Tactile Narratives in Virtual Reality

by

Punit Kunjam

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Author's Declaration

This thesis consists of materials all of which I authored or co-authored: see the Statement of Contributions included in the thesis. This is a true copy of the thesis, including any required final revisions, as accepted by my examiners.

I understand that my thesis may be made electronically available to the public.

Statement of Contributions

This thesis represents the culmination of a collaborative effort, integrating diverse expertise and contributions from various team members in a larger project. The larger motivation is important for positioning my specific contributions, and as such, this thesis takes a broad approach to represent the effort as a complete story, with emphasis on my contributions. This work is expected to be reported in one or two papers, the first of which has been written:

Bibhushan Joshi, Punit Kunjam, Ludwig W. Wall, Michael Barnett-Cowan, Jennifer Llewellyn, Kristina Llewellyn, Jennifer Roberts-Smith, Oliver S. Schneider: Sankofa as Interface: Tangible VR Interaction for Bearing Witness to Restorative Justice Narratives (In revision for a planned submission to CHI 2025)

The following individuals provided substantive technical contributions to the larger work discussed in this thesis:

- **Bibhushan Raj Joshi:** Led the interaction design decisions (Chapter 4), provided essential electronics, and contributed to the design and development of the Sankofa Interface. Additionally, Bibhushan is the first author of the "Sankofa as Interface: Tangible VR Interaction for Bearing Witness to Restorative Justice Narratives" paper, which established the foundation for the literature and motivation (Chapters 1, 2, and 3) in the thesis.
- **Chris Wang:** Assisted with the development of the initial version of the prototype, especially on earlier design efforts (Chapter 4.4.1). Developed and ran early software prototypes of the VR experience for the August 2023 workshop, which Punit could not attend.
- **Ludwig Wilhelm Wall:** Contributed to the modification and refinement of the 3D models of the Sankofa to align with the design goals, and informed technical information for sensing and actuation to support the interaction design.

My contributions encompass both technical and non-technical aspects, including but not limited to the design and implementation of versions of the Sankofa Interface, with a greater emphasis on Sankofa Interface Version 2, integration and testing of electronic components, and the development of the VR user interface described in Chapter 5. I was responsible for enhancing the Macaron tool to meet the specific requirements of this project. Additionally, I made significant contributions to section 4.4.2, building upon the

initial efforts in section 4.4.1, to further develop and refine the Sankofa Interface. I led the design and development of the vibration feedback design, including the workshops that informed the discussions and feedback in Chapter 6 and contributed to various software and hardware development tasks, ensuring the functionality and reliability of the system. I am expected to be the second author or co-first author (listed second) on the resubmitted Sankofa as Interface paper.

This project was carried out under the guidance and collaborative efforts of my supervisor, **Dr. Oliver Schneider**, and co-investigator, **Dr. Michael Barnett-Cowan**, whose insights and support were instrumental in ensuring the project's alignment with academic and practical objectives. A great deal of input was also provided by collaborators **Jennifer Roberts-Smith**, **Kristina Llewellyn**, and **Jennifer Llewellyn**.

Abstract

This research explores how to design haptic feedback systems in virtual reality (VR) environments to support relational presence, a concept central to the design of Virtual Learning Environments. Unlike traditional presence, which focuses on simulation, interactivity, and user satisfaction, relational presence emphasizes engagement with values such as impression, witnessing, self-awareness, awareness of difference, interpretation, inquiry, and affective dissonance. The objective is to develop haptic designs that enhance these aspects of relational presence, facilitating users' engagement with challenging content that prompts thoughtful questions about responsibility and action. The key technical contributions to this project include the design and implementation of the haptic feedback system, VR User Interface, the development of the Sankofa Interface, and enhancements to the Macaron haptic editor. These efforts were essential in aligning haptic feedback with emotional and narrative arcs, helping to refine the interaction design and ensure its effectiveness in promoting relational presence. The integration of advanced programming techniques and responsive haptic feedback synchronized with audio-visual elements contributed to the creation of a cohesive and relationally enhanced VR environment. Through these technical developments, this research identified mechanisms and design criteria that could help align haptic feedback with emotional and narrative arcs, potentially enhancing users' connection to the content and fostering a more reflective and empathetic engagement. By focusing on creating interactions that resonate emotionally and cognitively with users, rather than just achieving representational fidelity, this research contributes design principles that enable haptic technology to foster a richer, more reflective user experience in educational and narrative-driven VR applications.

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I would like to express my deepest gratitude to those who have supported me throughout the journey of my thesis.

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This thesis is a testament to the collective efforts and support of all these remarkable individuals. Thank you for being an integral part of this journey.

Dedication

I dedicate this thesis to my family.

Table of Contents

Author's Declaration ii

Statement of Contributions iii

Abstract v

Acknowledgements vi

Dedication vii

List of Figures xi

List of Tables xiii

1 Introduction 1

1.1 Contributions . . . 3

1.1.1 Sankofa Interface . . . 3

1.1.2 Macaron Development . . . 4

1.2 Outline of the Thesis . . . 4

2 Background 6

2.1 Presence in VR . . . 6

2.1.1 Embodiment in VR . . . 8

2.2 Virtual Learning Environments . . . 9
2.2.1 Examples of VLEs that successfully utilize presence . . . 10
2.3 Haptic Feedback . . . 11
2.3.1 Types of Haptic Feedback . . . 11
2.3.2 Applications of Haptic Feedback in VR . . . 12
2.4 Challenges of presence in sensitive content . . . 13
2.4.1 Design and Implementation Challenges . . . 14
2.4.2 Applications of VR dealing with Sensitive Content . . . 14
2.5 Relational Presence . . . 15
2.6 Sankofa . . . 16

3 Design Context: Digital Oral Histories for Reconciliation 17
3.1 Overview . . . 17
3.2 The VR Experience . . . 19
3.3 Educational and Restorative Goals . . . 19
3.4 Relational Presence . . . 20

4 Physical Prototype 22
4.1 Sankofa Interface . . . 22
4.2 Design Goals . . . 23
4.3 Interaction Design . . . 25
4.3.1 Intial Design Concepts and Transition to Gesture-Based Interaction 26
4.3.2 User Comfort and Accessibility . . . 28
4.3.3 Refined Interaction Design . . . 28
4.4 Construction . . . 29
4.4.1 Sankofa Interface Version 1 (SV1) . . . 30
4.4.2 Sankofa Interface Version 2 (SV2) . . . 32

5 Software Interface **34**
5.1 User Interface . . . 35
5.2 Audio to Vibration . . . 38
5.2.1 Independent Control Over Audio and Vibration . . . 38

6 Haptic Feedback Design **40**
6.1 The Role of Haptics in Relational Presence . . . 40
6.2 Iterative Development Process . . . 41
6.2.1 Refinement and Further Feedback . . . 42
6.2.2 Crafting Haptic Designs . . . 42
6.2.3 Extending Macaron . . . 46
6.2.4 Onboarding and User Guidance . . . 47
6.2.5 Collaborative Discussion . . . 48

7 Evaluation **51**
7.1 Planned User Study . . . 51
7.2 Reasons for Abandoning the User Study . . . 52
7.3 Future Evaluation of the Sankofa Interface . . . 54
7.3.1 Acceptance Testing Through Collaborative Discussion . . . 54
7.3.2 Future Deployment: Museum Exhibit . . . 55
7.3.3 Future Study of the Deployed Exhibit . . . 55

8 Discussion **57**
8.1 Pioneering Haptic Solutions in Virtual Reality . . . 57
8.2 Educational and Restorative Applications . . . 58
8.3 Challenges and Considerations . . . 59

9 Conclusion and Future Work **60**
9.1 Future Work . . . 61

References **63**

List of Figures

3.1 The Nova Scotia Home For Colored Children (Reference: Nova Scotia Archives Library Brookbank 1990-191) 18

3.2 Screenshots from the DOHR VR experience. The VR experience employs a combination of 360-degree video, immersive 3D graphics, and contextual images, allowing users to explore these recreated environments in a deeply engaging and reflective manner. 19

4.1 Interaction Flow with the Sankofa Interface in the DOHR VR Experience. This storyboard illustrates the sequence of user actions, from setting up and starting the VR story by picking up the Sankofa Interface to pausing and resuming the narrative by placing the interface on the table. 26

4.2 The figure shows a user, equipped with a VR headset and the Sankofa Interface during a VR storytelling experience. 29

4.3 The figure displays (a) the original wooden Sankofa sculpture provided by the DOHR team. This intricately carved figure served as the inspiration for the design of the Sankofa Interface, symbolizing the project's emphasis on historical awareness, reflection, and the importance of learning from the past, (b) Collection of Sankofa statues printed using different materials, showcasing the variety in texture, color, and finish. 30

4.4 Sankofa Interface Version 1 (SV1). The left image shows the 3D-printed prototype of the Sankofa object, designed to house the hardware components. The right image provides a closer look at the internal electronics, including the Arduino UNO microcontroller and associated circuitry, contained within a junction box. 31

4.5 This iteration of the Sankofa Interface features an integrated design with all hardware components housed within the base, eliminating the need for a separate junction box. The device includes a cavity inside the model to accommodate the haptic motor, with an infrared sensor located at the base for detecting interactions. 32

5.1 This figure displays the Unity editor interface, highlighting the main components integrated into the VR experience. Key elements include the 'Main Camera' for scene visualization, 'External Audio Output Device' for audio playback, 'Haptic Motor' for generating tactile feedback, 'Video Player' for video content delivery, and 'MCU' for managing data exchange with the Sankofa Interface. 35

5.2 User interacting with the Sankofa Interface while passthrough mode is enabled in VR. The inset in the upper left corner shows the passthrough view, allowing the user to see their surroundings while the Sankofa Interface is placed on the table, detected by the IR sensor. The passthrough mode is automatically disabled when the interface is picked up. 37

6.1 White-necked Rockfowl [13]. This is a rare bird species native to West Africa, known for its distinctive appearance and unique vocalizations. This bird inspired the sculpture and haptic feedback design for the Sankofa Interface, with various movements and sounds serving as a basis for the tactile sensations experienced by users in the VR storytelling experience. 43

6.2 This figure shows the original Macaron interface, which was later enhanced with additional features and updates to meet desired goals. 46

6.3 This figure shows the enhanced Macaron interface used for designing haptic feedback. Key features include the Audio Guide for separate visualization of audio waveforms, independent control over audio and haptic feedback output, and the ability to save and load haptic data independently. 47

List of Tables

6.1 This table presents the haptic designs and their corresponding waveforms developed for the Sankofa Interface. Each row details a specific haptic pattern, illustrating the waveform characteristics such as amplitude and frequency. . 45

Chapter 1

Introduction

Virtual Reality (VR) is emerging as a potentially transformative technology, which may significantly alter how we interact with digital content. By creating a sense of presence [136], VR applications enable users to feel as though they are truly "inside" the virtual environment. This sense of presence is achieved through various sensory inputs and other aspects including sense of control and agency, high-fidelity visual displays, spatial audio, and precise haptic feedback, all working harmoniously to simulate a realistic experience. Traditional VR applications have capitalized on this immersive quality to enhance user engagement, making activities like gaming [88, 56], virtual tours [40], and training simulations [89] more captivating and interactive. Virtual Learning Environments (VLEs) are a prominent example of VR applications that utilize the concept of presence to improve educational outcomes [103]. The integration of VLE into education allows for the creation of authentic tools where situated learning and assessment can take place, particularly in secondary school science classrooms, as evidenced by the development of a VLE prototype for assessing knowledge transfer [138]. During the COVID-19 pandemic, VLEs became essential, enabling educators to maintain communication and interaction with students, thus facilitating learning beyond traditional classroom settings [31]. For example, the use of Virtual Learning Objects, a digital tool designed to help students learn English for Specific Purposes in Columbia, has shown positive impacts on students' perceptions and improvements in linguistic competencies, demonstrating the potential of VLEs to motivate and enhance learning strategies [30].

Haptic feedback is a crucial element in the VR experience, providing tactile sensations that enhance the realism and interactivity of the virtual environment [58, 158, 127, 57]. By mimicking real-world touch sensations, haptic feedback can significantly enhance the sense of presence, making interactions feel more natural and intuitive [142, 113, 60]. In VR, hap-

tics can simulate textures, forces, and vibrations, adding a layer of realism that visual and auditory inputs alone cannot achieve. For instance, haptic rendering, involving computing forces and tactile sensations, is pivotal in creating realistic interactions for medical training and rehabilitation tasks. Deformable models have shown potential in improving motor skills and trajectory recollection [129]. Metamaterials in 3D-printed proxies can create flexible objects that alter tactile properties, extending the range of tactile experiences in VR [42]. Wearable tactile displays relocating haptic feedback away from the fingertip have been investigated for their impact on perceptual sensitivity, with findings suggesting that frequency modulation of vibrations results in more realistic sensations for coarser textures [47].

However, presence is not always desirable, particularly when dealing with content that is sensitive or emotionally charged [139]. Examples of such scenarios are institutional racism, abuse, or other forms of social injustice. In these scenarios, the strong emphasis on presence can sometimes lead to discomfort, distress, or even trauma, thereby necessitating a more nuanced approach to VR design. For instance, high levels of presence can evoke strong emotional reactions and physiological responses, such as increased heart rate and skin conductance, which are indicative of stress and discomfort [152]. This heightened sense of presence can be particularly distressing in scenarios designed to simulate traumatic events, as evidenced by studies showing that VR presentations of distressing scenes can lead to more vivid and emotionally intense intrusions compared to traditional on-screen presentations [9]. Moreover, the cognitive load required to maintain spatial presence can inhibit the processing of other information, potentially leading to cognitive overload and reduced recall, which can be distressing for users [2]. In response to this criticism, an alternative construct known as relational presence [121] has recently been proposed. Relational presence emphasizes the emotional and interpersonal connections between users and the content, focusing on fostering understanding and empathy without necessitating a strong sense of physical immersion.

Given that haptics are typically used to support presence, a significant question arises: How might we design haptics to support relational presence? This thesis explores how the design of haptic and tangible interaction, especially, vibrotactile (VT) feedback, can be tailored to support relational presence, particularly in VR applications, examining the specific characteristics and patterns of haptic feedback that are most effective in this context. The goal is to understand how haptic feedback can convey subtler, more nuanced sensations that support empathetic and reflective experiences, rather than just enhancing physical realism.

This research focuses on designing haptics specifically tailored to support relational presence by investigating VT's impact on people's experience in a VR environment. It

seeks to contribute to the broader field of VR design, particularly in educational settings where deep engagement with complex social issues is crucial. Through an iterative design and evaluation process, this research aims to provide actionable insights that could guide future developments in VR technology, making it not only an impressive tool for simulation but also a profound medium for education.

1.1 Contributions

My primary contributions to this thesis include:

- The development and implementation of a novel haptic interface "Sankofa Interface" designed to support relational presence in VR.
- Enhancement of Macaron [126], an open-source haptic editor, with improved user interface elements, advanced editing tools, and additional customization options to support the design and customization of haptic feedback patterns.
- Crafting haptic designs utilizing the enhanced features of Macaron to support relational presence in VR storytelling experiences.
- Development of a VR user interface using Unity to integrate the Sankofa Interface with storytelling experiences based on a restorative justice approach.
- The discovery and elaboration of the concept of physical re-embodiment through haptics to support relational presence in VR emerged from collaborative discussions with experts from diverse fields, including VR, dramatic arts, restorative justice, oral history, education, and social justice.

1.1.1 Sankofa Interface

The centrepiece of this research is the creation of a prototype haptic interface named Sankofa Interface. This interface is specifically designed to support relational presence in VR, offering a more nuanced and empathetic approach to dealing with sensitive content. The name "Sankofa" is derived from a Ghanaian Akan word which means "to go back and fetch it" symbolizing the idea of learning from the past to inform the present [51]. In the context of this research, the Sankofa Interface aims to provide a haptic feedback mechanism that fosters understanding and empathy, crucial for VLEs addressing issues

like institutional racism and abuse. By focusing on relational presence rather than physical presence, the Sankofa Interface aims to create a safe and reflective environment for users to engage with challenging content.

The Sankofa Interface incorporates three main components: a microcontroller, a vibration motor, and a proximity sensor. These components work together to deliver a sophisticated haptic feedback experience. The microcontroller serves as the core processing unit, receiving sound data from an external device via an inbuilt Bluetooth module. This data is then processed and sent to the internal Digital to Analog Converter (DAC), which is connected to the vibration motor. The vibration motor renders the vibrations, translating auditory information into tactile sensations that can be felt by the user. The proximity sensor adds an additional layer of interactivity, tracking Sankofa's position to trigger core functions inside the VR experience.

1.1.2 Macaron Development

Another significant contribution of this thesis is the substantial enhancement of Macaron [126], an open-source haptic editor. Macaron is utilized to design and customize haptic feedback patterns for various sound effects, a crucial aspect of creating immersive and emotionally engaging VR experiences. The enhancements made to Macaron are extensive, introducing new features that align with the goals of this research. These features include improved user interface elements, advanced editing tools, and additional customization options. The modifications and enhancements made to Macaron will be discussed in detail in subsequent chapters of the thesis, highlighting their importance and impact on the overall research objectives.

To complement the hardware components, I developed a software interface. This software interface is integral to the storytelling VR experience, which is based on a restorative justice approach. The VR experience aims to provide users with an immersive and reflective journey through stories that address issues of racism and abuse, encouraging empathy and understanding. The Unity-based interface ensures seamless integration with the Sankofa Interface, allowing for real-time synchronization of visual, auditory, and haptic feedback.

1.2 Outline of the Thesis

The rest of the thesis is structured into several chapters, each detailing the various aspects of the development and implementation of the Sankofa Interface. The outline is as follows:

- Chapter 2 reviews the relevant literature on presence in VR, virtual learning environments, haptic feedback, relational presence, and embodiment. It provides a foundation for understanding the theoretical frameworks and previous research that inform the development of the Sankofa Interface.

- Chapter 3 provides an in-depth overview of the Digital Oral Histories for Reconciliation initiative, including its educational and restorative goals. It describes the VR experience designed to educate users about the Nova Scotia Home for Colored Children, highlighting the project's focus on using oral histories and virtual reality to support reconciliation and promote historical consciousness.

- Chapter 4 details the design principles and construction process of the Sankofa Interface, including the selection of materials, hardware components, and the evolution from the initial design to the refined version. It also discusses the iterative development process and the integration of user feedback.

- Chapter 5 describes the development of the VR user interface using Unity, focusing on integrating the Sankofa Interface.

- Chapter 6 explores the conceptualization and implementation of haptic feedback, detailing the crafting of haptic designs including the extension of Macaron top support more nuanced designing haptic feedback patterns.

- Chapter 7 discusses the evaluation process for the Sankofa Interface, focusing on the planned and modified approaches due to feedback and ethical considerations, emphasizing the collaborative acceptance testing and real-world deployment outcomes.

- Chapter 8 presents a comprehensive discussion of the collaborative process, challenges, and theoretical considerations involved in developing the Sankofa Interface.

- Chapter 9 summarizes the key findings and contributions of the thesis. It outlines potential directions for future research and development, including advanced haptic technologies, expanded haptic vocabulary, user-centered design, and ethical guidelines.

Chapter 2

Background

This chapter explores the prior research that underpins this thesis. It delves into the concept of presence in VR, examining how immersive sensory inputs create a compelling sense of being "inside" the virtual environment. The discussion includes the application of VR in educational settings, particularly VLEs, and their impact on learning outcomes. It highlights the role of haptic feedback in enhancing realism and interactivity within VR environments. Additionally, the chapter addresses the challenges of using VR for sensitive content, introducing the concept of relational presence as a potential solution. It discusses the importance of re-embodiment in VR and its implications for relational presence. Finally, the chapter introduces the concept of "Sankofa" a term from the Akan language of Ghana, which symbolizes the importance of historical awareness and learning from the past. The Sankofa philosophy has an important influence on the design and implementation of the Sankofa Interface as a tool for fostering relational presence and empathy in VR.

2.1 Presence in VR

Presence in VR [73] refers to the perceptual illusion of being physically present in a non-physical world. It is a key goal in designing virtual environments, as high levels of presence can significantly enhance user engagement and the overall experience [109]. It is a multifaceted concept that encompasses physical [92], social [35], and co-presence [124], each contributing to the overall immersive experience. Physical presence refers to the sensation of being physically located in the virtual environment, which is often influenced by the system's technical specifications such as refresh rate, resolution, and degrees of freedom

(DoF). Social presence involves the feeling of being with others in the virtual space [84], which can be crucial for collaborative and multiplayer VR experiences. Co-presence, a subset of social presence, specifically refers to the mutual awareness of participants within the virtual environment [72].

According to Felnhofer and Kothgassner [43], presence and immersion are often confused but are distinct concepts. Immersion can be seen as an objective property of technology, characterized by features such as high-resolution displays, wide fields of view, and real-time motion tracking. Presence, on the other hand, is the subjective experience of "being there" in the virtual environment. They also highlighted the importance of user factors in the experience of presence. Psychological factors such as the suspension of disbelief and emotional engagement can significantly influence how users perceive and react to virtual environments. Understanding these factors is crucial for designing VR experiences that maximize presence while also being sensitive to the needs and experiences of different users.

The sense of presence is influenced by various factors, including the immersiveness of the technology and user-specific characteristics. Technologies that provide high levels of sensory input, such as head-mounted displays (HMDs) with stereoscopic vision and spatial audio [136], are typically more immersive and can lead to a stronger sense of presence. However, individual differences also play a significant role in determining the level of presence experienced by users. Age, for instance, has been shown to influence presence, with older participants reporting a higher sense of presence compared to younger ones [97]. Gender differences also emerge [54], with female participants generally experiencing a higher sense of presence than males. Cognitive abilities, such as those related to user-initiated motion [37], can predict presence scores, indicating that individual behaviors during VR experiences significantly impact the sense of being there. Susceptibility to motion sickness is another critical factor; it has a negative relationship with the sensory fidelity of presence, meaning that [23] higher motion sickness can reduce the sense of presence.

Peinl and Wirth [111] conducted an empirical cost-benefit analysis on the factors influencing presence in VR experiences, particularly focusing on the balance between effort and benefits in achieving high fidelity. Their study highlights that while factors such as visual quality, DoF, and realistic interaction significantly enhance presence, the relationship between effort and perceived presence is not always linear. High visual fidelity and 6 DoF substantially improve presence, but their study reveals that realistic interactions, although more complex to implement, yield significant gains in presence compared to simpler interactions.

Kim, Laine, and Suk [73] investigate the effects of presence in VR based on user charac-

teristics, specifically focusing on attention, enjoyment, and memory. Their study explores how factors such as gender, immersion level, and emotional valence influence these presence effects. Using a VR story presented through a head-mounted display (HMD) equipped with eye-tracking, they collected data from 53 university students. The results indicate that user characteristics significantly affect presence levels, with high immersion and positive emotional valence leading to greater attention, enjoyment, and memory retention. Notably, female participants and those with high immersion levels exhibited stronger presence effects.

Zhang et al. (2021) [155] explored the use of electroencephalography (EEG) to objectively measure auditory presence, traditionally assessed through subjective questionnaires. Their study involved reproducing urban soundscapes using an eight-loudspeaker setup to stimulate auditory presence, with presence levels evaluated both subjectively (via questionnaires) and objectively (via EEG). They discovered a significant correlation between the Theta/Beta (T/B) ratio from EEG data and subjective presence levels, suggesting that EEG could serve as a reliable tool for measuring presence in real-time.

2.1.1 Embodiment in VR

Embodiment in VR has attracted significant attention due to its profound impact on user experience, cognition, and emotional engagement. The sense of embodiment in VR encompasses three primary subcomponents: body ownership, agency, and self-location, which collectively contribute to the cognitive awareness of one's manifestation in a virtual environment. Zhang et. al has shown that the design of virtual hands and avatars plays a crucial role in inducing embodiment, with varying levels of realism affecting the subcomponents differently [154]. The concept of embodiment is not only pivotal in entertainment but also in serious applications such as education, training, and therapy. For instance, in serious games, the degree of presence and embodiment significantly influences learning outcomes and user engagement [11]. Moreover, the emotional implications of VR experiences are closely tied to the sense of embodiment, with strong emotional scenarios enhancing the feeling of being embodied in the virtual world [46]. This emotional connection is crucial for applications in medical therapy, such as phobia treatment, where the user's emotional response to the avatar's experiences can facilitate therapeutic processes.

Additionally, the embodiment in VR can be manipulated through multisensory stimulations, such as visuo-tactile and cardio-visual feedback, which have been shown to induce full-body illusions and affect components of bodily self-consciousness like self-location and perspective-taking [114]. The concept of bodily self-consciousness encompasses aspects

such as self-location and perspective-taking. These are essential components of our awareness of ourselves and our bodies in relation to the surrounding environment. Self-location refers to our ability to locate ourselves in space, while perspective-taking involves understanding our position and viewpoint in relation to other objects or individuals.

The interplay between embodiment and presence is also critical, as these processes often co-occur and share commonalities, leading to a more immersive and engaging VR experience [45]. In experiential marketing, the embodiment felt by users during VR experiences has been found to positively influence immersion, enjoyment, and consumer intentions, highlighting its potential to influence real-world behaviors [86]. Furthermore, the theory of embodied cognition, which posits that our body and intentional actions impact our perception and understanding of the world, has been extensively tested using VR systems, revealing that virtual embodiment can significantly affect design comprehension and cognitive processes [29]. In AR, the embodiment of virtual self-avatars is emerging as a promising area of research, with potential applications across various fields, although it remains less explored compared to VR [50].

2.2 Virtual Learning Environments

VLEs leveraging VR technology have reformed educational experiences by creating interactive and realistic scenarios that significantly enhance student engagement and learning outcomes. VR's immersive capabilities allow students to explore virtual models, historical reconstructions, and simulated experiments, providing a hands-on learning experience that traditional methods cannot match. For instance, VR can replicate complex and abstract STEM environments, enabling students to manipulate and understand intricate concepts that are otherwise impossible to visualize in a conventional classroom setting [83]. This immersive experience is particularly beneficial in fields requiring procedural knowledge and cognitive engagement, such as art education and higher education, where VR has shown a significant positive impact on student motivation and learning outcomes [20]. Additionally, VR's ability to simulate dangerous or urgent skill training scenarios offers a safe and effective way to practice skills that would be impractical or hazardous in real life [62]. The incorporation of non-verbal cues (NVCs) in VR learning environments further enhances realism and interpersonal communication, which are often lacking in traditional distance learning setups, thereby improving knowledge acquisition and the overall learning experience [69].

However, implementing VR in educational settings comes with its own set of challenges.. One major limitation is the need for high levels of fluidity and immersion; any deficiency in

these areas can significantly hinder learning outcomes and user experience [83]. Moreover, the accessibility of VR technology remains a concern, particularly for visually impaired students who may find it difficult to benefit from such environments without appropriate adaptations like voice feedback and voice commands [143]. Despite these challenges, the potential of VR to transform education is immense. It offers a new perspective on teaching methodologies and optimizes conventional teaching concepts by providing immersive, interactive, and imaginative learning situations [90]. During the COVID-19 pandemic, the importance of VLEs was underscored as they became the primary mode of education, allowing continuous learning despite physical restrictions [31]. The tactile stimulation and perceptual feedback systems in VR also contribute to active participation and engagement, making learning more effective and enjoyable [62]. As VR technology evolves, researchers and educators must address the existing challenges and explore innovative ways to integrate VR into educational curricula, ensuring that all students can benefit from these advanced learning environments [90].

2.2.1 Examples of VLEs that successfully utilize presence

One notable example is the use of immersive virtual reality (IVR) in production education and training, where a simple tool replica was developed to simulate different hand-held tools. This setup significantly improved the sense of presence, particularly in terms of experienced realism, which in turn positively impacted learning success [128]. Similarly, in the realm of social skills training, VR simulations have been designed to help trainees master difficult communicative situations. These simulations have been found to be as engaging and convincing as traditional role-play, underscoring the value of social presence in training social interactions [144]. Another compelling example is the use of VR headsets in noisy and distracting environments, which has been shown to increase presence and attention, although the actual memorization outcomes were higher for desktop screen users [110].

In the field of computer science education, immersive visualizations in VR environments have been used to teach complex concepts like asymmetric encryption and finite state machines. These environments foster a sense of presence that is influenced by both technological immersion and the emotional state of the user, contributing to improved learning outcomes [34]. Additionally, a study involving high school students playing an immersive 3D VR cell biology game found that spatial presence was linked to how students allocated their attention and their interest in the subject, rather than their prior knowledge or VR experience [145].

In the wine industry, immersive VR experiences have been used for sommelier training, where the role of immersion and social presence was found to be crucial for effective learning [104]. Furthermore, research involving graduate students in online immersive learning environments demonstrated that student engagement in these spaces can enhance their sense of presence and community, which are critical for successful learning outcomes [24]. Lastly, the use of environment-activated motion (EAM) in IVR experiences, such as playing with a virtual robot dog, has been explored, although it was found that EAM may not significantly impact the sense of presence, suggesting that future interventions should focus more on user interaction and environment design [36].

2.3 Haptic Feedback

Haptic feedback is a technology that simulates the sense of touch by applying forces, vibrations, or motions to the user. This technology is widely used in various applications, including prosthetics, electronic devices, and computing systems, to enhance user interaction and performance.

2.3.1 Types of Haptic Feedback

Haptic feedback encompasses various types, each offering unique sensory experiences and applications. One prevalent type is VT feedback, which uses vibrations to simulate touch sensations. This method is particularly effective in enhancing user presence and performance in VR environments, as demonstrated by a study where VT feedback outperformed other forms in terms of presence and task-related performance metrics [77].

Another type is force feedback, which provides resistance or force to simulate physical interactions. This feedback type is beneficial in VR for tasks like throwing and stacking, where it reduces execution time by providing a more realistic interaction [77].

Additionally, temperature feedback, which involves the use of heat and cold, can be used to convey information, as explored in sensory substitution devices for the visually impaired. This type of feedback can help in interpreting non-verbal cues during communication by remapping visual stimuli into tactile sensations [80].

In addition to technologies that focus on specific sensory modalities like vibration, force, and temperature, there are approaches designed to simulate complex environmental interactions. These complementary technologies enhance the realism and immersion of

virtual environments by replicating physical properties or providing passive haptic cues [122].

Passive haptics [39], for instance, involve the use of physical props or encountered-type haptic devices that users can touch or manipulate in the real world, which corresponds with their virtual counterparts. This approach helps bridge the gap between the virtual and physical worlds, making interactions in VR more intuitive and convincing [158].

Among the advanced methods for simulating physical properties, Magnetorheological [68] (MR) fluid-based feedback stands out. In this technology, the viscosity of MR fluid changes in response to a magnetic field, allowing for variable damping.

Wearable haptic devices also utilize these feedback types, including VT and force feedback, to improve user convenience and efficiency in various applications, from hand-worn to foot-worn devices [159]. Each type of haptic feedback offers distinct advantages, making them suitable for diverse applications in enhancing human-machine interaction and user experience.

2.3.2 Applications of Haptic Feedback in VR

Haptic feedback in VR has a wide range of applications, significantly enhancing user experience and interaction across various fields. VT haptic feedback has been shown to significantly improve prosthetic task performance for amputees by providing non-invasive tactile sensory feedback [15]. However, traditional haptic feedback systems are often unscalable, tethered, and non-retrofittable, limiting their accessibility and distribution. To address these challenges, a novel system called "Haptic Touch" [7] has been developed, featuring a wireless, retrofittable, and scalable design using flexible PCBs. This system includes a tactile sensing glove with 27 sensors and a haptic feedback armband with 6 vibration motors, both equipped with rechargeable batteries and wireless communication capabilities. Preliminary experiments with Haptic Touch demonstrated an 83% accuracy in two-point touch discrimination and improved object manipulation performance when using derivative-based haptic feedback strategies. Additionally, haptic feedback in computing systems can be tailored based on the utilization parameters of electronic pens, providing specific patterns of feedback to enhance user experience [137]. Advanced methods also integrate image information with motor vibrations to achieve customized, refined, and diversified haptic feedback in electronic devices [156].

In surgical education, haptic feedback is crucial for simulating tactile sensations during procedures [105], such as in a cervical laminoplasty, allowing trainees to practice and perfect their skills without compromising patient safety. This is achieved through affordable,

modifiable systems that combine VR imagery with haptic devices to replicate the feel of surgical tools and bone textures [10]. In spatial search tasks, bimanual haptic feedback has been shown to improve the accuracy and speed of spatial direction recognition, outperforming traditional sensory cues like spatial audio and visual arrows. This is particularly useful for tasks requiring precise spatial awareness and minimal head movement [49]. Additionally, haptic feedback enhances the immersive experience in VR by providing force-tactile feedback during natural gesture interactions, such as grasping and manipulating virtual objects. This leads to more accurate and efficient user interactions in virtual environments [22]. Handheld VR haptic controllers, like Bstick-Mark2, further expand the applications by enabling real-time monitoring and control of finger movements, allowing users to interact with virtual objects and environments more naturally and intuitively [74]. In augmented reality (AR), haptic feedback can be used to provide directional cues through VT signals, aiding in object location and prioritization without cluttering the visual space. This is particularly beneficial in human-robot teaming applications, where situational awareness and control interfaces are critical [3].

2.4 Challenges of presence in sensitive content

VR has emerged as a powerful tool for addressing sensitive content such as institutional racism [121], abuse, and social injustice by creating immersive experiences that foster empathy and provoke critical reflection. By immersing users in scenarios that critique structural racism and document social injustices, VR can cultivate the compassion and solidarity needed for positive social change [1]. For instance, the VR experience "injustice" places users in a racially charged situation where users witness police brutality and must make moral and ethical decisions, thereby exploring the emotional impact of VR compared to traditional film [25]. A pilot program at the Zucker School of Medicine and Northwell Health used a VR module to simulate experiences of racism and microaggressions, resulting in enhanced empathy among medical professionals and a commitment to improving cross-cultural communication and inclusion [123]. However, the rapid adoption of Mixed Reality (MR) technologies also raises concerns about potential misuse and ethical issues, such as the creation of abusive scenarios. This necessitates a critical examination of these technologies within the Human-Computer Interaction (HCI) community to develop strategies that mitigate negative impacts while maximizing their positive potential [55].

2.4.1 Design and Implementation Challenges

Creating VR experiences with sensitive content involves several technical and design challenges that need careful consideration to ensure ethical and effective outcomes. One primary challenge is balancing the immersive nature of VR with the potential emotional impact on users, especially in therapeutic settings such as aged care or mental health therapy, where predicting adverse reactions can be difficult [149]. Additionally, designing for sensitive narratives, such as those in human rights museums, requires strategies to avoid re-victimizing individuals while maintaining audience engagement and addressing technology gaps [16]. The complexity of user emotions, such as those encountered with Facebook's Memories feature, highlights the importance of understanding affective sense-making and the context in which sensitive content is viewed [98]. Furthermore, researchers working in sensitive areas like crisis and mental health face methodological, ethical, and emotional challenges, necessitating a collaborative approach to develop best practices and support systems for those involved in such research [18]. Finally, attention guidance techniques in Extended Reality (XR) must be carefully designed to manage user experience issues like cybersickness and ensure effective storytelling without overwhelming the user [78]. Addressing these challenges requires a multidisciplinary approach, incorporating insights from HCI, psychology, and design to create VR experiences that are both impactful and respectful of the user's emotional well-being.

2.4.2 Applications of VR dealing with Sensitive Content

VR has been increasingly utilized to address sensitive content such as institutional racism, abuse, and social injustice, leveraging its immersive nature to foster empathy and drive social change. One notable application is the immersive journalism of Nonny De La Pena, which covers critical issues like abortion rights, poverty, and suspect interrogation, aiming to raise awareness and stimulate empathy among viewers [27]. Similarly, the United Nations Virtual Reality (UNVR) Series, including the acclaimed "Clouds Over Sidra" VR film, has been instrumental in highlighting the plight of Syrian refugees, thereby promoting empathy and support for humanitarian causes. Research has shown that VR can significantly enhance intercultural sensitivity, as demonstrated in a study where participants exposed to VR showed a marked improvement in their emotional empathy and intercultural sensitivity, which was sustained better over time compared to traditional video exposure [87]. This aligns with the broader understanding that immersive media can serve as an "empathy machine," crucial for media literacy educators and social justice activists to critique structural racism and document social injustices effectively [1]. Additionally, VR's

application in therapeutic settings, such as diversional therapy in aged care and treatment for phobias and post-traumatic stress, underscores its potential to address sensitive issues while highlighting the ethical challenges and the need for careful co-design strategies [149]. Despite the promising applications, the impact of VR on children, particularly in gaming environments, remains a subject of ongoing research, with concerns about its effects on physical, cognitive, and psychosocial development [67]. For instance, Prolonged exposure to VR can lead to physical issues such as eye strain and motion sickness [19], which are particularly concerning for younger users whose bodies are still developing. Cognitive effects include potential difficulties in distinguishing between the virtual and real worlds, which could lead to confusion or altered perceptions of reality [148]. Psychosocial impacts include the potential for VR to influence children's behavior and social interactions [26].

2.5 Relational Presence

Relational presence is an alternative construct that emphasizes the emotional and interpersonal connections between users and the content, rather than just the physical or sensory immersion typically associated with traditional presence. Relational presence in VR is a multifaceted concept that has garnered significant attention across various domains, including education, virtual work, and serious games. In educational settings, VR has been explored for its potential to enhance relational pedagogies, particularly in early childhood education. A study co-designed a VR game scenario to simulate interactions with a virtual infant, finding that learners quickly became sensorially engaged and demonstrated important relational skills [151]. This aligns with broader research indicating that the sense of presence in VR can significantly impact learning outcomes, as evidenced by a systematic review of 140 studies over 24 years, which highlighted the need for further exploration of this relationship [76]. In the realm of virtual work, co-presence—feeling integrated and connected with team members—has been identified as a critical factor for productivity and relationship building. A comprehensive literature review of 34 journal articles emphasized the importance of aligning co-presence technology with job characteristics to enhance virtual work environments [115]. Similarly, in serious games, presence and embodiment are key dimensions that influence user experience and learning. An in-depth analysis of existing studies revealed that while these concepts are well-studied in video games, their application in serious games remains underexplored, suggesting a need for further research to understand their impact on educational and training outcomes [11].

While traditional notions of presence focus primarily on physical and sensory immersion, the concept of Relational presence [121] shifts the traditional focus of presence in

VR from physical immersion to the emotional and interpersonal connections between users and content. The Digital Oral Histories for Reconciliation (DOHR) [135] project aimed to create a VLE that fosters a deeper understanding of historical injustices, particularly systemic racism, by connecting learners emotionally and intellectually with the lived experiences of those who suffered these injustices. Unlike traditional VR environments that focus on creating a convincing illusion of being in a particular place, relational presence emphasizes the user's awareness of the narrative's emotional context and their role as an empathetic witness rather than a passive observer.

2.6 Sankofa

Sankofa, a concept derived from the Akan people of Ghana, embodies the idea of looking back to retrieve valuable knowledge from the past to inform the present and future. This principle is vividly illustrated in various domains, including film, education, and health. Haile Gerima's film [85] "Sankofa" exemplifies this by using a fictional narrative to explore the trans-Atlantic slave trade, emphasizing the importance of historical memory and the African Diaspora's resilience and redemption. In education, the Sankofa approach has been employed to decolonize and localize peacebuilding efforts in Ghanaian classrooms, integrating Indigenous perspectives to address historical injustices and promote peace education competencies. This approach is also reflected in the Sankofa Drum and Dance Ensemble [59], which engages elementary students in Ghanaian music, fostering cultural appreciation and social cohesion. Additionally, the concept has been adopted in higher education to create a culturally relevant teaching paradigm at a Historically Black University, addressing low retention and graduation rates by incorporating ethnocentric pedagogy and global perspectives [91]. In health, the Sankofa pediatric HIV disclosure study in Ghana [120] highlights the importance of culturally sensitive interventions to improve the mental health and well-being of HIV-infected children and their caregivers, demonstrating significant reductions in depression scores post-intervention [117]. The broader philosophical implications of Sankofa are discussed in the context of African traditional education, advocating for the integration of historical wisdom and Indigenous knowledge systems to address contemporary challenges and foster spiritual recovery and reconciliation [133, 101]. Furthermore, the discovery of Sankofa pyrenaica [96], a new type of dinosaur egg, underscores the concept's relevance in paleontology, linking past and present through the evolutionary connections between birds and nonavian theropods.

Chapter 3

Design Context: Digital Oral Histories for Reconciliation

The DOHR project serves as a pivotal design framework in this thesis, illustrating the application of haptic technology in VR to support relational presence. This chapter delves into the DOHR project to provide a comprehensive understanding of its educational and restorative objectives, and how these informed the design of the Sankofa Interface. By exploring the historical context of the Nova Scotia Home for Colored Children (NSHCC), the development of the VR experience, and the project's focus on fostering historical consciousness and empathy, we aim to contextualize the design choices made throughout this research. The in-depth examination of DOHR not only showcases the practical implementation of the concepts discussed in previous chapters but also highlights the unique challenges and opportunities presented by using VR and haptic feedback in sensitive content. This contextual framework sets the stage for understanding the subsequent technical and theoretical discussions in this thesis.

3.1 Overview

The DOHR initiative aims to educate Grade 11 students about the NSHCC (Figure 3.1). Established in 1921, the NSHCC was a segregated welfare institution for African Nova Scotian children, where residents endured institutionalized racism for over 70 years. DOHR collaborates with former residents to co-design a curriculum that shares their experiences as part of the restorative inquiry into the Home. The curriculum's goal is to use former

residents' oral histories to enhance students' understanding of institutionalized racism and foster better community relations. Piloted in two Halifax area schools in October 2019, the project was introduced at a symposium where attendees learned about the curriculum and initial findings. Former residents discussed their motivations for the project, while other DOHR members presented insights on using oral history—first-person accounts of past experiences—as a restorative educational tool to address historical injustices [94]. The symposium also covered how historical thinking lessons help students develop a historical consciousness, aiding them in making sense of the past to inform their present and future [81]. Additionally, DOHR's use of virtual reality to support reconciliation follows pedagogy-led design principles, emphasizing educational goals over technological ones. This project is notably the first history education initiative focused on first-person narratives to promote reconciliation for African Nova Scotians.



Figure 3.1: The Nova Scotia Home For Colored Children (Reference: Nova Scotia Archives Library Brookbank 1990-191)

3.2 The VR Experience

The VR experience (Figure 3.2) is designed to facilitate learning through historical thinking, oral history education, and restorative learning principles, with a duration of thirteen to fifteen minutes. Users will utilize a Meta Quest VR headset and start with a 360º documentary-style video that introduces three storytellers at the current site of the care institution. These storytellers will share accounts of neglect, abuse, and resilience. The narrative will be enriched by a combination of 3D graphics, 360º and 2D video, images, environmental and spatially-located sound, voiceover narration, and text. The experience ends with students crafting a "restorative plan," prompting them to contemplate their learning and ponder their role in addressing the historical harms rooted in systemic racism.

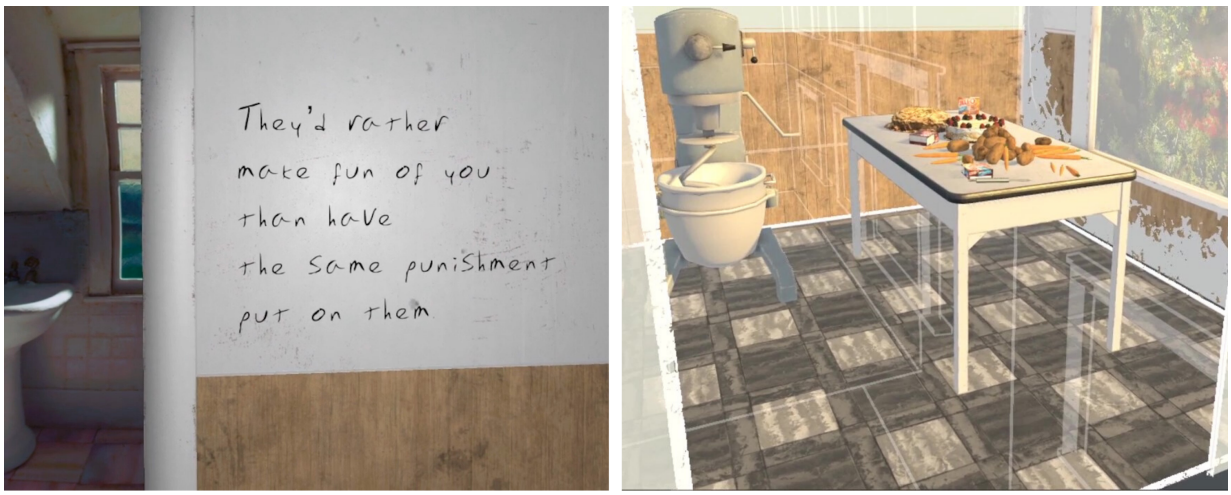


Figure 3.2: Screenshots from the DOHR VR experience. The VR experience employs a combination of 360-degree video, immersive 3D graphics, and contextual images, allowing users to explore these recreated environments in a deeply engaging and reflective manner.

3.3 Educational and Restorative Goals

The DOHR project is part of the former residents' broader "Journey to Light," which encompasses sharing their stories and working towards restoration and reconciliation. The project emphasizes restorative principles, which directly inform the design decisions of

the VR experience. The visual style transitions from 360^{o} video in the introductory and concluding scenes to a mixed-mode, impressionistic representation of lived experiences in a real-world environment. This approach avoids using avatars and limits interactivity to observational opportunities, ensuring that story events are not explicitly portrayed but rather narrated with the storytellers' voices positioned close to the listener.

The restorative approach of the DOHR project emphasizes healing, understanding, and community engagement, guiding the design process of the VR experience. This approach prioritizes the narratives of former residents, using their personal histories as powerful tools for education and reflection. By focusing on relational presence, the project seeks to create an environment where users not only witness the stories of trauma and resilience but also engage with them thoughtfully and empathetically. This emphasis on empathy and understanding shapes the design decisions, from the development of the haptic feedback mechanisms to the overall narrative structure of the VR experience.

The incorporation of haptic technology, specifically through the Sankofa Interface, is a considered choice to enhance the emotional and cognitive engagement of users through relational presence. The tactile sensations provided by the interface are designed to mirror the emotional tone and depth of the stories, providing a somatic connection that deepens the user's understanding and empathy. The restorative justice principles embedded in the DOHR project ensure that the design remains sensitive to the content's gravity and the users' emotional well-being. By creating a space for reflective engagement rather than immersion, the project aligns with broader goals of historical consciousness and societal healing.

3.4 Relational Presence

The desire for incorporating haptic technology into the DOHR project arose from the need to enhance the emotional and cognitive engagement of users. Unlike traditional VR experiences that emphasize immersion and presence, the DOHR project aims to foster relational presence. This concept prioritizes the user's role as a witness rather than a participant, focusing on creating a space for reflection and empathy. This approach necessitates that any haptic or tangible interfaces be designed thoughtfully and nuanced to align with the project's constraints and goals. Despite these constraints, the storytellers and team members were enthusiastic about exploring new technologies.

Haptic technology was chosen for its ability to convey subtle, non-verbal cues that complement the visual and auditory components of the VR experience. By mirroring

the emotional tone and depth of the stories, the tactile sensations help users connect with the content on a somatic level. This approach aligns with the project's broader goals of fostering historical consciousness and promoting a thoughtful engagement with the narratives. The integration of haptic feedback is not a technological enhancement but a deliberate design choice that reflects the project's commitment to restorative justice principles and the respectful handling of sensitive content.

By focusing on relational presence and restorative principles, the DOHR project provides a unique educational tool that allows users to engage deeply with the historical and emotional context of the care institution. This thoughtful design aims to foster empathy, reflection, and a sense of responsibility toward addressing historical injustices.

Chapter 4

Physical Prototype

The development of the Sankofa Interface required a thorough exploration of both conceptual and technical design elements. This chapter details the design principles, construction process, and iterative refinement of the physical prototype. By focusing on a tangible interface, the project sought to bridge the gap between virtual and physical experiences, enhancing the overall immersion and emotional engagement of users.

4.1 Sankofa Interface

The Sankofa Interface was developed to enhance accessibility and engagement with the DOHR narrative stories in VR. This interface employs haptic interaction to provide users with a more meaningful VR experience, promoting self-awareness, learning, and reflection.

The Sankofa Interface was created through a collaborative effort that involved using theoretical literature and studies in restorative justice, virtual reality, and haptics. The process included participants from different fields such as restorative justice, virtual reality, dramatic arts, oral history, social justice, and education. The design of the Sankofa Interface was improved through iterative development and continuous critique of design concepts.

Initially, we formed connections with the DOHR team members and gained insight into each other's areas of expertise. To understand the structure of each story and how users would interact with the stories, the haptics team explored the DOHR project developed by other team members. At the outset of the project, the team convened multiple times

online to establish rapport, comprehend the project's objectives, and introduce the concept of haptics to the rest of the team. These virtual meetings were essential for laying the groundwork and aligning the diverse expertise of the individuals involved, including those from restorative justice, virtual reality, dramatic arts, oral history, social justice, and education. The discussions during these sessions were comprehensive, covering various aspects of the DOHR project and its goals.

To build on these initial interactions, the team arranged an in-person meeting to further deepen the collaborative process. This face-to-face gathering was pivotal, allowing team members to engage more personally and explore the Sankofa Interface's potential applications in the VR experience. The hands-on nature of this meeting enabled a more interactive exchange of ideas and facilitated a deeper understanding of the design goals. It also provided an opportunity to introduce other team members to haptic technology through demonstrations and prototypes.

During these sessions, numerous aspects of the Sankofa Interface were discussed, including restorative justice principles, relational presence, and the design considerations necessary to create an impactful experience. The diverse perspectives and expertise of the team members enriched the conversation, leading to a well-rounded understanding of the project's challenges and opportunities. This collaborative environment was crucial in refining the design concepts, ensuring that the final interface would be well-aligned with the project's educational and restorative objectives.

During the workshops, we introduced several Sankofa objects to offer collaborators further opportunities for involvement in the design process. These objects were constructed using different materials, shapes, and sizes. This hands-on approach allowed for a more interactive and inclusive design process, ensuring that the final interface was well-aligned with the project's educational and restorative goals.

By leveraging the collaborative efforts of a diverse team and incorporating iterative design principles, the Sankofa Interface was developed to provide a rich, engaging, and educational VR experience that supports the DOHR project's mission of promoting historical consciousness and reconciliation through immersive storytelling.

4.2 Design Goals

The Sankofa Interface was developed with specific design goals to enhance the educational and emotional impact of VR storytelling within the DOHR project. These design goals

focus on integrating touch with storytelling, enhancing relational presence, and creating deeper connections between users and the narratives.

D1: Integrating Touch with Storytelling: The Sankofa Interface aims to integrate touch sensations with the storytelling process in VR. This integration is achieved by providing meaningful haptic feedback that corresponds to key moments in the narrative, reinforcing relational presence and enhancing the overall immersive experience. The haptic feedback in Sankofa is inspired by the sounds produced by the White-necked rockfowl bird found in West Africa. These sensory cues include tail flicks, wing movements, head bobs, bird calls, and footsteps, among others. By translating these natural movements and sounds into tactile sensations, the interface creates a multisensory experience that deepens users' engagement with the story. As users watch the VR stories, the haptic feedback helps to emphasize significant moments, ensuring that the physical sensations are synchronized with the emotional and narrative arcs of the stories. This integration not only enriches the storytelling process but also makes the VR experience more memorable and impactful.

D2: Enhancing Relational Presence: A primary design goal of the Sankofa Interface is to support relational presence, which emphasizes the emotional and interpersonal connections between users and the content. The haptic feedback from Sankofa serves as a constant reminder of users' physical presence and their role as witnesses to the stories being told. By providing subtle disruptions, such as gentle vibrations or tactile pulses, the interface keeps users aware of their responsibility to engage with and reflect on the narratives. These physical sensations act as cues that draw users' attention back to their role in the VR experience, preventing them from becoming passive observers. Instead, they are encouraged to actively participate in the storytelling process, fostering a sense of empathy and understanding. This heightened relational presence helps users to connect more deeply with the stories and the individuals sharing their experiences, promoting a more profound and reflective engagement with the content.

D3: Creating a Deeper Connection: The Sankofa Interface is designed to align haptic feedback with the emotional and narrative arcs of the stories. For instance, the sensation of the bird's heartbeat or breathing can constantly remind its presence with the user, providing comfort during emotionally intense moments, while the bird's cooing can signify a welcoming presence at the beginning of the story. These haptic cues are designed to mirror the emotions conveyed in the stories, allowing users to physically feel the impact of the narrative. This multisensory approach helps to bridge the gap between the virtual and physical worlds, making the VR experience more immersive and emotionally resonant. By aligning haptic feedback with the storytelling process, the Sankofa Interface enhances users' emotional connection to the narrative, fostering a deeper understanding and empathy for the experiences being shared.

D4: Accessibility: The design of the Sankofa Interface prioritizes accessibility and ease of use, making the experience inclusive for individuals with varying levels of familiarity with VR technology. The interface is designed to be intuitive, reducing the need for complex VR controllers and ensuring that users can easily interact with the VR content. This approach is particularly important for accommodating users with different physical abilities and ensuring that the VR experience is accessible to a wide audience. The Sankofa Interface, focusing on simplicity and user-friendliness, aims to create an engaging and accessible experience for all participants, regardless of their prior experience with VR technology.

4.3 Interaction Design

The Sankofa Interface serves as a critical mediator and control interface for the VR storytelling experience within the DOHR project. The interaction design (Figure 4.1) for the Sankofa Interface underwent significant changes throughout the project's development, influenced by the design goals and iterative feedback from the DOHR team. Initially, the design concepts focused on incorporating various interaction methods, including the potential use of physical buttons. However, as the project progressed, the transition to gesture-based interaction became the preferred approach, integrating the use of proximity sensors to enhance user experience and accessibility.

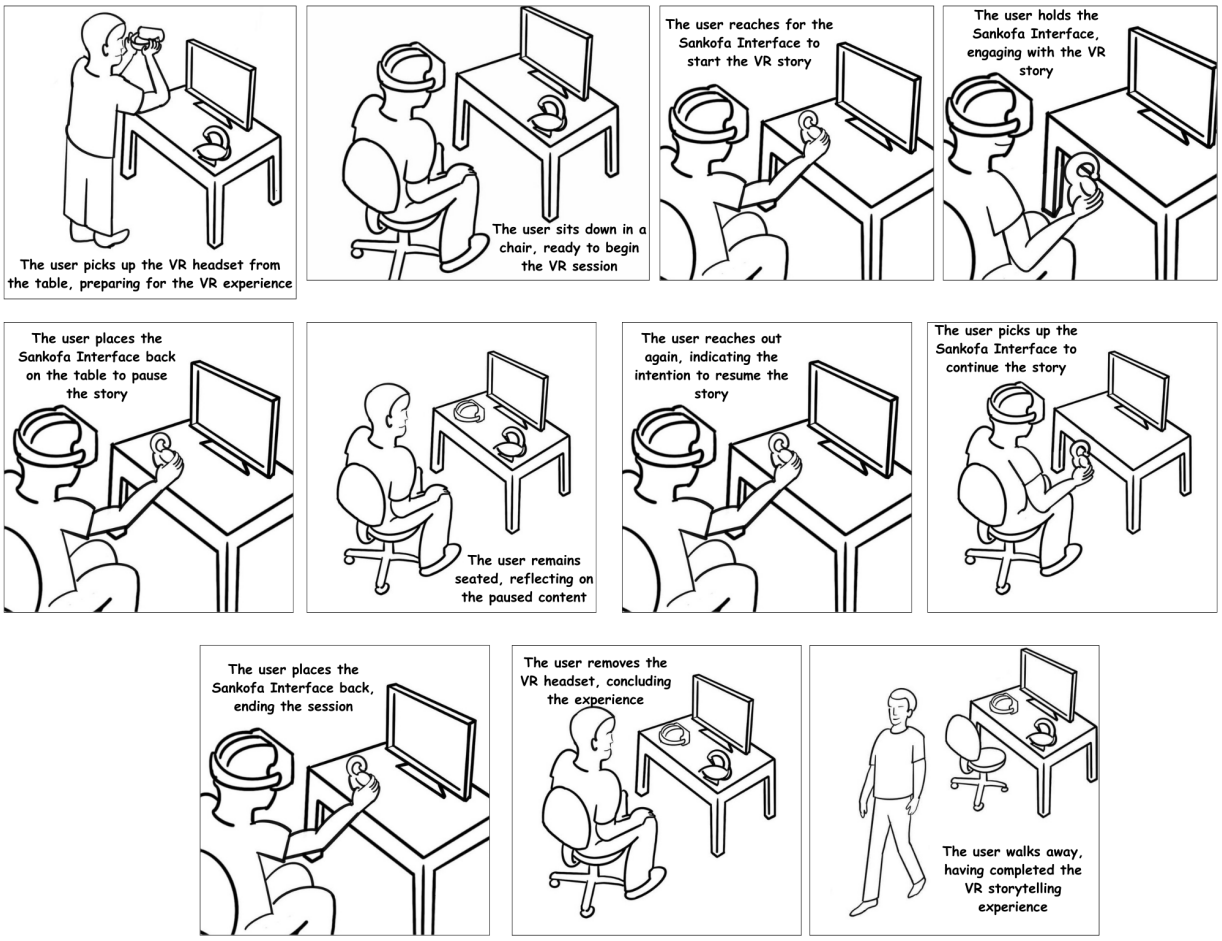


Figure 4.1: Interaction Flow with the Sankofa Interface in the DOHR VR Experience. This storyboard illustrates the sequence of user actions, from setting up and starting the VR story by picking up the Sankofa Interface to pausing and resuming the narrative by placing the interface on the table.

4.3.1 Intial Design Concepts and Transition to Gesture-Based Interaction

In the early design discussions, the Sankofa Interface was envisioned to include a range of interactive features to facilitate user control over the VR experience. One of the primary considerations was the inclusion of a physical button that users could press to immediately

stop the VR experience if they felt uncomfortable or distressed by the content. This feature was deemed crucial, given the sensitive nature of the narratives presented, which included themes such as institutional racism and abuse.

The design aimed to provide users with an intuitive and tangible method of navigating the VR content, with controls for starting, pausing, and resuming the story. The concept of using physical buttons was considered to offer a straightforward and accessible interface, particularly for users who might not be familiar with VR technology. However, as the design process continued, it became apparent that physical controls could pose challenges. The use of VR headsets limits users' ability to see and manipulate physical objects accurately, potentially leading to discomfort or confusion. This realization prompted a reconsideration of the interaction methods to ensure a more seamless and inclusive user experience.

Following further discussions and feedback from the DOHR team, the design direction shifted towards a gesture-based interaction model. This approach was chosen to simplify the user interface and enhance accessibility. The gesture-based interaction model introduced the use of proximity sensors to detect the surface on which the Sankofa Interface was placed. The primary function of these sensors was to identify when the device was placed on or lifted from a desk, triggering corresponding functions such as starting, pausing, or resuming the VR experience.

The transition away from physical buttons was driven by the desire to create a more natural and immersive interaction method. The proximity sensors allowed users to engage with the VR content through simple gestures, such as placing the Sankofa Interface on the table to pause the narrative or lifting it to resume. This design choice eliminated the need for physical buttons, reducing potential distractions and maintaining the user's focus on the narrative.

The inclusion of proximity sensors as part of the gesture-based interaction model provided several benefits. It allowed for a more fluid and seamless interaction. Users could interact with the Sankofa Interface in a way that felt more organic and less intrusive. This design element also contributed to the accessibility of the interface, making it easier for users of all abilities to engage with the VR experience.

The iterative feedback loop with the DOHR team played a critical role in refining these design decisions, ensuring that the final product was both functional and sensitive to the needs of its audience.

4.3.2 User Comfort and Accessibility

The design also prioritized user comfort and accessibility. Users are seated throughout the VR experience to minimize the risk of cybersickness and enhance overall comfort. This seated arrangement is particularly beneficial for individuals who use wheelchairs, ensuring that the interface is accessible to a diverse user base. Additionally, by keeping users seated, the design deters unnecessary movement within the physical space, reducing space requirements and potential hazards.

The focus on seated interaction also aligns with the goal of creating a safe and controlled environment where users can fully engage with the VR narratives without distractions or discomfort. This approach underscores the importance of considering physical comfort and accessibility in the design of VR interfaces, ensuring an inclusive and engaging experience for all users.

4.3.3 Refined Interaction Design

The refined design of the Sankofa Interface prioritizes simplicity and ease of use, allowing users to interact with the VR storytelling experience (Figure 4.2) seamlessly. The following interaction methods were implemented to facilitate an intuitive user experience:

- **Play:** Users can initiate the VR story by simply picking up the Sankofa Interface. This action is natural and straightforward, eliminating the need for complex button presses or touch commands. The physical act of lifting the object symbolizes engagement and readiness to begin the narrative journey.
- **Pause:** To pause the narrative, users place the Sankofa Interface on a table. This gesture serves as a natural way to interrupt the flow of the story, providing an easy method for users to take a break or collect their thoughts. The design leverages the simple action of placing the object down, which intuitively signals a pause in the experience.
- **Resume:** Once paused, the story can be resumed by picking up the Sankofa Interface again. This continuity ensures that users can effortlessly re-engage with the narrative without unnecessary disruptions. The simplicity of this gesture-based control system helps maintain the user's focus on the story rather than the mechanics of the interface.

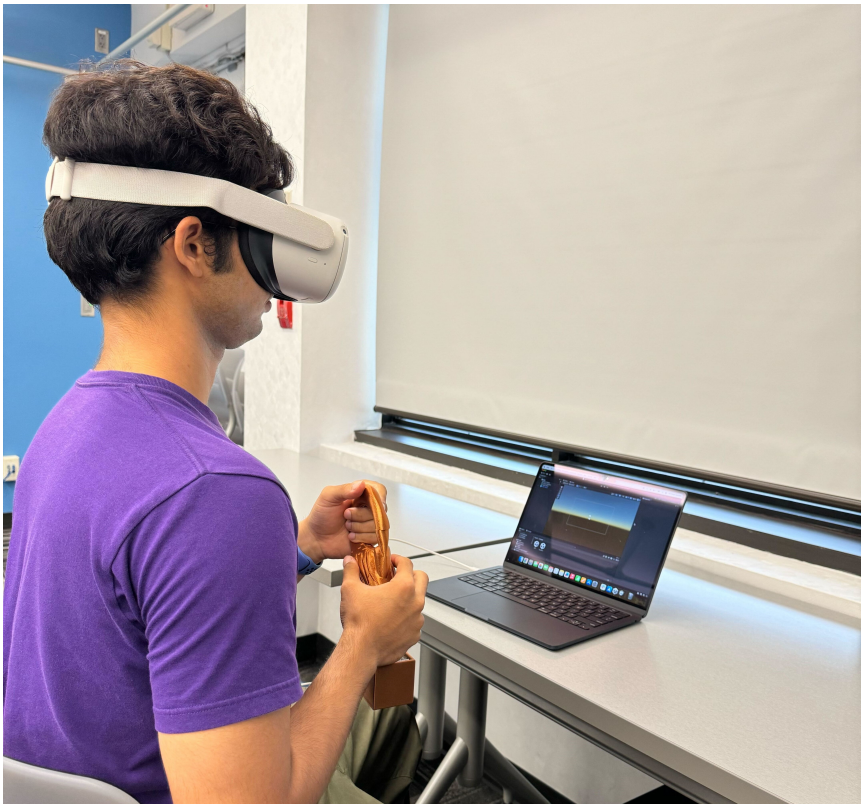


Figure 4.2: The figure shows a user, equipped with a VR headset and the Sankofa Interface during a VR storytelling experience.

4.4 Construction

The construction of the Sankofa Interface combined cutting-edge technologies (haptic feedback mechanisms, optimized 3D printing with high-resolution materials like resin, and integrating microcontrollers and proximity sensors) with user-centric design principles to create an empathetic and engaging VR experience. This section details the stages of construction, from initial concept to final implementation, highlighting the interdisciplinary collaboration and iterative development that were integral to the project's success.



(a) (b)

Figure 4.3: The figure displays (a) the original wooden Sankofa sculpture provided by the DOHR team. This intricately carved figure served as the inspiration for the design of the Sankofa Interface, symbolizing the project's emphasis on historical awareness, reflection, and the importance of learning from the past, (b) Collection of Sankofa statues printed using different materials, showcasing the variety in texture, color, and finish.

The DOHR team provided us with a wooden sculpture of the Sankofa (Figure 4.3a), which we later scanned and modified to mount the hardware components inside it. The 3D model of the Sankofa was printed using different materials, including PLA (polylactic acid), TPU (thermoplastic polyurethane), and ABS (acrylonitrile butadiene styrene). After providing the DOHR team with the 3D models made from these materials (Figure 4.3b), we concluded that the resin print was preferred. The team appreciated the resin model for its detailed texture, smoothness, weight, and overall feel when held.

4.4.1 Sankofa Interface Version 1 (SV1)

The first version of the Sankofa Interface, SV1 (Figure 4.4), featured a separately built base housing an infrared (IR) sensor. The choice of the IR sensor over other types was

driven by its precision in detecting proximity and movement, which are crucial for ensuring responsive interaction with the VR environment. IR sensors are less affected by ambient light variations and offer reliable performance in detecting hand movements and object placements, making them ideal for this application.

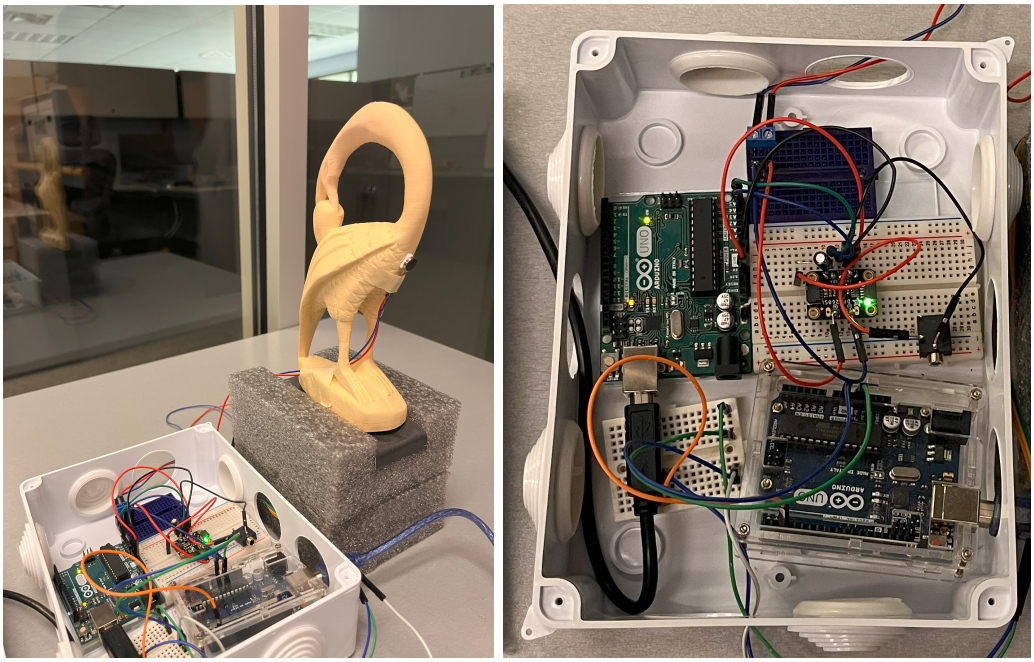


Figure 4.4: Sankofa Interface Version 1 (SV1). The left image shows the 3D-printed prototype of the Sankofa object, designed to house the hardware components. The right image provides a closer look at the internal electronics, including the Arduino UNO microcontroller and associated circuitry, contained within a junction box.

To evaluate the tactile feedback mechanism, we tested the SV1 with different types of motors, including Linear Resonant Actuators (LRA) and Eccentric Rotating Mass (ERM) motors. Each type of motor has unique characteristics: LRA motors provide precise and high-frequency vibrations, which are essential for detailed haptic feedback, while ERM motors offer stronger and more generalized vibrations, suitable for broader feedback applications. Through extensive testing, we aimed to determine which motor type produced the desired tactile output that could effectively enhance the storytelling experience.

Powering the electrical components of the SV1 was an Arduino UNO contained within a junction box. This microcontroller was chosen for its versatility and ease of use in

prototyping. The Arduino UNO facilitated the integration and control of various hardware components, enabling quick iterations and adjustments during the development process.

The DRV2605 haptic motor controller, equipped with an in-built audio-to-vibration functionality, played a critical role in controlling the vibration motors. This controller allowed us to convert audio signals into corresponding vibration patterns, enabling the Sankofa Interface to produce haptic feedback that synchronized with the VR narratives.

4.4.2 Sankofa Interface Version 2 (SV2)

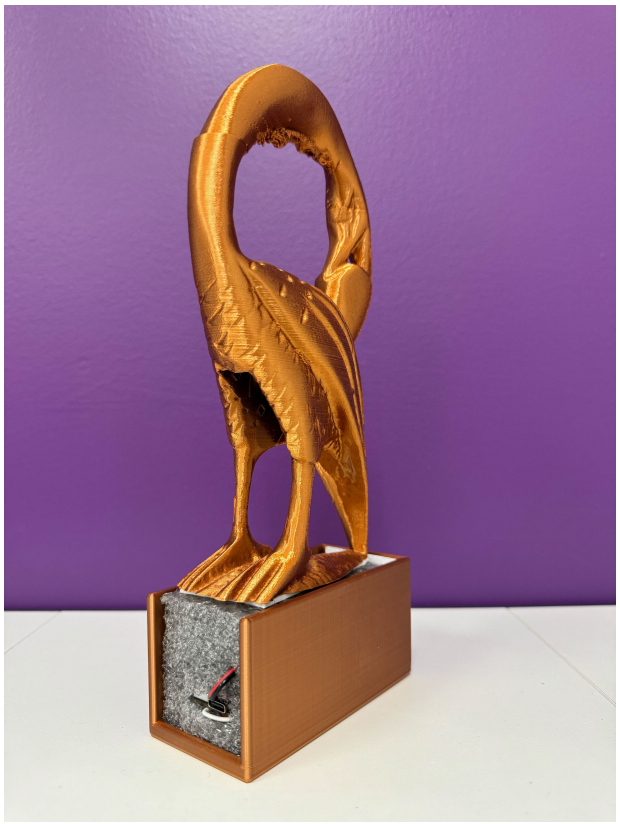


Figure 4.5: This iteration of the Sankofa Interface features an integrated design with all hardware components housed within the base, eliminating the need for a separate junction box. The device includes a cavity inside the model to accommodate the haptic motor, with an infrared sensor located at the base for detecting interactions.

We demonstrated SV1 to the DOHR team, whose feedback included the decision to drop the LRA/ERM motors. The primary issues were the lack of synchronization between the voice narratives of the storytellers and the vibrotactile feedback, which compromised the overall experience, and the difficulty in achieving a level of haptic feedback that would adequately support relational presence. The LRA motors were found to be limited in their versatility and unable to produce the specific resonant frequencies required to accurately convey the nuances of the voice input. To address these concerns, we decided to use a more advanced haptic motor—the TacHammer Drake from Titan Haptics. The TacHammer Drake is known for its high-fidelity haptic feedback, capable of delivering a wide range of tactile sensations with precise control. This motor can generate more dynamic and varied haptic responses, significantly enhancing the immersive quality of the VR experience.

Alongside the TacHammer Drake, we utilized Titan Haptics' own microcontroller unit (MCU), Titan Core. The Titan Core is a compact, 32-bit ESP32 processor, chosen for its small size, powerful processing capabilities, and ease of integration with haptic motors. This microcontroller allowed us to seamlessly incorporate the haptic feedback system within the Sankofa Interface, ensuring smooth operation and high performance.

We also modified the 3D model of the Sankofa Interface to include a cavity inside its belly to fit the haptic motor and redesigned its base to accommodate the IR sensor and MCU. Unlike SV1, which had a separate junction box and a base with positioning limitations, SV2 (Figure 4.5) is a single entity housing all the hardware internally. The IR sensor, now integrated into the base, enables the interface to be placed anywhere on the table to toggle play/pause functions, enhancing the user's interaction with the VR experience.

Throughout the construction process, iterative development and user feedback were essential. Each version of the Sankofa Interface underwent rigorous testing and evaluation to ensure that it met the project's goals. Feedback from the DOHR team and potential users informed subsequent design iterations, leading to continuous improvements in functionality, usability, and user experience with suggestions to improve the audio-to-vibration functionality, which will be discussed in a later section.

This iterative approach allowed us to refine the tactile feedback mechanisms, optimize sensor placement, and improve the overall design of the interface. The collaboration between engineers, designers, and the DOHR team ensured that the final product (SV2) was not only technically robust but also aligned with the educational and emotional objectives of the VR storytelling experience.

Chapter 5

Software Interface

The software interface brings together the various elements of the VR experience in the DOHR project. This chapter details the development and integration of the software aspects that enable the Sankofa Interface to function within the VR environment. By leveraging Unity's capabilities and advanced programming techniques, I was able to create a cohesive system that manages video playback, haptic feedback, passthrough mode in VR, and user interactions. This chapter discusses the design and implementation of the VR user interface, the audio-to-vibration feature, the passthrough mode for enabling real-world visibility, and the necessity of having independent control over audio and haptic elements. These components work in harmony to enhance the overall user experience, ensuring that the haptic feedback is not only synchronized with the narrative but also tailored to support the project's goals.

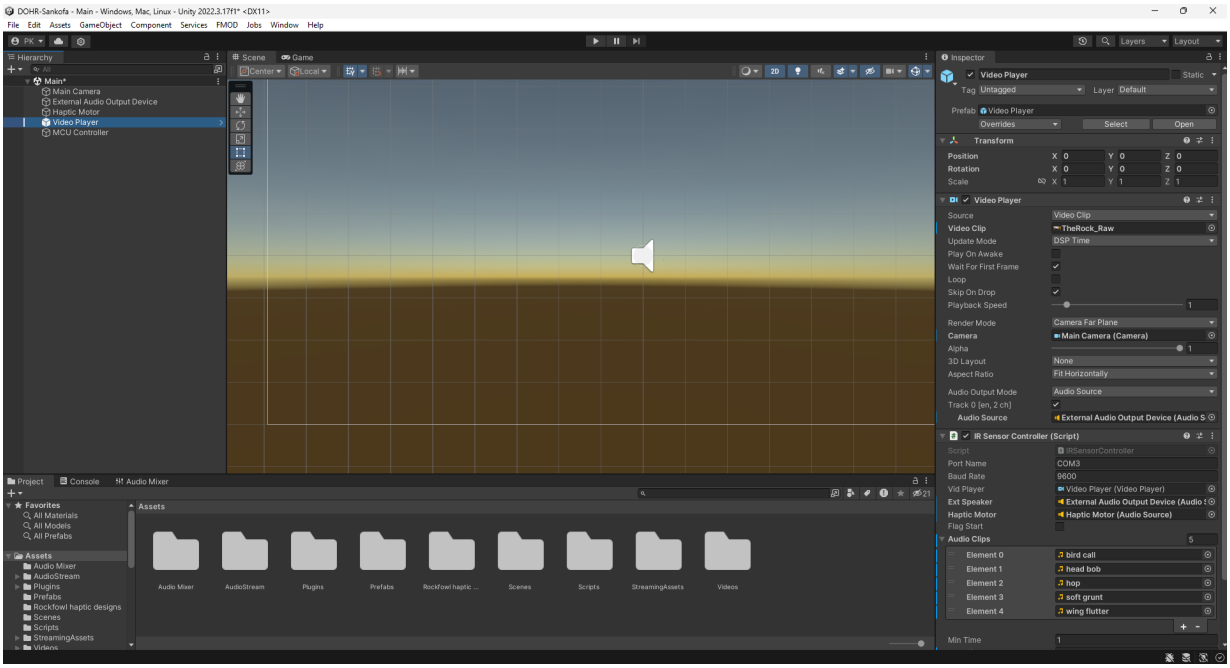


Figure 5.1: This figure displays the Unity editor interface, highlighting the main components integrated into the VR experience. Key elements include the 'Main Camera' for scene visualization, 'External Audio Output Device' for audio playback, 'Haptic Motor' for generating tactile feedback, 'Video Player' for video content delivery, and 'MCU' for managing data exchange with the Sankofa Interface.

5.1 User Interface

I developed a comprehensive VR user interface (UI) (Figure 5.1) using Unity to integrate the Sankofa Interface into the DOHR project's VR experience. The UI is designed to manage various components and interactions within the virtual environment, ensuring a smooth and immersive experience for users. Key elements of the Unity scene include:

- **Video Player:** The Video Player is a central object in the Unity scene, responsible for streaming and displaying the video content within the VR environment. This component is crucial for delivering the narrative visuals and ensuring that the video playback is synchronized with other sensory elements, such as audio and haptic feedback. The Video Player supports various video formats and can be configured to play specific clips based on user interactions with the Sankofa Interface.

- **Haptic Motor:** The Haptic Motor object in the scene is tasked with processing the input WAV (Waveform Audio) files that are converted into vibrotactile feedback signals. This component plays a pivotal role in enhancing the sensory experience by translating audio cues into tactile sensations. The WAV files contain the audio frequencies mapped to specific vibration patterns, which I carefully designed to enhance relational presence in VR. This ensures that users can feel the vibrations in a way that complements the audio elements of the story, fostering a deeper connection and engagement with the narrative.

- **Microcontroller Unit (MCU):** The MCU manages the communication between the Unity application and the microcontroller unit embedded inside the Sankofa Interface. This component is responsible for sending and receiving data to and from the MCU, facilitating real-time interaction between the user and the virtual environment. The MCU handles various tasks, including processing signals from the IR sensor attached to the Sankofa. The IR sensor's data is used to trigger specific events, such as enabling and disabling the passthrough mode, or play/pause functionality, based on the object's position and orientation.

- **Passthrough Mode:** A key feature introduced in the latest version of the Sankofa Interface is the passthrough mode. I implemented this mode to allow users to see their real-world surroundings when the Sankofa Interface is placed on a surface, such as a table. The IR sensor embedded within the Sankofa detects the surface, triggering the passthrough mode by switching from the immersive VR view to a transparent passthrough view. This ensures that users can maintain spatial awareness while not fully immersed in the virtual environment. The passthrough mode is disabled when the user picks up the Sankofa Interface from the table, thereby returning them to the immersive VR environment.

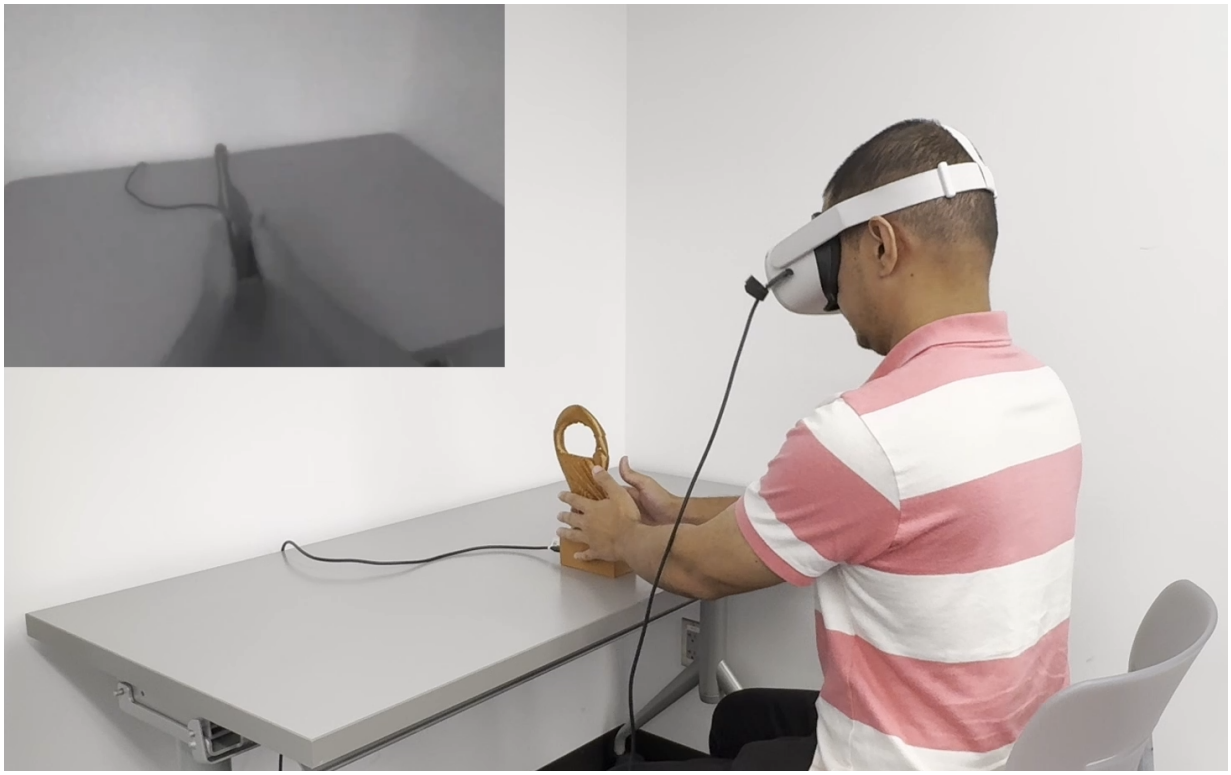


Figure 5.2: User interacting with the Sankofa Interface while passthrough mode is enabled in VR. The inset in the upper left corner shows the passthrough view, allowing the user to see their surroundings while the Sankofa Interface is placed on the table, detected by the IR sensor. The passthrough mode is automatically disabled when the interface is picked up.

- **External Audio Output Device:** The External Audio Output Device component is designed to play a separate WAV file containing the original audio of the video being displayed in the scene. This ensures that the narrative's audio is delivered clearly and separately from the vibrotactile feedback, providing a richer and more layered sensory experience. The speaker system can be configured to maintain audio clarity and quality, making sure that users can focus on both the story's auditory and haptic elements without any interference or distortion.

5.2 Audio to Vibration

The "Audio to Vibration" feature of the Sankofa Interface delivers the functionality that allows the audio signals to be translated into haptic feedback, which users can physically feel through the haptic motor embedded inside the Sankofa Interface. The process of developing this feature involved extensive research, experimentation, and fine-tuning to ensure a seamless and effective implementation.

To enable the MCU to convert audio signals into haptic feedback, I explored various sensor modules with inbuilt audio-to-vibration features. While some modules provided basic functionality, they often came with significant drawbacks. A common issue was the delay in mapping audio signals to vibration output, which created a noticeable lag between the visual/audio content and the haptic feedback. This delay disrupted the immersive experience and failed to align with the narrative timing, thus compromising the user's engagement and the overall effectiveness of the VR storytelling.

To overcome these challenges, I sought a more robust solution. After thorough investigation and testing, I found an open-source library `ESP32-A2DP`[1] that offered a more reliable and responsive audio-to-vibration conversion. However, the library required modifications to be compatible with the specific components and configuration of the Sankofa Interface. I customized the library's code to work seamlessly with all the components attached to the Sankofa Interface. These adjustments allowed for real-time processing of audio signals, providing users with immediate and contextually appropriate tactile sensations.

5.2.1 Independent Control Over Audio and Vibration

One of the technical hurdles I encountered was Unity's default limitation in handling multiple audio output devices. Unity's built-in audio system is typically designed to output sound to a single device, which posed a problem for my setup where I needed to send distinct audio signals to both the external speakers and the haptic motor inside the Sankofa Interface. This challenge highlighted the importance of having independent control over the audio and haptic feedback to maintain the integrity of the narrative and ensure a cohesive user experience.

To address this limitation, I implemented significant modifications to Unity's audio system. This involved advanced audio programming, including customizing Unity's audio

[1] ESP32-A2DP: A Simple Arduino Bluetooth Music Receiver and Sender for the ESP32, https://github.com/pschatzmann/ESP32-A2DP

mixer. The modifications allowed me to route different audio signals to specific output devices, enabling me to separately control the audio played through the external speakers and the signals sent to the haptic motor. By doing so, I ensured that the original narrative audio could be heard clearly by the users while the corresponding haptic feedback was accurately delivered.

The need for independent control over audio and vibration was crucial in achieving the desired results. This need became particularly evident after receiving feedback from the DOHR team, which suggested moving away from a direct voice-to-vibration mapping approach. The initial feedback described the vibrations as disjointed, which detracted from the storytelling experience. As a result, I shifted to a more abstract representation of haptic feedback, requiring precise control over the audio and haptic channels to fine-tune the amplitude, frequency, and nature of the vibrations.

The successful implementation of the audio-to-vibration feature marked a significant achievement in the development of the Sankofa Interface. By integrating responsive haptic feedback with the audio-visual elements of the VR experience, I created a more immersive and engaging environment. The carefully synchronized vibrations not only mirrored the nuances of the audio content but also had the potential to amplify the relational presence and connection to the narrative. This sophisticated interplay between sound and touch adds a layer of depth to the storytelling, allowing users to experience the narratives in a multisensory manner.

Chapter 6

Haptic Feedback Design

This chapter explores the conceptualization and implementation of haptic feedback, focusing on how it was crafted to enhance relational presence and support the narrative structure. The design process involved iterative testing and refinement to align the haptic sensations with the emotional and thematic elements of the stories being told.

6.1 The Role of Haptics in Relational Presence

As we progressed further through iterative design and feedback, the goals evolved to become more specific and nuanced, reflecting a deeper understanding of the peoples' experiences and the particular considerations of the DOHR project.

The new goals, maintaining bodily awareness, reinforcing the role of a witness, disrupting immersive presence, and mirroring emotional and narrative arcs, emerged from a combination of practical design considerations and theoretical insights gained during the development process. These goals are closely related to the initial objectives but are more refined, focusing on specific aspects of the user experience that were identified as crucial through the iterative design process and collaborative discussions with the DOHR team.

- **Maintaining Bodily Awareness:** The initial focus on relational presence evolved into the goal of maintaining bodily awareness, which emerged from recognizing the need to keep users grounded in their physical reality. This was essential to prevent complete detachment from the real world, which could potentially lead to discomfort

or distress, especially given the sensitive nature of the content. The haptic feedback serves as a reminder that users are not merely passive participants in a virtual environment. They are present in their own bodies.

- **Reinforcing the Role of a Witness:** The goal of reinforcing the role of a witness arose from the initial objective of fostering a deeper understanding of the narratives. It became apparent that haptic feedback could play a significant role in prompting users to reflect on the stories and their implications, thus enhancing the educational and restorative aspects of the experience. Haptic feedback and the tangibility of the interface are designed to subtly remind users of their responsibility as witnesses. The tactile sensations encourage users to not only engage with the stories but also reflect on their significance and the lessons they impart. This awareness extends beyond the VR experience, as users are encouraged to pass on the knowledge and insights they gain.

- **Disrupting Immersive Presence:** The concept of disrupting presence was developed in response to the realization that full immersion was not always desirable, particularly when dealing with emotionally charged or traumatic content. This goal ensures that users remain aware of their observer status and do not become overly absorbed in the virtual environment. Traditional VR aims to make users forget their physical surroundings. In contrast, our haptic design intentionally disrupts this immersion to keep users grounded in their role as observers.

- **Mirroring Emotional and Narrative Arcs:** The 'Mirroring Emotional and Narrative Arcs' was a refinement of the goal to create a meaningful VR experience. This goal focuses on conveying the emotional journey of the narratives, allowing users to connect with the stories on a deeper level without experiencing the distress associated with the traumatic events described. The haptic feedback aims to mirror the emotional and narrative arcs of the stories without replicating the harm described. This nuanced approach allows users to connect with the storytellers' experiences on an emotional level without directly feeling the pain or trauma recounted in the narratives.

6.2 Iterative Development Process

The development of the Sankofa Interface involved multiple iterations, each closely communicated and discussed throroughly with the DOHR team. The initial approach involved

using the voice signals directly to generate vibrations, allowing users to feel the voice of the narratives through the haptic motor. This was accomplished by sending the audio signals simultaneously to multiple output devices, including the haptic motor and the external audio output device. However, when demonstrated to the DOHR team, the feedback was that the resulting vibrations felt like "jabbering," the vibrations felt unbalanced and lacked synchronization with the narrative, which detracted from the storytelling experience. This approach inadvertently created a tactile avatar of the speaker, undermining the symbolic significance of the Sankofa and conflicting with the principles of relational presence.

In response to this feedback, we prioritized creating a more gentle and continuous haptic experience. The aim was to produce sensations that maintain a connection with the user without overwhelming them. This adjustment sought to enhance the relational presence, positioning the Sankofa Interface as a companion that subtly reminds users of their role as witnesses, thereby maintaining a connection to the real world.

6.2.1 Refinement and Further Feedback

Subsequent discussions and testing sessions emphasized the importance of subtle haptic feedback that could be more pronounced during emotional or intense moments in the narrative. This approach aimed to support the narrative without overshadowing it, ensuring that the haptic feedback complemented rather than competed with the other sensory inputs.

The design team explored developing a specific haptic vocabulary. This vocabulary included different gestures and vibrations that communicated distinct meanings, allowing users to interpret the haptic feedback more intuitively. This enhancement aimed to provide a richer and more nuanced experience, aligning the tactile sensations with the emotional and thematic elements of the narratives.

6.2.2 Crafting Haptic Designs

The haptic feedback produced by the Sankofa Interface draws inspiration from the sounds and movements of the White-necked rockfowl bird (Figure 6.1) found in West Africa. These include but are not limited to "Wing Flutters," "Head Bob," "Hop," "Bird Calls," and other gestures. Through these carefully selected haptic cues, the Sankofa Interface aims to communicate not just the factual content of the stories but also the underlying emotions and cultural context. This tactile vocabulary (some of the examples provided in Table 6.1) enhances the narrative experience, allowing users to feel a deeper connection to

the storytellers' experiences and fostering a richer understanding of the complex themes presented. The gestures and sounds of the White-necked rockfowl bird serve as a symbolic bridge, linking the physical sensations to the historical and cultural significance of the stories.



Figure 6.1: White-necked Rockfowl [13]. This is a rare bird species native to West Africa, known for its distinctive appearance and unique vocalizations. This bird inspired the sculpture and haptic feedback design for the Sankofa Interface, with various movements and sounds serving as a basis for the tactile sensations experienced by users in the VR storytelling experience.

- **Bird Call:** The bird call was designed to replicate the cadence and rhythm of the White-necked rockfowl's vocalizations. This waveform features a series of quick, sharp spikes, simulating the distinct calls of the bird. The intention was to create a tactile experience that mirrors the bird call's abrupt and high-pitched nature.
- **Head Bob:** The head bob vibration pattern exhibits a rhythmic twisting, similar to the natural motion of a bird's head moving left and right. The waveform's consistent peaks and troughs represent the smooth and deliberate nature of this gesture. This design choice aimed initially to convey a sense of acknowledgment or agreement.

- **Hop**: The waveform for the hop gesture includes a series of sudden, upward spikes followed by a brief period of inactivity. This pattern mimics the energetic motion of a bird jumping or hopping. The design captures the essence of a quick, upward movement, intending to evoke a feeling of lightness and agility. This sensation aims to align with the call for a sense of movement or transition.

- **Wing Flutter:** The wing flutter features rapid, small-amplitude oscillations, resembling the fluttering motion of a bird's wings. This design was chosen to evoke a sense of gentle movement and airiness. The subtle and continuous vibrations are intended to create a calming effect, mirroring the soothing nature of a bird's wing flutter. This tactile sensation is meant to enhance moments in the narrative that involve a gentle transition.

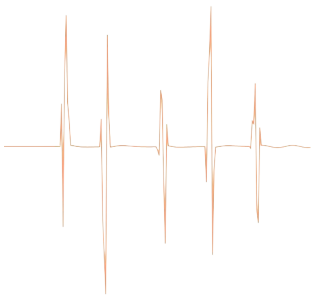
Haptic Design	Waveform
Head Bob	
Bird Call	
Wing Flutter	
Hop	

Table 6.1: This table presents the haptic designs and their corresponding waveforms developed for the Sankofa Interface. Each row details a specific haptic pattern, illustrating the waveform characteristics such as amplitude and frequency.

6.2.3 Extending Macaron

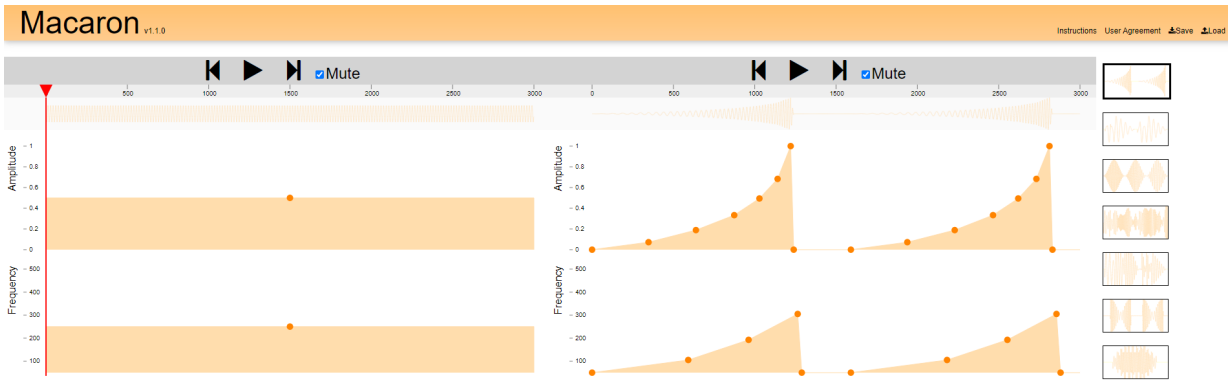


Figure 6.2: This figure shows the original Macaron interface, which was later enhanced with additional features and updates to meet desired goals.

I used Macaron (Figure 6.2) to design the haptic feedback for the sounds produced by the White-necked rockfowl bird, which inspired the tactile sensations integrated into the Sankofa Interface. Macaron [126] is a versatile tool used for designing haptic feedback patterns. It provides a platform for visualizing and editing haptic feedback, allowing for precise control over the tactile sensations produced by the Sankofa Interface. However, to meet our specific design goals, I made several modifications (Figure 6.3) to Macaron's codebase:

- **Audio Guide Feature:** I implemented an audio guide feature that separates the visualization of the loaded audio clip's waveform from the haptic waveform. This separation facilitates the design process by allowing designers to see both the audio and haptic waveforms simultaneously.
- **Audio and Haptic Output Routing:** Similar to the modifications made in the Unity editor, I needed to route audio playback to the external speaker while directing haptic feedback output to the Sankofa Interface. This feature was crucial for testing, as it allowed us to listen to the audio and feel the corresponding haptic feedback in real-time.
- **UI and Feature Enhancements:** I made several enhancements to Macaron's user interface, including resizing the vibrotactile feedback editor, adding duration adjustment controls, implementing a mute/unmute feature, and enabling independent

loading and saving of haptics and audio files (in WAV or JSON format). Additionally, I fixed various bugs to improve the tool's overall stability and usability.

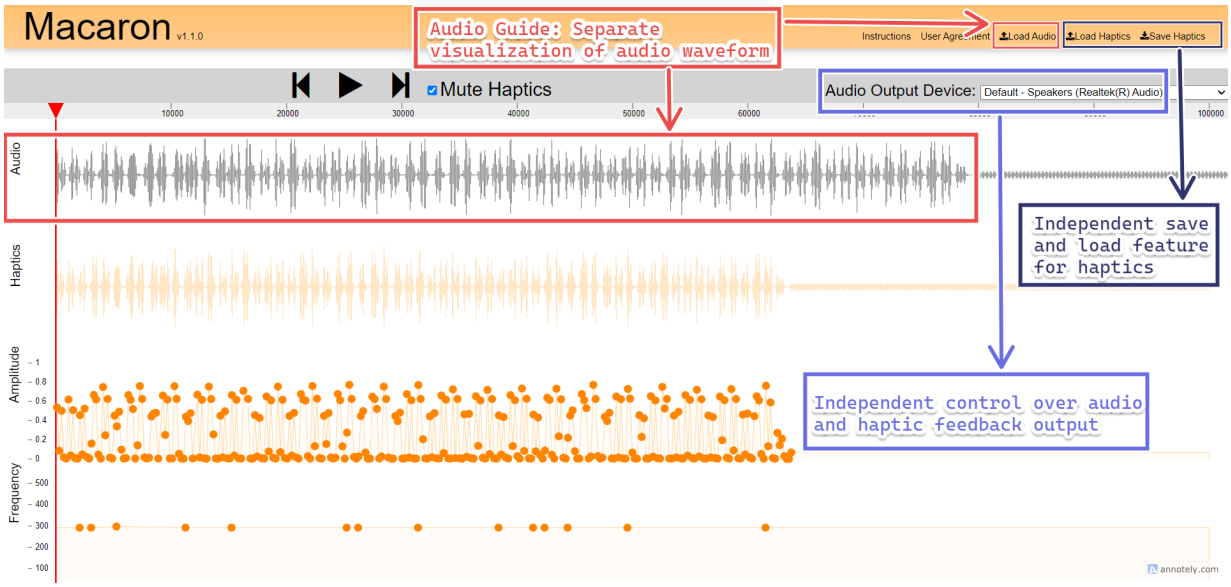


Figure 6.3: This figure shows the enhanced Macaron interface used for designing haptic feedback. Key features include the Audio Guide for separate visualization of audio waveforms, independent control over audio and haptic feedback output, and the ability to save and load haptic data independently.

6.2.4 Onboarding and User Guidance

Another critical aspect that emerged was the need for proper onboarding to help users understand the role of the Sankofa Interface and the significance of the haptic feedback. This was important for setting user expectations and enhancing the overall experience. Clear instructions on how to interact with the device and what to expect during the experience were identified as necessary components.

The team discussed detailed onboarding materials and user guidance, ensuring that participants were well-informed about the interface's functions and the intended purpose of the haptic feedback. Additionally, ongoing adjustments were made to the intensity and synchronization of the vibrations to ensure they closely align with the stories.

6.2.5 Collaborative Discussion

The collaborative discussions with the DOHR team provided valuable insights into the development and refinement of the Sankofa Interface's haptic feedback design. These conversations were instrumental in shaping the conceptual and practical aspects of the project, particularly concerning the role of haptics in enhancing relational presence and supporting the narrative structure.

Design Language and Haptic Trajectories: One of the key outcomes of the discussions was the shift from a direct voice-to-vibration mapping approach to a more abstract representation of haptic feedback. This change was necessitated by the initial feedback describing the vibrations as inconsistent which detracted from the storytelling experience. The team explored the concept of "abstract trajectories" to complement the visual and audio elements, aiming to provide a more nuanced and less literal interpretation of the narrative. This approach allowed for a more meaningful haptic experience that aligned with the emotional arcs of the stories.

Relational Presence and Empathy: The discussions primarily focused on the concept of relational presence. Unlike typical VR experiences that seek total immersion, the Sankofa Interface was created to maintain users' awareness of their own bodies and their role as witnesses to the stories. This approach aims to cultivate a sense of responsibility and empathy, prompting users to contemplate the narratives rather than becoming completely absorbed. The team introduced the concept of "Strategic Remembrance," [125] which seeks to involve users in a reflective process that encourages them to consider the implications of the stories they witness.

Abstract vs. Literal Representation: The team deliberated on the level of abstraction in haptic feedback. While literal representations, such as simulating environmental sensations, were considered, the consensus was to employ haptics to evoke broader emotional or symbolic meanings. The notion of creating a "Relational Ontology," [100] was introduced, suggesting that haptic feedback should help users understand their relationship to the stories and the real-world implications of their witnessing.

Challenges in Haptic Feedback Design: Designing haptic feedback that avoids misinterpretation presented significant challenges. The team recognized the potential for users to associate abstract haptic sensations with familiar experiences, which may not align with the intended narrative. The challenge lies in creating a haptic language that is both meaningful and universally interpretable within the context of the experience. This complexity requires careful consideration of the haptic patterns and their intended emotional and narrative impact.

One of the technical challenges identified was the issue of real-time synchronization between the haptic feedback and the audio narrative. Discrepancies in amplitude and frequency caused delays or mismatches in the expected sensations, potentially disrupting the user experience. Addressing this challenge is crucial for maintaining a consistent and immersive experience, as any misalignment can detract from the intended emotional and narrative engagement.

Strategic Use of Haptic Feedback: The concept of "Strategic Remembrance," was revisited, emphasizing the strategic use of haptic feedback to enhance narrative engagement without becoming a distraction. The design aims to balance the emotional impact of the narrative with the physical sensations, avoiding overuse or inappropriate timing of haptic cues. This careful calibration ensures that the haptic feedback supports the narrative rather than overshadowing it, allowing users to remain focused on the story.

Prototyping and Testing: The team emphasized the iterative nature of the design process, stressing the importance of creating small-scale prototypes to test various haptic experiences. This approach allows for continuous refinement of the sensations to ensure they align with the narrative and emotional tone of the stories. Prototyping and user testing are essential steps in validating the effectiveness of the haptic feedback and making necessary adjustments.

Considerations for Realism and Abstraction: The team also discussed the balance between realism and abstraction in the haptic feedback. While highly realistic feedback could distract users from the narrative, an abstract approach allows for a more nuanced and flexible expression of emotions and narrative elements. This balance is crucial in creating a haptic experience that is engaging and appropriate for the sensitive content of the narratives.

Cultural and Ethical Considerations: The design process also took into account the cultural and ethical implications of the haptic feedback.

The design process was deeply rooted in understanding the historical and cultural significance of the narratives being told. The stories related to the NSHCC involve sensitive topics such as institutional racism, abuse, and resilience. We recognized that haptic feedback had to be carefully crafted to reflect these contexts respectfully. For instance, instead of replicating the harshness of the traumatic events, the haptic feedback was designed to evoke empathy and reflection without causing distress.

Our team worked closely with former residents of the NSHCC, community members, and experts in restorative justice to ensure that the haptic feedback aligned with the cultural significance of the narratives. This collaborative approach allowed for direct input

from those who had lived through the experiences being depicted, ensuring that the haptic feedback did not misrepresent or trivialize their stories.

A key ethical consideration was to avoid re-traumatizing users who might have personal connections to the narratives or who might be sensitive to the content. The haptic feedback was intentionally designed to avoid mimicking the physical sensations of violence or distress. Instead, the feedback aimed to gently guide users through the emotional landscape of the stories, fostering a sense of understanding and connection without evoking pain or discomfort.

Chapter 7

Evaluation

The evaluation of the Sankofa Interface is a critical component of understanding how effectively the system supports relational presence in a VR environment. While a traditional user study was initially planned, the complexity of the project's ethical and cultural context led to the development of alternative evaluation strategies. This chapter outlines the reasons for moving away from a formal user study and instead focuses on the ongoing and future efforts to assess the interface through acceptance testing, collaborative feedback, and real-world deployment. It also discusses the future plans for studying the Sankofa Interface in its museum exhibit setting, ensuring that the design and technical contributions are continuously refined to meet the project's goals and support meaningful engagement with the narratives.

7.1 Planned User Study

Originally, a user study was planned to evaluate the effectiveness of the Sankofa Interface, particularly focusing on its ability to support relational presence and foster meaningful engagement with the stories presented in the VR environment. The study was designed to assess how users experienced the integration of haptic feedback and whether the Sankofa Interface successfully contributed to a reflective and emotionally resonant experience.

The proposed user study aimed to involve participants from diverse backgrounds to gather insights into how the interface impacted their engagement with the VR narratives. The study would have involved several key steps:

- **Participant Selection:** Participants would be selected from different demographic groups, including museum visitors, students, and individuals with varying levels of familiarity with VR technology. A diverse group of participants was crucial to ensure a broad range of perspectives on how well the interface supported relational presence.

- **Study Design:** The study was structured with pre- and post-experience questionnaires to evaluate user experience both with and without the Sankofa Interface. Participants would go through the DOHR VR stories twice: first using the Sankofa Interface and then without it, relying only on audio and visual feedback. This comparative design was intended to determine the impact of haptic feedback on relational presence and emotional engagement with the content.

- **Measures:** Participants would complete a pre-experience questionnaire to assess their expectations and familiarity with VR technology, their initial emotional state, and their understanding of the narratives.

  After each session, participants would complete a post-experience questionnaire designed to capture their emotional engagement, the perceived depth of their connection to the stories, and their impressions of the haptic feedback. The goal was to gauge whether the Sankofa Interface enhanced their overall experience and how it compared with the absence of it.

- **Post-Experience Interviews:** These interviews were intended to gain in-depth insights into participants' emotional experiences, perceptions of the haptic feedback, and reflections on the stories. The qualitative data gathered from these interviews would provide a nuanced understanding of how the Sankofa Interface impacted the overall experience.

However, due to the nature of the content and the sensitivity of the stories involved, the planned user study was eventually abandoned. There were several compelling reasons that led the team to reconsider and ultimately withdraw from conducting the study.

7.2 Reasons for Abandoning the User Study

- **Inappropriateness and Potential Exploitation:** The stories shared through the Sankofa Interface and the broader DOHR project are deeply personal and culturally significant. Presenting these stories outside of their approved context, particularly in a controlled experimental setting, was deemed inappropriate. There was a concern

that isolating the stories for study purposes would not honor the storytellers' wishes, which emphasize the need to maintain the complexity and integrity of their experiences. The storytellers were particularly concerned that distilling their stories into a testable format could be exploitative, reducing the narratives to data points rather than respecting the lived experiences behind them.

Moreover, the Sankofa Interface is part of a larger restorative justice initiative, where the stories are not simply entertainment or educational material but serve a broader purpose in healing and reconciliation. Conducting a user study in this context could trivialize the gravity of the narratives and risk violating the principles of respect and ethical listening that the project is built upon.

- **Ecological Validity and Contextual Integrity:** The user study would have required changing or modifying the VR narratives to fit the experimental setup. This would significantly alter the context in which the stories are experienced, leading to concerns about ecological validity. The Sankofa Interface was designed to function within a very specific context—one that aligns with the principles of restorative justice and relational presence. Changing this context to fit an experimental study would strip the stories of their full narrative power and fail to replicate the authentic conditions under which the interface is intended to be used.

  Conducting a study with altered stories would have produced findings that lacked ecological validity, meaning the results would not accurately reflect how the Sankofa Interface operates within its intended setting. This would undermine the entire purpose of the research, as the goal was to explore how the interface supports real-world experiences of witnessing and relational presence in a restorative justice framework.

- **Limitations in Addressing the Research Question:** Ultimately, the planned user study would not have addressed the core research question: How do we design haptics in a way that follows the restorative process? The answer to this question lies in the design and collaborative process itself, as well as in the final acceptance and reflection from the team's varied expertise, including VR developers, storytellers, and restorative justice practitioners.

  A formal study might have provided useful data on user preferences or emotional engagement, but it would not have captured the deeper, more meaningful insights related to how haptics can be integrated into a restorative justice project. Instead, the true evaluation of the Sankofa Interface comes from the collaborative feedback and reflective process engaged by the design team and the storytellers. Their acceptance and approval of the final design are the most meaningful indicators of success in this context.

While the user study was initially planned, it became clear that traditional methods of evaluation were not suitable for this project. The sensitive nature of the content, the need to maintain ecological validity, and the overarching research goal led to the decision to abandon the study. Instead, the evaluation of the Sankofa Interface has been shaped by the iterative design process and the collaborative feedback of the storytellers and experts involved in the project. This reflective and collaborative approach provided the most appropriate and meaningful way to assess the success of the haptic feedback design in supporting relational presence and advancing the restorative justice process.

7.3 Future Evaluation of the Sankofa Interface

While the traditional user study approach was ultimately abandoned, the Sankofa Interface remains a subject of ongoing and future evaluation efforts. These efforts focus on ensuring that the design aligns with the broader goals of the DOHR project, the principles of restorative justice, and the technical requirements of creating a meaningful and engaging VR experience. The following section outlines the planned strategies to evaluate the Sankofa Interface, particularly in relation to my technical contributions and the collaborative work with storytellers, VR developers, and restorative justice practitioners.

7.3.1 Acceptance Testing Through Collaborative Discussion

The Sankofa Interface was developed through an iterative process involving feedback from a diverse group of collaborators, including VR developers, restorative justice experts, storytellers, and museum staff. As the project neared completion, these collaborative discussions continued to play a critical role in shaping the interface's final form. One of the primary methods of evaluating the interface was acceptance testing conducted through these ongoing discussions.

Acceptance testing involves evaluating the system against its intended goals and ensuring that it meets the specific requirements defined by the interdisciplinary team. In the case of the Sankofa Interface, acceptance testing was carried out through frequent meetings and design reviews where the storytellers and practitioners provided feedback on whether the interface supported the principles of relational presence, respectful engagement with the narratives, and ethical listening.

My technical contributions, particularly in implementing the audio-to-vibration features, VR user Interface, programming the microcontrollers, the use of IR sensors for

detecting placement and triggering modes, the development of the pass-through mode, and Macaron development for haptic feedback design process were all evaluated through this collaborative acceptance testing process. Feedback from these sessions was integrated into iterative refinements of the interface to ensure that it aligned with the project's goals and respected the integrity of the stories.

Through this collaborative feedback loop, we ensured that the Sankofa Interface was technically robust while maintaining its alignment with the broader values of the project. This type of acceptance testing is important in projects like this, where the traditional metrics of success, such as user satisfaction or usability, are not sufficient to capture the ethical and cultural nuances of the work. The real success lies in the acceptance and approval of the interface by the storytellers and practitioners whose voices and experiences are central to the project.

7.3.2 Future Deployment: Museum Exhibit

The next significant step in the evaluation of the Sankofa Interface is its planned deployment at the Black Cultural Centre for Nova Scotia, where it will be part of an interactive exhibit. This exhibit will provide visitors with an opportunity to engage with the VR storytelling experience facilitated by the Sankofa Interface. This deployment represents a pivotal moment for the project, as it moves from the design and development phase into the real-world application phase.

The exhibit will allow a diverse group of museum visitors to interact with the Sankofa Interface, experiencing the carefully crafted narratives and haptic feedback that support relational presence. This deployment provides a unique opportunity to observe how well the interface functions in a public setting and how it resonates with a broader audience.

While a formal user study was not appropriate in the design phase, the deployment of the interface in the museum exhibit will serve as an informal method of evaluation. Visitor feedback, observations from museum staff, and insights from curators will help us gauge the success of the interface in a real-world setting. In particular, we will be interested in learning how well the haptic feedback supports relational presence and whether the interface facilitates meaningful engagement with the stories in the exhibit.

7.3.3 Future Study of the Deployed Exhibit

Following the deployment of the Sankofa Interface at the Black Cultural Centre for Nova Scotia, there are plans for an ongoing study of the exhibit's impact. This study will be

designed to gather insights on how visitors interact with the interface, focusing on both qualitative and quantitative measures to evaluate its effectiveness.

The future study will likely involve observation and feedback collection from museum visitors, where they will be invited to share their reflections on the experience. This study could also involve interviews with curators and museum staff, who will provide valuable insights into the interface's functionality and its impact on visitor engagement.

The study will likely aim to address several key questions:

- Does the Sankofa Interface facilitate a deeper connection with the stories?
- How does the integration of haptic feedback through the Sankofa Interface impact the visitor's understanding and emotional engagement with the narratives?
- Are there any challenges or barriers to using the interface in a museum setting, and how can these be addressed in future iterations?

These questions will guide the ongoing evaluation of the Sankofa Interface in its deployed state, allowing us to assess its effectiveness and identify areas for improvement. Future iterations of the interface may be developed based on the findings of this study, further refining the technical aspects and enhancing the overall user experience.

In terms of technical contributions, my role will continue to be crucial in monitoring the performance of the Sankofa Interface during the exhibit. Ensuring the stability of the pass-through mode, haptic designs, the IR sensor-triggered interactions, and the synchronization between audio and haptic feedback will be essential tasks as the interface is deployed for long-term use. Any necessary adjustments to improve performance or user experience will be made based on observations and feedback from the museum staff and visitors.

Chapter 8

Discussion

This chapter discusses the broader implications of the findings from the research on the Sankofa Interface and its application in VR environments to support relational presence. It situates them within the broader literature and explores how they contribute to the understanding and application of VR and haptic technology.

8.1 Pioneering Haptic Solutions in Virtual Reality

The development and implementation of the Sankofa Interface provide significant insights into the integration of haptic feedback in VR environments, particularly in educational and narrative-driven applications. As our team began to converge on an interaction design and vibration patterns that could be effectively integrated into the DOHR project, we identified key considerations and guiding principles that suggest a promising path for haptic and tangible interfaces to support relational presence. These insights point toward the potential of using haptic feedback to deepen emotional and cognitive engagement within VR environments, particularly in educational and narrative-driven applications.

Our findings align with existing literature that emphasizes the importance of sensory inputs in creating a sense of presence in VR, which is influenced by a combination of visual, auditory, and haptic stimuli [128, 71, 52]. The Sankofa Interface contributes to this body of work by providing a practical example of how vibrotactile feedback might be brought into a restorative process and potentially support relational presence, focusing on emotional and interpersonal connections rather than just physical immersion. Additionally, the iterative design process and feedback loops highlighted the importance of user-centered design in

developing haptic interfaces. The transition from initial design concepts to a refined, gesture-based interaction model underscores the need for adaptability and responsiveness to user needs and preferences[146, 150, 147, 79].

The Sankofa Interface's use of vibrotactile feedback provides a counterpoint to the prevailing trends in haptic technology, which emphasize the role of touch in reinforcing emotional connections and facilitating deeper reflective engagement in virtual environments [157, 41, 6].

Leveraging a combination of sensory modalities to create immersive VR experiences emphasizes the potential of integrating advanced haptic technologies and multisensory feedback. Designers can craft richer and more captivating virtual environments by harnessing the capabilities of haptic feedback, visual displays, and auditory cues. This approach caters to a wide range of applications and use cases, enhancing the overall VR experience for users.

8.2 Educational and Restorative Applications

The application of the Sankofa Interface within the DOHR project underscores the potential of VR as a tool for educational and restorative justice initiatives. The project has established a platform for former residents of the Nova Scotia Home for Colored Children to recount their experiences, aligning with the principles of restorative justice, and places emphasis on healing, fostering understanding, and fostering community engagement.

This approach is supported by the literature on VR in education, which highlights the role of immersive environments in enhancing learning outcomes and fostering empathy. Several studies on VLEs by various researchers demonstrate the positive impact of immersive technologies on student engagement and empathy [82, 4, 140]. The focus on relational presence and the use of haptic feedback to mirror emotional narratives offer a novel contribution to this field. It provides a tangible example of how VR can be used not only for simulation and training [61, 153] but also for creating meaningful, reflective experiences that promote historical consciousness and empathy.

Furthermore, the design of the Sankofa Interface aligns with the principles of experiential learning [141, 5], which highlights the significance of involving learners in active, hands-on experiences. Through providing tactile feedback that complements the visual and auditory components of the VR experience, the Sankofa Interface is intended to aid users in forming a deeper connection with the content, creating a more profound and immersive learning environment. The integration of haptic feedback in educational VR applications

[118, 17] also highlights the potential for using multisensory approaches to support diverse learning styles.

The development of the Sankofa Interface also contributes to the theoretical frameworks of presence, relational presence, and embodiment in VR. This research goes beyond the conventional understanding of presence by emphasizing the emotional and interpersonal elements. It aims to incorporate relational and empathetic dimensions into the concept of presence. This perspective is supported by existing literature that underscores the significance of social and emotional factors in establishing a feeling of presence in virtual environments [119, 65, 8].

8.3 Challenges and Considerations

While the findings of our research are promising, several challenges and considerations emerged that warrant further exploration. One significant challenge is the balance between immersion and emotional impact, particularly when dealing with sensitive content. Our results highlighted the need for careful design to ensure that high levels of presence do not lead to discomfort or distress[37, 32].

The transition from physical buttons to gesture-based interactions highlighted the importance of accessibility and user comfort. Ensuring that the interface is inclusive and easy to use for individuals with varying levels of familiarity with VR technology is crucial. This consideration aligns with the broader literature on accessibility in VR [14, 116, 107]. Another important consideration is the ethical implications of using haptic feedback in VR experiences, particularly when dealing with sensitive or potentially distressing content [131, 66]. The design of the Sankofa Interface aimed to create a safe and reflective environment for users to engage with challenging narratives, but further research is needed to explore the potential risks and benefits of using haptic feedback in different contexts.

The Sankofa Interface's integration with Unity and the enhancements made to Macaron highlight the importance of combining multiple technologies to create a cohesive and immersive VR experience. The use of advanced haptic motors and microcontrollers, such as the TacHammer Drake and Titan Core, underscores the need for high-fidelity feedback systems that can provide the nuance required by artists to convey complex emotional and narrative content. While the enhancements to Macaron provided valuable support for the development of the Sankofa Interface, further improvements are needed to facilitate the creation of more sophisticated and customizable haptic feedback patterns. This includes the development of better features and softwares, more precise haptic actuators, and more effective methods for testing and refining haptic feedback.

Chapter 9

Conclusion and Future Work

The development of the Sankofa Interface within the DOHR project represents an advancement in the application of haptic feedback to enhance relational presence in VR storytelling. This thesis has explored the theoretical foundations, design considerations, and technical challenges associated with integrating haptic feedback into a narrative-driven VR experience. Through collaborative discussions, iterative prototyping, and rigorous testing, we achieved a nuanced understanding of how haptics can be employed not just to immerse users in a virtual environment but also to maintain their awareness of their physical presence and their role as witnesses.

We moved away from a literal voice-to-vibration mapping to a more abstract representation, which was found to better align with the narrative's emotional arcs. This approach allowed for a more meaningful and less intrusive haptic experience. The concept of relational presence was central to the project's design philosophy. Unlike traditional VR experiences that aim for full immersion, our approach emphasized maintaining users' awareness of their own bodies and their responsibility as witnesses. This focus on relational presence was supported by the strategic use of haptic feedback, which was carefully calibrated to enhance engagement without overwhelming the user. This approach can be valuable for designers aiming to create immersive yet reflective VR experiences.

The Sankofa Interface disrupts the traditional focus on full immersion in VR design by emphasizing relational presence. It maintains users' awareness of their physical presence and their role as witnesses, fostering a deeper, more empathetic engagement with content which aligns this perspective with the broader literature on presence [73] and embodiment [86] in VR, expanding these concepts to encompass emotional and interpersonal dimensions.

The significance of user-centred design in creating effective haptic interfaces [12, 63] is

underscored by the collaborative and iterative design process, which incorporates feedback from the DOHR team. This approach guarantees that the technology aligns with user needs and preferences, thereby enhancing usability and engagement. It also emphasizes the importance of involving users in the design and testing phases for continuous refinement and improvement, which is valuable advice for designers of similar systems.

Furthermore, The development of a specific haptic vocabulary allowed for a more intuitive interpretation of the feedback. This vocabulary provided a framework for designing tactile sensations that corresponded to different emotional and narrative states, facilitating a deeper connection between the user and the narrative. The project was mindful of the sensitive nature of the content, particularly the historical and emotional significance of the stories. The design process prioritized creating a respectful and thoughtful experience that honored the stories being told. This can serve as a useful framework for other designers looking to integrate haptic feedback into narrative-driven VR experiences [21, 38]. The vocabulary's intuitive nature facilitates a deeper connection between users and the content, enhancing the overall impact of the VR experience.

9.1 Future Work

While the Sankofa Interface has laid a strong foundation for the integration of haptic feedback in VR storytelling, several avenues for future research and development remain open. One area of exploration could involve advanced haptic technologies, such as multimodal feedback systems that combine tactile sensations with thermal or force feedback. These technologies could provide a richer and more immersive sensory experience, further enhancing the emotional impact of the narratives.

Expanding the haptic vocabulary to include a wider range of gestures and sensations could offer greater flexibility in conveying complex emotional and narrative content. This expansion would allow for more nuanced and varied feedback, enabling more personalized and engaging experiences. Furthermore, incorporating user-centred design principles in future iterations of the Sankofa Interface could allow for the personalization of haptic feedback based on individual preferences and sensitivities, enhancing user comfort and engagement.

There is also significant potential for integrating the findings from the Sankofa Interface into broader educational frameworks, potentially expanding its application across various subjects and age groups. This could involve developing guidelines for educators on effectively using haptic feedback in classroom settings to enhance learning and empathy. As

the use of haptic feedback in VR storytelling continues to evolve, establishing comprehensive ethical guidelines will be essential. Future research could focus on developing best practices for using haptics in sensitive and potentially distressing content, ensuring user safety, emotional well-being, and respectful representation of marginalized communities.

Longitudinal studies could provide valuable insights into the impact of the Sankofa Interface on users' emotional and cognitive engagement with the narratives. Such studies would help assess the effectiveness of haptic feedback in fostering empathy and understanding, as well as its potential role in promoting social justice and historical awareness.

In Conclusion, the findings of the Sankofa Interface suggest a way for haptic and tangible technology to enhance relational presence. Additionally, the findings identify crucial considerations and guiding principles to support this in the future. The project's emphasis on abstract representation, relational presence, and careful consideration of cultural and ethical factors has contributed to a thoughtful and impactful user experience. While challenges remain, the innovations and insights gained from this project provide a robust foundation for future exploration in the fields of VR and haptic technology. The continued evolution of these technologies promises to offer new and exciting ways to engage with digital narratives, fostering deeper connections and understanding among users.

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