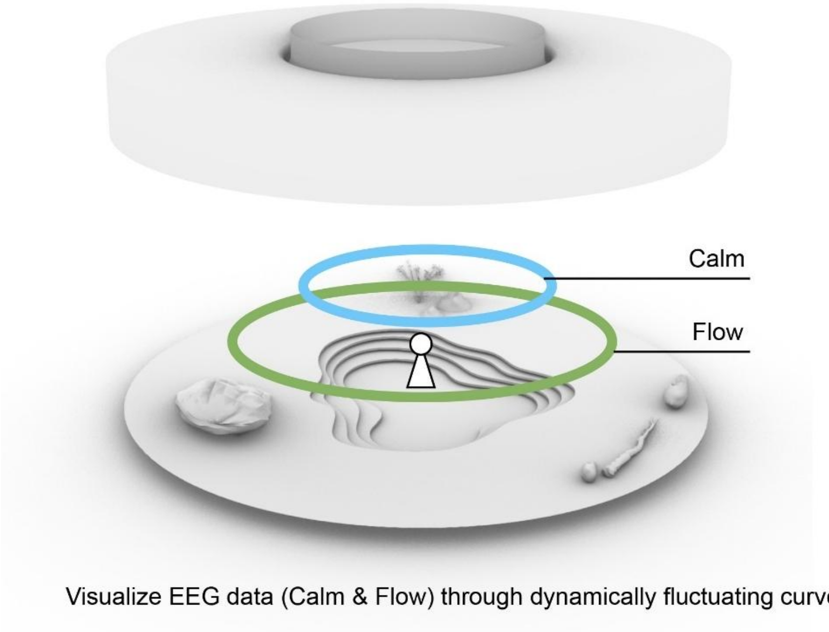

Figure 20- Interactive Spatial Concept of Prototype 3

Two particle-based light trails with trailing effects were chosen from the Unity Asset Library and programmed to orbit around the user's headset position as the central reference point to achieve this effect. In the initial testing phase with the Muse 2 connection, it was noted that the natural range of Calm and Flow values generally varied between 0.1 and 0.4. The direct application of these values as the Y-axis position of the particles resulted in subtle and challenging variations to discern. A magnification factor was implemented to enhance the impact of EEG fluctuations on motion, thereby providing a clearer and more intuitive depiction of emotional variations.

The implementation of a trailing effect was a significant refinement, enabling the previous paths of the light trails to remain visible rather than vanishing instantaneously. This addition offered continuity and temporal depth, allowing users to perceive their current emotional state and track past fluctuations over time. The overlapping and dynamic motion of the trails created a layered visual composition, emphasizing the notion of emotion as a developing and interactive element within the environment. The visualization facilitated users' awareness of their emotional fluctuations, promoting enhanced engagement with their cognitive and emotional states, thereby underscoring the significance of passive emotional imprinting in the environment.

The script development process for EEG data integration entailed an analysis of the original data retrieval methods from the NeuroGame Template, followed by modifications to enable real-time control of the vertical movement of light trails in accordance with Calm and Flow values. This implementation centered on modifying the Y-axis position of each particle effect through the application of the subsequent formula:

Base Height + Acquired Value * Magnification Factor

During following testing, a key challenge emerged: the raw EEG data displayed sudden fluctuations, resulting in abrupt and unnatural movements in the visualized curves. Mathf linear interpolation was employed to facilitate smoother and visually appealing transitions between the current and target Y-axis positions. This interpolation mitigated abrupt variations in EEG values, leading to a more fluid and organic movement of the trails (Figure 21).

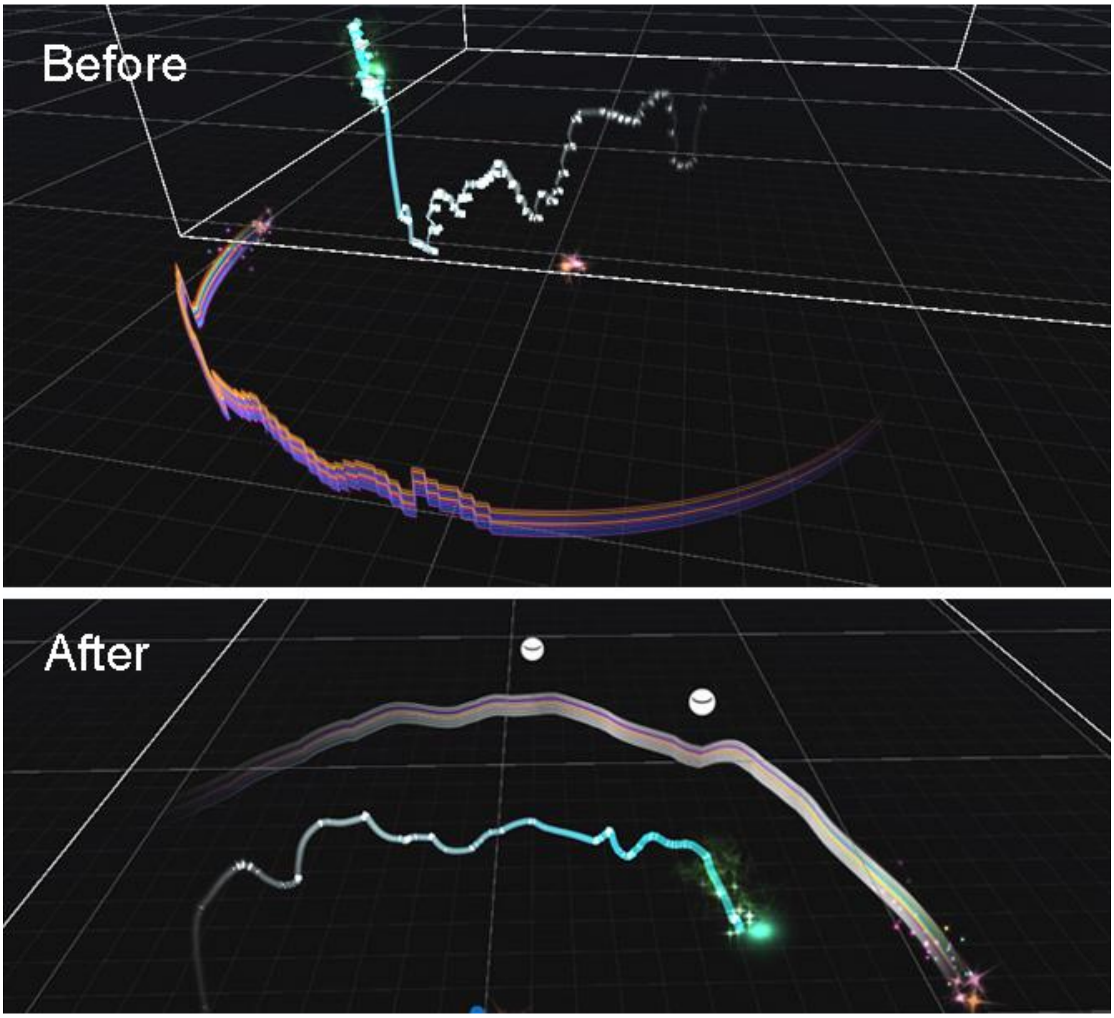

Figure 21 The Comparison of Particle Effect Before and After Fluid Effect

Following the finalization of the script, comprehensive testing was performed using the Muse 2 device. During this phase, the trail length and magnification factor were adjusted to optimize the balance between smooth motion and clarity of variation. Consequently, Calm and Flow are now depicted as dynamic, evolving visual elements rather than static numerical values, thereby enhancing the relationship between emotional awareness and environmental interaction within the VR space. The finalized debugged EEG VR interaction scene is presented below (Figure 22).

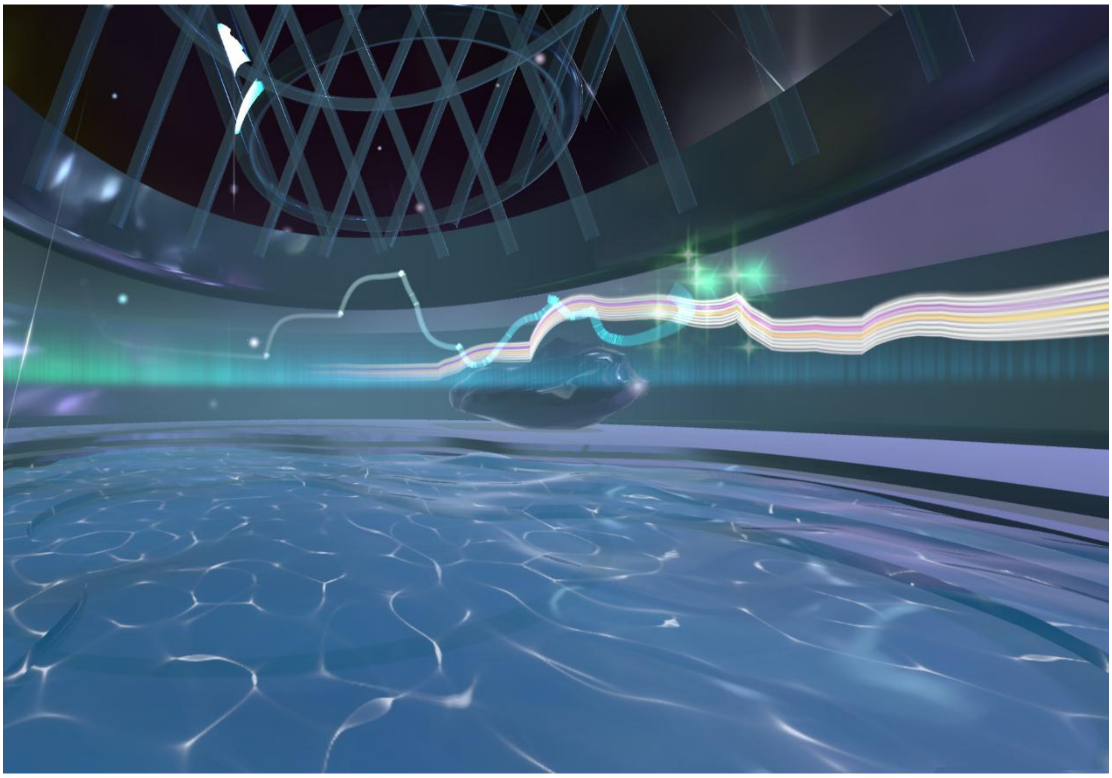

Figure 22- EEG-VR Integrated Environment (By Author)

4.3.3 Reflection

Prototype 3 converted EEG data into interactive and visually engaging components within the VR environment, signifying real-time emotional visualization. The prototype utilized Calm and Flow values to create dynamic, trailing light bands, offering users a direct and intuitive method for perceiving their emotional fluctuations within a spatial framework. The integration of passive emotional imprinting facilitated a dynamic visual landscape, strengthening the relationship between cognitive states and environmental engagement. This version demonstrates improved integration of EEG-driven interactions, resulting in smoother transitions and enhanced continuity in the visualization process compared to earlier iterations.

Notwithstanding these advancements, numerous areas persist that require additional investigation and enhancement. The system presently depends exclusively on Calm and Flow values, which, although essential for emotional self-awareness, restrict the variety of interactions and the depth of engagement. Future developments may incorporate supplementary EEG metrics, including focus, eye blinks, or jaw clenching, to facilitate more intricate and nuanced interactions. Furthermore, although passive creation has been utilized for non-directive emotional expression, integrating it more thoroughly with Focused Attention meditation techniques may improve the system's capacity to facilitate emotional regulation and cognitive engagement. The forthcoming phase seeks to establish a more organized meditative experience, enabling users to actively employ attention-focused techniques while monitoring their emotional states, thereby enhancing the relationship between self-awareness and deliberate mental practice.

A comprehensive assessment of these elements is shown in the Radar Chart (Figure 23).

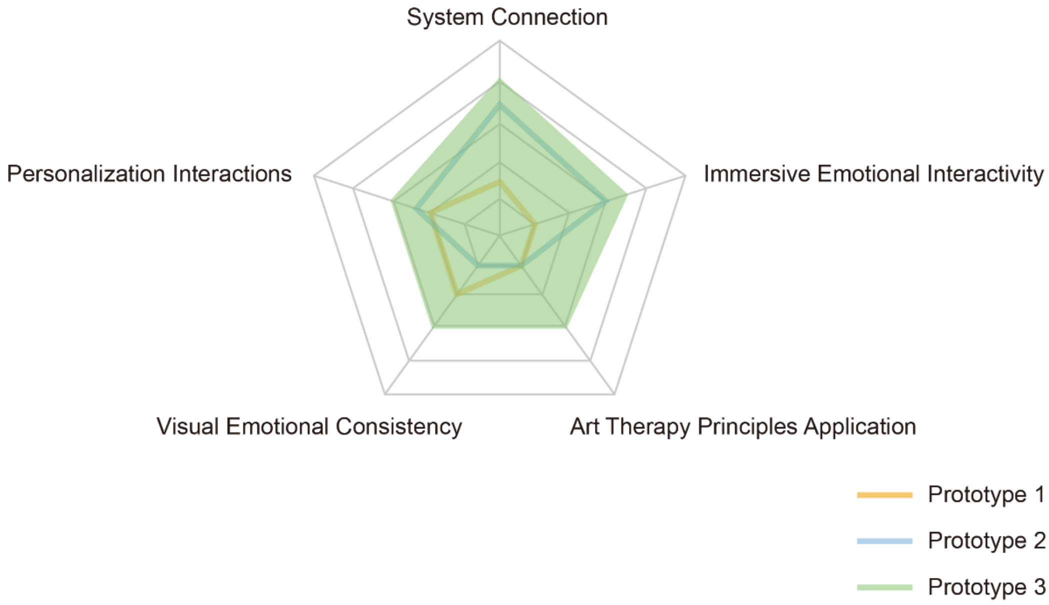

Figure 23- Radar Chart for Prototype 3

System Connection (4/5)

Building on the previously established EEG-VR connection, this iteration integrated EEG signal visualization into the environment, ensuring that emotional responses were meaningfully represented within the VR space. The ability to translate real-time brainwave data into interactive visual elements significantly improved the system's responsiveness, further strengthening the link between neural activity and immersive experience. Nonetheless, an aspect that need enhancement is the first 15-second latency from the system's activation to the moment the Muse 2 headset begins to receive steady signals. Subsequent iterations may investigate the incorporation of supplementary interactions during this waiting period to facilitate a more fluid and engaging transition into the event.

Immersive Emotional Interactivity (3.5/5)

A new emotion-driven interaction method was introduced, using passive creation as a tool for engagement. By enabling users' emotions to shape the visual composition of the space, the prototype enhanced immersion and personal connection to the environment. However, while this passive interaction method added depth to the experience, the overall level of immersion could still be further improved by incorporating additional multisensory feedback systems, such as spatial audio cues, to create a more holistic emotional response mechanism.

Art Therapy Principles Application (3/5)

This iteration incorporated Open Monitoring (OM) meditation principles and introduced the concept of passive emotional creation, aligning the VR experience with therapeutic and self-reflective practices. However, it still lacks structured guidance or structured intervention techniques that could make the system more effective for therapeutic applications. Future improvements could explore integrating structured mindfulness exercises or guided emotional regulation techniques to provide more intentional and structured engagement.

Visual Emotional Consistency (3.5/5)
The visualization of EEG data through two dynamic light trails provided a clear and intuitive representation of Calm and Flow values, making emotional fluctuations more perceivable and engaging. The continuous, smooth movement of the trails ensured visual coherence, reinforcing users' ability to associate their emotional state with the environment's dynamic changes. However, the system currently lacks a more explicit way of conveying the meaning of these visual elements. Additional visual markers or subtle instructional cues could be incorporated to help users better understand and interpret the role of the light trails in relation to their emotional states.

Personalization Interactions (3.5/5)
The system introduced personalized interactions through EEG-driven light trails, allowing each user's unique emotional fluctuations to influence the visual composition. While this created a more individualized experience, the range of interactive elements remains somewhat limited. Expanding the system to include multiple layers of interaction, such as customizable visual settings or additional reactive environmental elements, could further enhance the sense of personalization and deepen user engagement.

4.4 Prototype 4

4.4.1 Ideation & Motivation

This prototype investigates the application of art therapy concepts in virtual reality to visualize and engage with emotions, notably enhancing the integration of Focused Attention (FA) and Open Monitoring (OM) meditation approaches. The experience commences with a systematic breathing practice rooted on FA meditation, facilitating rapid relaxation, emotional regulation, and a transition of focus into the virtual environment. Upon reaching a predetermined attention threshold, the system shifts to the responsive VR environment developed in prior prototypes, allowing users to participate in an open exploration phase (OM meditation). This amalgamation of FA and OM fosters gradual emotional involvement, wherein controlled concentration promotes relaxation, but unstructured exploration enhances self-awareness and introspection (Chiesa, 2011; Lutz et al., 2008; Travis & Shear, 2010).

In addition to the meditation-based improvements, Prototype 4 introduces a supplementary concept of feedback where improvements in emotional states are directly reflected in the evolving virtual environment. As users achieve higher levels of Calm and Flow, the Mindscape dynamically transforms—becoming visually richer, more vivid, and warmer—thereby reinforcing the idea that positive emotional states can foster a supportive, encouraging environment. Furthermore, EEG-driven interactions have been expanded: beyond Calm and Flow, additional signals from Eye Blink and Jaw Clench have been integrated to enhance interaction diversity and depth. In practice, EEG signals now trigger both visual and auditory feedback, creating a multi-sensory immersive experience that strengthens the connection between emotions and the virtual world. Pre- and post-experience guidance sequences have also been incorporated to ensure smooth transitions throughout the session.

The motivation for these refinements is to cultivate a more comprehensive and captivating experience that enhances emotional immersion and regulation. The system seeks to provide a soothing and therapeutic experience by incorporating ideas of meditation and art therapy, enabling users to engage with their emotions in a systematic and intuitive manner. The incorporation of multi-sensory input and augmented EEG interactions significantly improves immersion, personalization, and emotional expression, rendering the experience more flexible and responsive to users' requirements.

4.4.2 Design & Method

This prototype incorporates a breathing training phase at the outset of the experience to facilitate users in achieving relaxation, emotional regulation, and focused attention on the virtual environment through Focused Attention (FA) meditation techniques. The breathing exercise adheres to the principles of the Wim Hof breathing method, a technique recognized for its efficacy in stress reduction, enhanced focus, and improved physiological regulation. The exercise involves a cyclical process that starts with controlled inhalations and exhalations, followed by a breath-hold phase, which is repeated for several rounds to enhance relaxation and improve attention regulation (Wim Hof Method, 2024).

The breathing scene is organized within a basic skybox environment, enhanced by an animated mask that simulates a blinking effect (Figure 24). The animation adjusts in accordance with the breathing prompts, serving as a visual aid to assist users in regulating their breathing pace. The accompanying text instructions enhance the rhythm and pattern of inhalation, exhalation, and breath-holding, facilitating an intuitive and guided initiation into the meditation process.

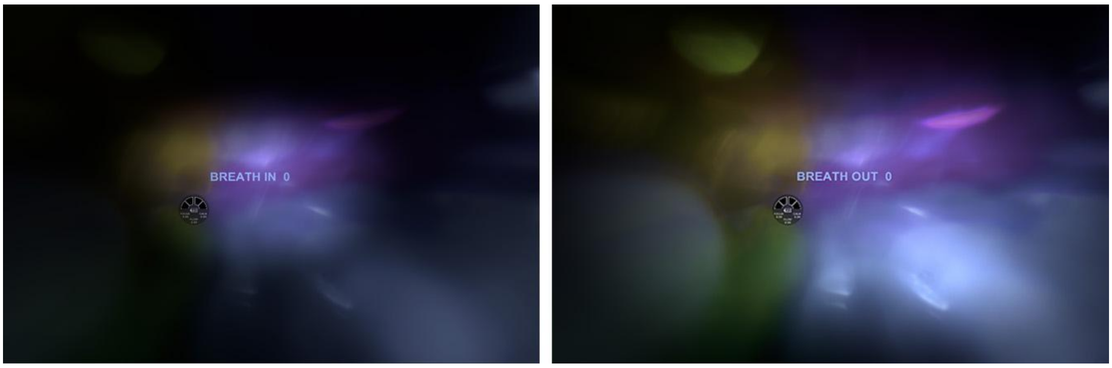

Figure 24- Different visual effect of Breath in and Breath out stage

The system assesses user attention levels via EEG input, adjusting the progression of the experience accordingly. Upon reaching a specified attention threshold, the breathing phase ends, and the primary VR environment along with interactive elements is activated. The threshold value was established via internal tests, balancing the necessity for adequate breathing practice duration with the avoidance of excessively high requirements that may impede progression into the primary scene. At this point, the system transitions from FA-guided breathing into the OM meditation phase, where users enter the responsive VR environment established in previous prototypes for self-guided exploration (Figure 25).

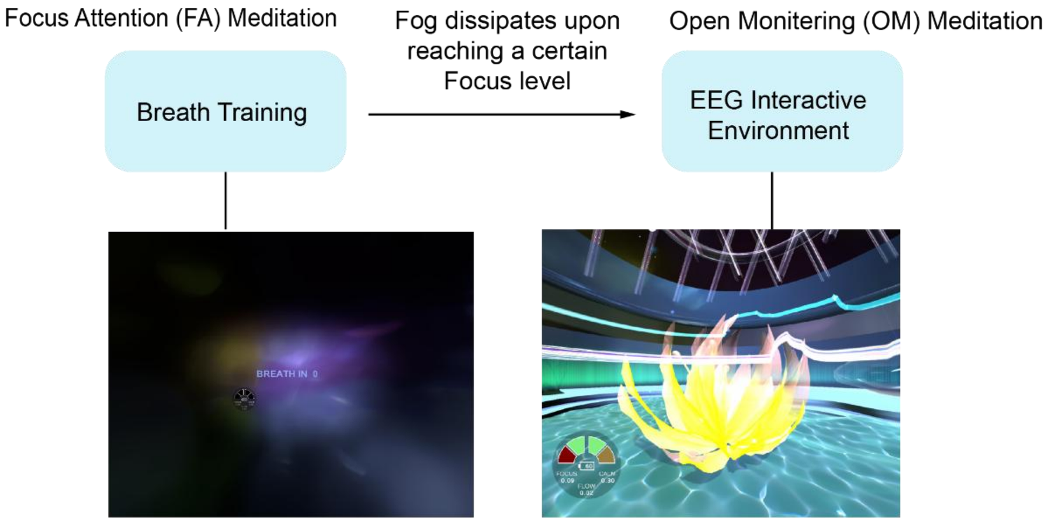

Figure 25- Core System Diagram Applied Meditation Theory in Prototype 4

Building upon previous prototypes, the iteration in Prototype 4 incorporates new interactive features to further deepen the immersive atmosphere and emotional involvement. The EEG-responsive interactions have been broadened beyond Calm and Flow, integrating Eye Blink and Jaw Clench as new interactive signals. These additions improve interaction diversity while complementing the calm and nature-inspired aesthetics of the environment. The general concept of EEG-VR spatial interaction elements in Prototype 4 is depicted below (Figure 26).

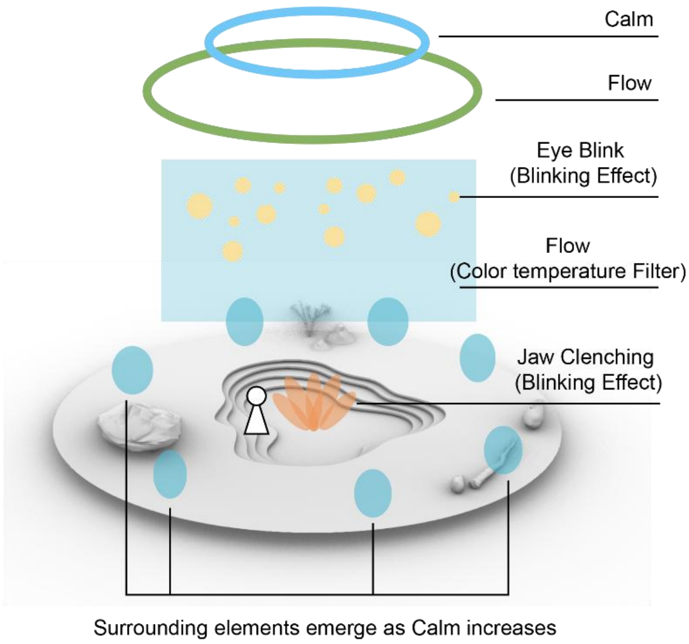

Figure 26- General Concept Diagram of EEG-VR Spatial Interaction Elements in Prototype 4

The interactions of Eye Blink and Jaw Clench are governed by a comparable script-based triggering system, wherein the Muse 2 EEG headset identifies the appropriate actions and initiates predetermined animations inside the scene.

In Eye Blink, floating particles in space intermittently enlarge and diminish, producing a slight flickering effect (Figure 27). This response facilitates a subconscious, organic contact, augmenting the perception of the world dynamically responding to the user's inherent behaviors.

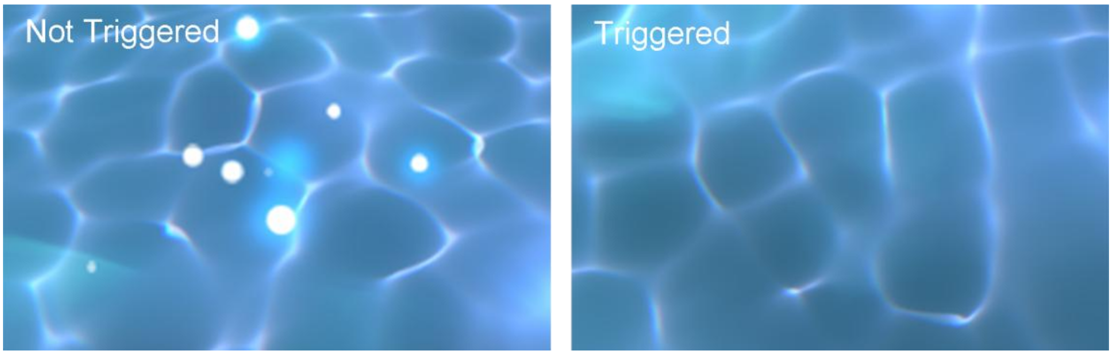

Figure 27- Eye Blink Triggered Particles Effect

In a similar manner, the Jaw Clench elicits a growing lotus flower in the picture, which activates a luminous flow effect that pulses across its petals upon detection (Figure 28). This effect graphically illustrates energy transfer and emotional stimulation, enhancing the peaceful and lyrical ambiance of the environment.

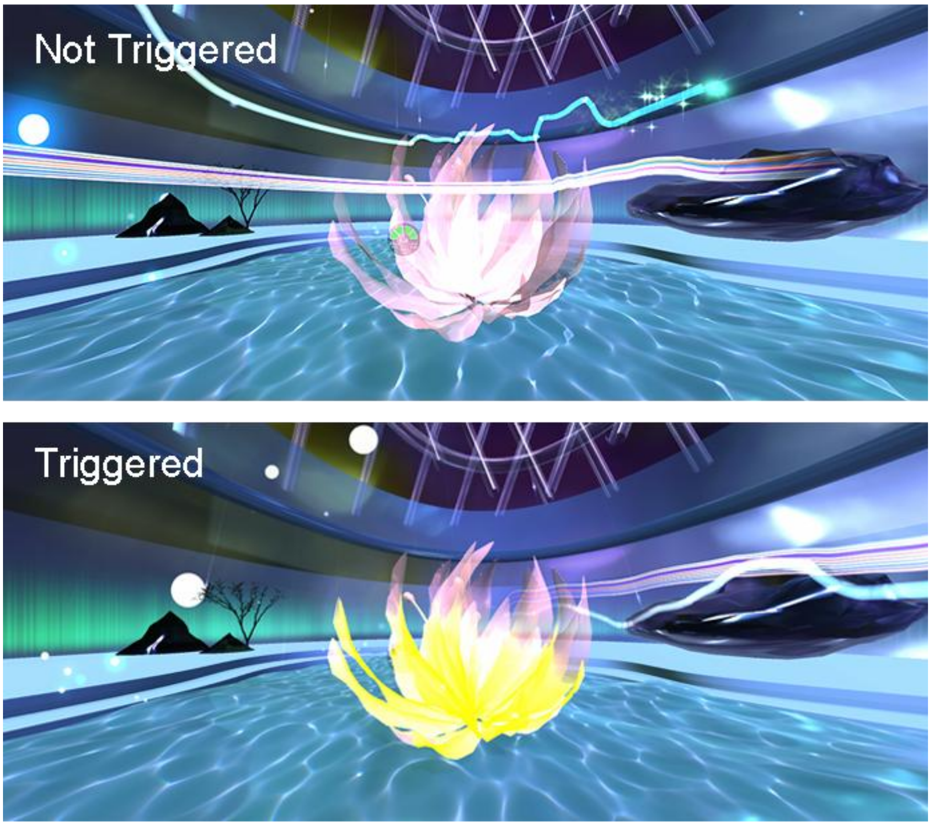

Figure 28- Jaw Clench Triggered Light Effect

Beyond these new interactions, Flow and Calm values have also been expanded to influence broader environmental elements.

Flow now controls the scene’s color temperature. A yellow-toned overlay filter has been added to the environment. As Flow increases, the filter’s transparency gradually rises, resulting in a warmer overall ambiance (Figure 29). This adjustment aligns with the emotional association of warm colors with comfort and positive affect, creating an environment that visually adapts to the user's engagement level.

Figure 29- Flow-driven Color Temperature Adjustment

Calm influences the growth of natural elements in the scene. As the Calm value increases, plants slowly emerge and populate the surroundings. The system is programmed with three predetermined thresholds, and for each level reached, two additional plants appear in the environment. When all three thresholds are met, a total of six plants are present, visually reinforcing a sense of gradual emotional stabilization (Figure 30).

Figure 30- Calm-driven Plant Growth

All EEG-based interactions underwent calibration via tests, ensuring balanced response thresholds that deliver clear visual feedback without overloading the user. These enhancements not only augment the visual appeal of the scene but also intensify the interactive and contemplative aspects of the experience, rendering the virtual environment a more immersive, responsive, and emotionally resonant location.

This prototype incorporates auditory feedback alongside visual feedback to augment immersion and meditative involvement. A background music track accompanies the experience, produced with the AI-generated music program Udio[12]. The creation prompt featured keywords like "ethereal meditation music, integrating subtle natural ambiance and gentle instrumental components," guaranteeing that the audio aligns with the desired tranquil environment. As the breathing exercise concludes and the main scene commences, aquatic sounds are included into the background music, harmonizing with the water elements in the VR world and enhancing a unified audio experience.

Furthermore, EEG-based auditory interactions were integrated, utilizing the same triggering methods as the visual feedback scripts. Upon detection of a jaw clench, the sound of a Tibetan singing bowl is played, harmonizing with the background music to enrich the contemplative ambiance and elevate a Zen-like experience. Likewise, Eye Blink activates a bowl sound; however, due to its increased frequency, a lower-pitched, softer variant was chosen to

[12] https://www.udio.com/

mitigate auditory interference. Personal testing facilitated changes to reduce the volume, enabling a harmonious and cohesive integration within the experience.

These multi-sensory interactions augment the immersive nature of the environment, fostering a more engaged and interactive meditation experience. By integrating visual and audio feedback, the system enhances the association between the user's emotional state and the environment, thus rendering interactions more intuitive and responsive. The incorporation of auditory components with visual signals boosts interaction and facilitates deeper user immersion in the virtual environment, promoting a concentrated and contemplative mood that improves the overall efficacy of the experience.

Following the establishment of the fundamental EEG-VR interactions in Prototype 4, supplementary guidance elements were integrated at both the entry and exit points of the experience to enhance its structure and coherence (Figure 31).

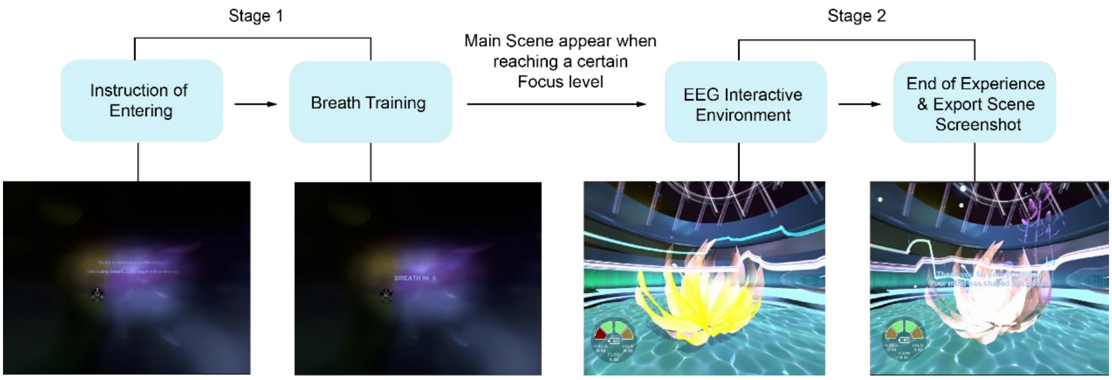

Figure 31- Complete Interaction Flow with Guidance Integration

Initially, opening messages like "Ready to step into your Mindscape?" and "Take a deep breath... Let's begin with a warm-up." were stated to mentally prepare consumers for the shift into the immersive environment. Likewise, at the end of the encounter, concluding remarks such as "Thank you for your presence. Your mind has shaped this space." and "This is your creation. Take a moment to appreciate the world you've built." were presented to promote contemplation on the distinctive interplay between the user's emotions and the surroundings.

To enhance the concept of passive emotional creation, the system autonomously snaps a screenshot of the concluding scene at the end of each session. As emotional states vary and affect the visual patterns present in the surroundings, each created screenshot is a unique record of the user's individual experience.

Following several test iterations, the overall experience time was established at around three minutes. This duration guarantees that users have adequate exposure to all fundamental interactions without excessive prolongation in the OM meditation phase, which may otherwise result in disengagement. After three minutes, the script activates the concluding prompts and archives the final scene screenshot in a specified folder, signifying the session's completion.

4.4.3 Reflection

Prototype 4 demonstrates how art therapy principles can be integrated into VR to facilitate emotional engagement and self-expression. By incorporating both FA and OM meditation techniques, it creates a structured yet flexible experience that guides users into a mindful state before allowing for open-ended exploration. The evolving environment, shaped by real-time emotional input, reinforces the connection between internal states and external visualization, emphasizing the role of passive creation in emotional processing. The inclusion of guided prompts at key moments further enhances introspection, helping users recognize how their emotions influence the space around them.

While this prototype explores the potential of VR as an artistic and meditative tool for emotional awareness, it remains an initial step in understanding its role within art therapy. Future development could deepen its alignment with established art therapy methodologies, moving beyond conceptual exploration to a more structured therapeutic framework. Additionally, further studies could assess its effectiveness in emotional relief, evaluating its impact on users' well-being and its viability as a structured emotional support tool.

Based on the self-evaluation criteria, the development and outcomes of Prototype 4 were assessed across multiple key criteria (Figure 32).

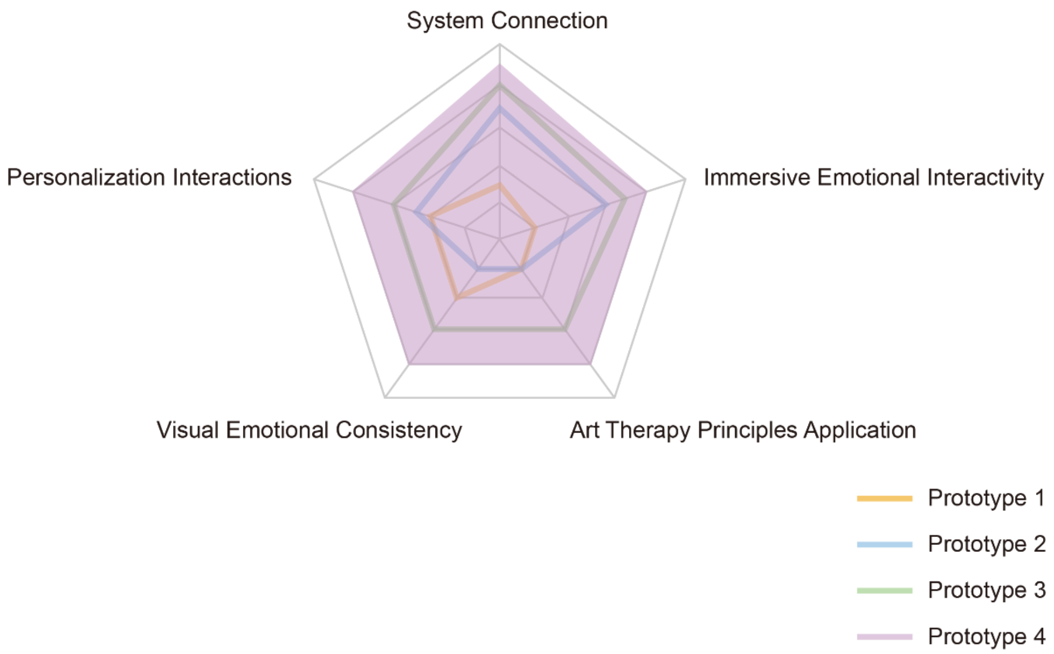

Figure 32- Radar Chart for Prototype 3

System Connection (4.5/5)

While the core system connection remained unchanged from the previous prototype, the introduction of the FA-based breathing exercise addressed the 15-second signal delay issue present in prior iterations. This enhancement ensures a smoother transition into the experience, making the overall interaction feel more seamless and coherent.

Immersive Emotional Interactivity (4/5)
The addition of expanded EEG-driven interactions—including Eye Blink and Jaw Clench—alongside newly introduced sound-based feedback significantly improved the depth and richness of engagement. These elements enhanced immersion by reinforcing the feeling that the environment was actively responding to users' emotional and physiological states.

Art Therapy Principles Application (4/5)
The integration of Focused Attention (FA) meditation at the start, combined with Open Monitoring (OM) exploration, established a structured meditative flow. Additionally, guided instructions further reinforced the passive creation concept, strengthening the alignment with art therapy principles and promoting emotional self-expression.

Visual Emotional Consistency (4/5)
The visual interactions remain intuitive and aligned with human perception, such as the blinking-triggered flickering effect and the gradual plant growth corresponding to Calm levels. As emotional states improve, the Mindscape transforms into a warmer, more vibrant environment, reinforcing the connection between emotional well-being and environmental aesthetics.

Personalization Interactions (4/5)
The expanded EEG-based interactions offer a high degree of personalization, as each user's unique EEG data influences different visual and auditory responses. Additionally, the final screenshot recording captures a personalized visual imprint of the user's emotional state, making each session a unique and reflective experience.

5. Discussion

5.1 Evaluation Process

The project's development adhered to an iterative method, informed by self-assessment and criteria-based evaluation to enhance emotional involvement, meditative integration, and interaction depth. Prototype 1 concentrated on investigating emotion-responsive feedback systems, testing visual components that could amplify emotional states and cultivate a more immersive environment. Prototype 2 improved on these notions by creating a fully interactive virtual reality setting that incorporates EEG signals to generate a real-time, responsive environment. Building upon this basis, Prototype 3 incorporated visual interactions that directly mirrored EEG data, enabling users to observe the influence of their emotional states on the virtual environment in real-time. Ultimately, Prototype 4 enriched the experience by augmenting audio and visual interactions, integrating Focused Attention (FA) and Open Monitoring (OM) meditation methodologies, and further anchoring the system in art therapy concepts. Every developmental phase was predicated on prior reflections, progressively enhancing both the conceptual and technical dimensions to establish a more captivating, contemplative, and emotionally nurturing interactive system.

In addition to internal testing, the final prototype (Prototype 4) was evaluated at two public exhibitions: Open HDMI and DFX. These exhibitions offered opportunities to examine participants' reactions and gather insights regarding the system's influence on user engagement, interaction, and emotional response. It’s also important to note that, during both Open HDMI and DFX exhibitions, no data or EEG recordings were stored, ensuring that the experience remained purely artistic and meditative. The exhibitions were designed to offer participants an immersive, real-time interaction with their emotional states without any form of data tracking or collection. This approach aligns with the project's emphasis on personal exploration and emotional engagement, prioritizing the participant’s experience over analytical data collection.

5.1.1 Insights from Open HDMI Exhibition

This project was initially presented at the 2025 Open HDMI event, where participants engaged in live demonstrations. Observational analyses of participant behavior during the exhibition yielded significant insights into the efficacy of the experience. Users typically shown curiosity and enthusiasm while initially entering the virtual area, interacting with the environment in an exploratory fashion. Throughout the session, numerous participants progressively entered a more tranquil and reflective state, consistent with the desired meditative outcome (Figure 33, 34). The aesthetic design of the virtual area garnered favorable response, with participants valuing the organic and immersive characteristics of the setting (Figure 35, 36). The novelty of EEG-driven interaction was a significant point of interest, as users noted the distinctive experience of observing their emotions displayed in real-time.


Figure 33- Participants Interacting with the Final Prototype at the Exhibition (1)
Figure 34- Interacting with the Final Prototype at the Exhibition (2)

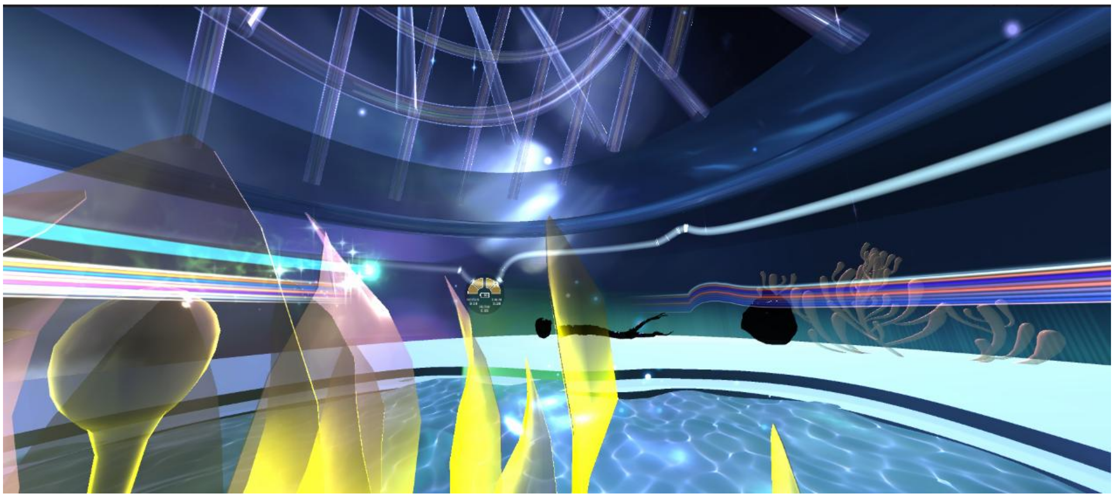

Figure 35- VR Scene Has Been Shown during the Exhibition (1)

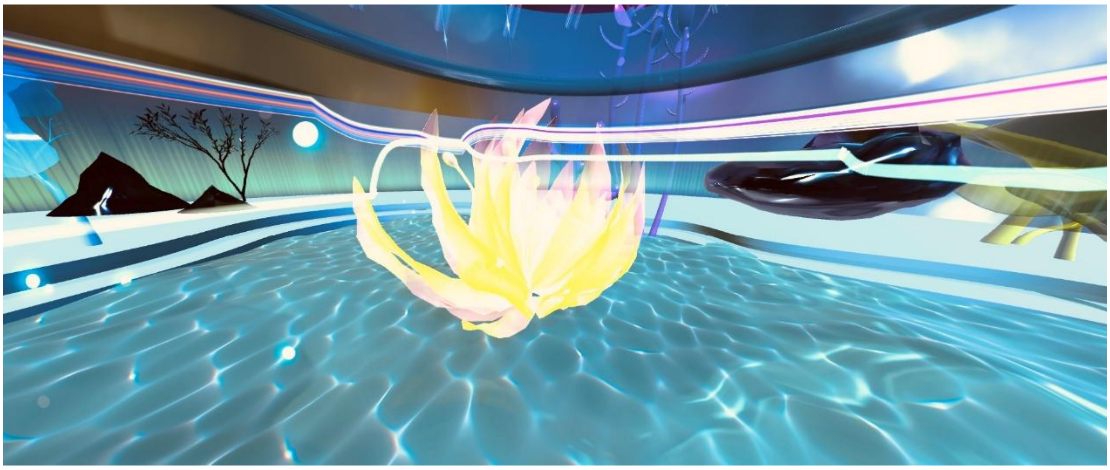

Figure 36- VR Scene Has Been Shown during the Exhibition (2)

Nonetheless, the show exposed some usability issues. Several participants encountered difficulties in achieving the necessary attention threshold, hindering their entry into the primary scene. This issue underscored the necessity for a more flexible threshold system or enhanced onboarding instructions to assist users in attaining the requisite concentration levels. Moreover, ambiguity regarding the EEG connection status was a prevalent issue. A number of customers expressed uncertainty regarding the correct positioning of the headset and the appropriate capturing of their EEG data. Moreover, there was ambiguity concerning the numerical depiction of EEG results, specifically regarding the correlation between variations in concentration and calmness and alterations in visual and auditory feedback. These observations suggest that enhanced real-time input regarding system connectivity and user performance could markedly enhance accessibility and usability.

5.1.2 Insights from Open DFX Exhibition

The DFX exhibition, held from March 27 to April 2 at OCAD, presented an enhanced prototype that integrated improvements based on feedback received during the earlier Open HDMI exhibition. Modifications included lowering the attention threshold, which enabled a smoother transition for more participants into the next scenario. A new UI overlay was implemented within the VR interface, displaying real-time metrics for Calm, Focus, and Flow, along with indicators for the connection status of the four Muse 2 electrodes. This enhancement allowed participants to better distinguish between Calm and Flow visual effects, monitor EEG connectivity, and make necessary adjustments for a more optimized experience.

A guiding chart was placed at the entrance of the exhibition space, detailing all interaction methods within the experience. This included eye blink and jaw clench interactions, as well as visual feedback related to Calm and Flow values. The chart also provided clear instructions on how to properly wear the Muse 2 EEG headband and Meta Quest 3 headset to ensure accurate signal reception. Participants were seated in a comfortable, swiveling chair to allow easy exploration of the VR environment while maintaining a relaxed posture suitable for meditation. They received instructions on using both devices prior to beginning the session. Once inside the virtual environment, users had the option to remain seated and shift their viewpoint or stand and engage more dynamically with the surroundings.

This exhibition furthered the understanding of user behavior and interaction patterns, building upon insights gained from Open HDMI and helping to identify additional areas for system improvement. Below are some images captured during the exhibition.

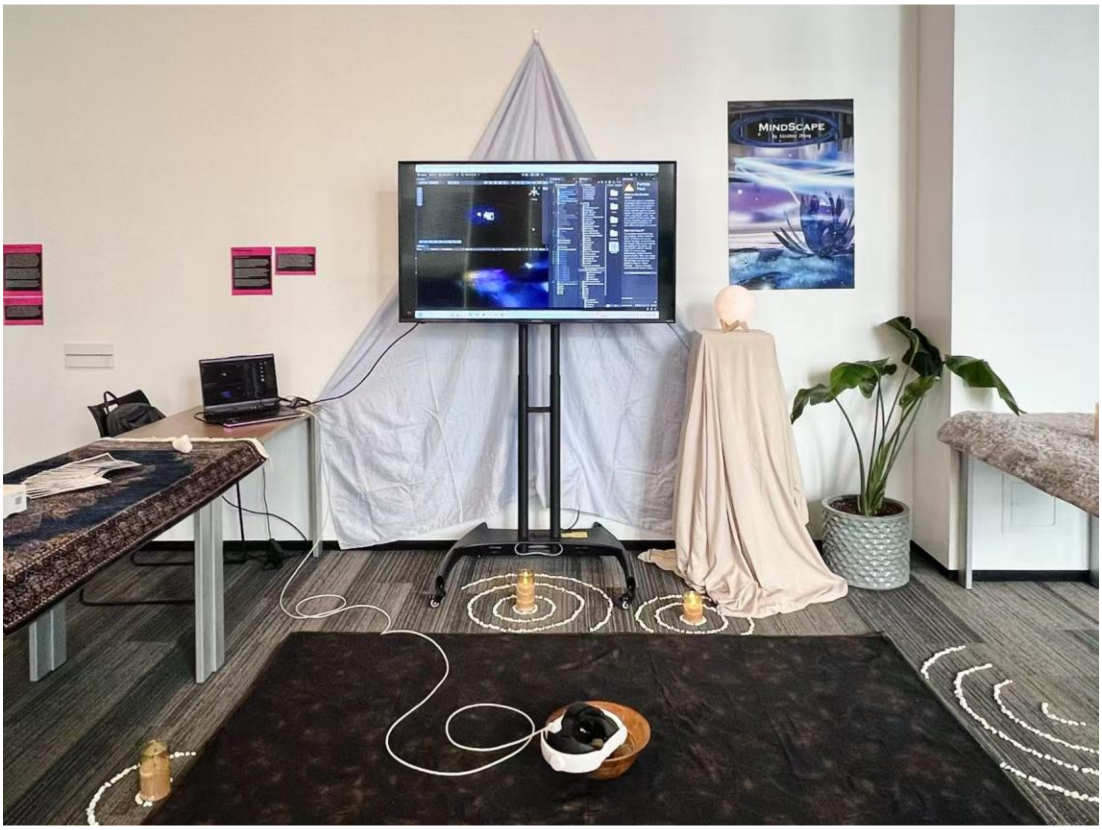

Figure 37- Exhibition Overall Setup

Figure 38 - Participants Experienced MindScape VR

5.2 Reflection on Research Question

This study investigated the incorporation of EEG-based real-time emotion identification in virtual reality settings to overcome the shortcomings of conventional emotional healing applications. The study methodically investigated the essential components for constructing a dynamic, interactive system that facilitates emotional regulation and fosters healing through art therapy principles, through the iterative construction of four prototypes.

Each prototype tackled distinct facets of the research question by deconstructing it into particular sub-questions. Prototype 1 examined the fundamental components of an emotionally responsive experience, analyzing which system interactions and visual features facilitate emotional alleviation. Prototype 2 concentrated on incorporating EEG-based emotion identification within virtual reality, linking brainwave data to virtual interactions to facilitate emotional management. Prototype 3 investigated the capacity of immersive VR environments to convert real-time EEG data into visually captivating and interactive components that promote emotional equilibrium. Prototype 4 implemented art therapy ideas in the VR experience, allowing users to visualize and interact with their emotions in a more organized and expressive manner.

The final prototype demonstrated the potential of EEG-driven feedback and realistic VR interactions to establish a tailored, adaptive system for emotional support. The incorporation of real-time emotional data into a dynamically changing environment offered a novel avenue for self-expression and emotional introspection, overcoming the shortcomings of conventional therapy, meditation, and mobile applications—namely, insufficient personalization, lack of immediate feedback, and limited immersive engagement. Furthermore, by incorporating art therapy-inspired passive creation and meditation guiding, the system facilitated users' intuitive and artistic engagement with their emotions, thereby connecting introspection with exterior emotional expression.

A comparative analysis is performed to assess the contributions of this project against two pertinent meditation applications—Sink in Sync and Tripp. Although both applications provide immersive experiences, neither completely blends real-time emotional feedback within an adaptable, interactive environment that dynamically responds to user emotions while using art therapy concepts. Sink in Sync prioritizes communal EEG synchronization over individual emotional processing, while Tripp offers planned VR meditation sessions but lacks real-time emotional adaptation. This research implements a system wherein users' EEG-derived emotional states directly influence their virtual environments, promoting individualized interaction and reflective artistic production. The subsequent table delineates critical differences in emotional input, interaction modalities, feedback systems, real-time adaptability, and the incorporation of art therapy, illustrating how this system surpasses current techniques (Table 2).

Aspect	MindScape	Sink in Sync	Tripp
Emotion Input	Muse 2 EEG (Calm, Flow, Eye Blink, Jaw Clench)	Muse 2 EEG (Brainwave between two users)	No EEG, user manually selects emotion states
Interaction Type	User's brain activity directly influences the VR environment	Interaction triggered only when two users' EEG data match	Pre-designed interactions and guided meditation sequences
Feedback Mechanism	Multi-sensory (visual + auditory) feedback based on EEG data	Visual feedback based on EEG synchronization, no auditory elements	Static visuals and music, not influenced by real-time user states
Real-Time Emotion-VR Interaction	Fully interactive, dynamically evolving space	Limited, only triggered when brainwaves sync	No real-time adaptation to user emotions
Art Therapy Integration	Integrates art therapy concepts, supports emotional self-expression	No art therapy focus, mainly social bonding	Some visual and audio relaxation elements but lacks emotional creation

Table 2- Comparative Analysis of Popular VR-Based Meditation Applications

This comparative study clarifies how the developed system tackles the research topic by synthesizing real-time EEG feedback, immersive VR interactions, and art therapy principles into a cohesive framework. This project uniquely combines real-time emotional feedback with an adaptable, interactive environment for self-exploration, unlike previous programs that concentrate exclusively on guided meditation (Tripp) or social EEG synchronization (Sink in Sync). The system enables users to dynamically see their feelings in a virtual environment, offering a distinctive platform for intuitive and artistic interaction with emotional states.

The final prototype clearly illustrated how EEG-driven VR environments might improve emotional control by providing rapid, tailored reactions to brainwave activity. This initiative is distinguished by its integration of passive artistic creation and structured meditative instruction, presenting a novel method for emotional recovery. This adaptive and interactive experience offers a more engaging and immersive alternative to conventional meditation and therapy, while also presenting a novel approach for emotional self-awareness and expression, thereby highlighting the potential of EEG-VR integration in digital mental health solutions.

5.3 Personal Reflection & Challenges

This research developed a comprehensive EEG-VR system that blends real-time emotional feedback into an interactive and immersive environment. The development process yielded a workable prototype that showcased the potential of integrating EEG-driven interactions, VR spatial design, and art therapy concepts to enhance emotional involvement. Nonetheless, due to the extensive breadth of this research and time limitations, several elements—such as systematic user testing and the validation of its efficacy in fostering good emotional states—could not be thoroughly examined. The prototype demonstrates the promise of this method; nevertheless, additional research is necessary to evaluate its long-term effects on emotional well-being systematically.

Numerous technical and conceptual obstacles arose during the development process. A significant challenge was the integration of the Muse 2 EEG device into the VR system. Initially, identifying an effective and dependable approach to integrate EEG data with Unity's VR architecture presented a considerable challenge. The issue was fixed upon discovering the NeuroGame Muse 2 Unity Template, which offered a systematic method for capturing and implementing brainwave data within the VR experience.

Furthermore, collaborating with Unity 6 and maintaining seamless interaction with Meta Quest 3 posed numerous challenges. Numerous conventional VR features—such as teleportation and button-based interactions—could not be effortlessly incorporated due to compatibility limitations. Efforts to integrate these capabilities often led to connectivity issues between Unity and the Meta Quest 3 headset. Consequently, alternate interaction methods were necessitated, emphasizing EEG-driven inputs and passive user engagement over conventional controller-based interactions.

Notwithstanding these limitations, the initiative yielded significant insights into the amalgamation of neurotechnology and virtual reality for emotional inquiry. The experience underscored the significance of adaptation in design and problem-solving, especially in the context of evolving technology. Subsequent iterations of this research may enhance the system by resolving technical constraints, broadening interaction capabilities, and doing user-centered assessments to confirm its therapeutic efficacy.

5.4 Future Work

Incorporating Gamification Elements: Future iterations could explore the integration of gamification principles to enhance engagement and motivation. Implementing goal-based tasks, progressive challenges, or interactive rewards could encourage users to engage more deeply with the experience while maintaining the meditative and therapeutic focus.

Multi-Sensory Enhancements and Haptic Feedback: Introducing haptic feedback mechanisms, such as subtle vibrations in response to EEG fluctuations or interaction cues, could reinforce the connection between user emotions and the VR environment. Additional sensory elements, including adaptive scents or temperature shifts, may further enhance immersion and emotional engagement.

Refining Interaction and Data Visualization: Improving the clarity of interactive design and data visualization would help users intuitively understand how their actions influence the virtual environment. Enhancing visual cues, UI elements, and spatial design could ensure that interactions feel more intuitive, reducing confusion and improving accessibility.

Developing Rigorous User Testing Methods: A more structured user testing framework should be established to evaluate the system's effectiveness in emotional regulation. Future studies should incorporate both qualitative and quantitative analysis, including physiological measurements, self-reported emotional assessments, and structured feedback sessions, to assess its long-term benefits.

Expanding Personalization and Adaptability: Future improvements could introduce adaptive algorithms that personalize the VR experience based on users' emotional patterns over time. Machine learning techniques could be leveraged to dynamically adjust scene elements, interaction difficulty, or feedback intensity, tailoring the experience to individual needs and preferences.

Exploring Real-World Applications: Beyond experimental settings, future research could explore how this system may be applied in real-world contexts, such as therapeutic practices, guided meditation sessions, or digital wellness programs. Collaborations with mental health professionals and researchers could provide further validation and optimize its use in professional settings.

6. Conclusion

6.1 Revisiting Goals & Objectives

This study aimed to investigate the amalgamation of EEG-based real-time emotion identification with virtual reality environments to improve emotional control and foster participation using the concepts of art therapy. The objective was to create an interactive, emotionally responsive system that visualizes emotional states inside an adaptive virtual reality environment, integrating meditative techniques with passive creativity to promote self-reflection and emotional awareness. The project utilized an iterative design method to investigate the successful integration of EEG data into VR for the development of a dynamic and immersive emotional support system.

6.2 Outcomes & Contributions

This study offers an initial investigation into the integration of EEG-driven biofeedback within virtual reality environments to enhance emotional engagement. The study analyzes existing literature to identify deficiencies in current emotional healing applications and investigates the potential contributions of art therapy, meditation techniques, and biofeedback to immersive digital experiences.

This research examines spatial composition and color theory during the design phase to ascertain how visual and environmental components may affect emotional states in virtual reality. This facilitates the creation of scene design prototypes, wherein real-time Muse EEG signal exchanges enable users' emotional variations to be represented through dynamic visual alterations. These prototypes investigate passive creation as an alternate technique for emotional engagement, allowing users to interact with a virtual environment that responds non-verbally to their cognitive states.

Further iterations incorporate art therapy concepts and meditation frameworks, combining Focused Attention (FA) and Open Monitoring (OM) techniques with EEG-driven virtual reality environments. This technique enhances the design of a meditation-centric experience, wherein emotional states discreetly influence the virtual environment, promoting introspection and self-regulation without necessitating active user participation.

This study proposes a speculative notion that examines the viability of real-time biofeedback-driven interactions within immersive environments, rather than delivering a fully constructed system. Although additional refinement and assessment are required, these findings indicate potential avenues for future study on emotion-responsive VR experiences, especially in enhancing interactivity, customization, gamification and adaptable scene design.

6.3 Research Limitations

This study explores the feasibility of integrating EEG-driven emotional interaction in VR, but several limitations remain in both technical and experiential aspects. The accuracy of EEG data is limited due to the use of consumer-grade hardware with only four electrodes, which can provide a general reference for emotional states but lacks the precision required for detailed emotional analysis. External factors may affect signal consistency, and the system cannot fully capture complex emotional changes. Future research could explore higher-precision EEG devices and integrate additional biometric data, such as heart rate, to enhance emotional responsiveness and adaptability.

Additionally, while this study incorporates meditation and art therapy principles, it lacks structured guidance or real-time feedback mechanisms that traditional therapeutic approaches often include. The current system allows users to engage in a visually adaptive environment, but without clear ways to assess its impact, it remains an exploratory experience rather than a structured therapeutic tool. Future work could introduce guided prompts or interactive elements to provide users with more structured engagement.

The depth of interaction within the VR environment is also limited. While the system visually responds to EEG signals, interactions are predefined, with minimal user-driven customization. One key challenge is that users are not explicitly informed about what actions trigger interactions, making it difficult for them to fully engage with the system. Future iterations could introduce game-like elements to enrich the experience, offering clearer interaction cues that guide users in exploring the environment more intuitively. Expanding adaptive scene transitions, unlockable features, or reward-based interactions could also help sustain engagement over time.

Finally, user experience was observed through exhibitions, where participants engaged with the system in a controlled setting. While this provided valuable feedback on initial impressions, there was no formal user evaluation to assess long-term effects or engagement patterns. Future studies could incorporate structured assessments or comparative studies to better understand how users interact with biofeedback-driven VR environments in different contexts.

Despite these limitations, this study provides an initial exploration of EEG-driven interactions in VR. Future research can build upon these findings by improving signal accuracy, enhancing user engagement strategies, and refining the integration of interactive and therapeutic elements to create a more immersive and dynamic emotional support system.

6.4 Future Development

Future work may concentrate on improving interaction clarity and engagement methodologies. The existing technology does not provide clear instructions on how users might affect the VR world, perhaps resulting in misunderstanding. Incorporating visual or auditory indications that reflect the timing and manner in which EEG signals elicit changes could enhance the intuitiveness of interactions. Moreover, layered interactions, including gradual scene transitions or dynamic environmental changes influenced by prolonged emotional states, could enhance engagement and responsiveness.

A crucial aspect is enhancing the incorporation of meditation and art therapy techniques. This study examines Focused Attention (FA) and Open Monitoring (OM) meditation, although the transition between these stages is inadequately defined. A more explicit progression structure, such as sequential guided breathing or incremental visual modifications, could enhance the immersive quality of the meditative experience. Likewise, optimizing existing production procedures, in which users' emotional states progressively influence intricate visual components, could improve the system's expressive quality.

Ultimately, enhancing EEG data integration may augment the system's responsiveness. The existing configuration depends on a rudimentary analysis of EEG signals, constraining the profundity of feedback. Integrating real-time signal smoothing or amalgamating various biometric inputs—such as nuanced variations in heart rate or respiratory patterns—could establish a more flexible and individualized interaction model.

6.5 Final Remarks

This study explores the feasibility of integrating EEG-driven emotional feedback into VR environments, investigating how biofeedback, meditation techniques, and art therapy principles might shape immersive emotional experiences. Through iterative prototyping, it examines how spatial design, color theory, and passive creation can be applied to VR to create a dynamic, responsive environment. While the system offers an initial exploration of these possibilities, it remains a conceptual framework rather than a fully validated therapeutic tool.

The findings highlight both the potential and challenges of EEG-driven interaction. On one hand, the real-time visualization of emotional states creates a unique form of engagement, offering users an alternative way to reflect on their emotions through passive creation. On the other hand, technical constraints, interaction clarity, and the absence of structured evaluation leave open questions about its long-term effectiveness and adaptability for different users.

Rather than providing definitive answers, this study raises new questions about the role of biofeedback, interactivity, and guided experiences in digital emotional support systems. Future research will need to refine signal accuracy, engagement strategies, and structured integration of therapeutic principles to determine whether such systems can move beyond speculative concepts into practical applications. Nonetheless, this work contributes to the growing conversation on how neurotechnology and immersive media might intersect to create new forms of emotional engagement and self-awareness in digital spaces.

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