

Preserving the *Afghan Rubab* through Interactive Technologies

Master Graduation Project 2025

Design for Interaction

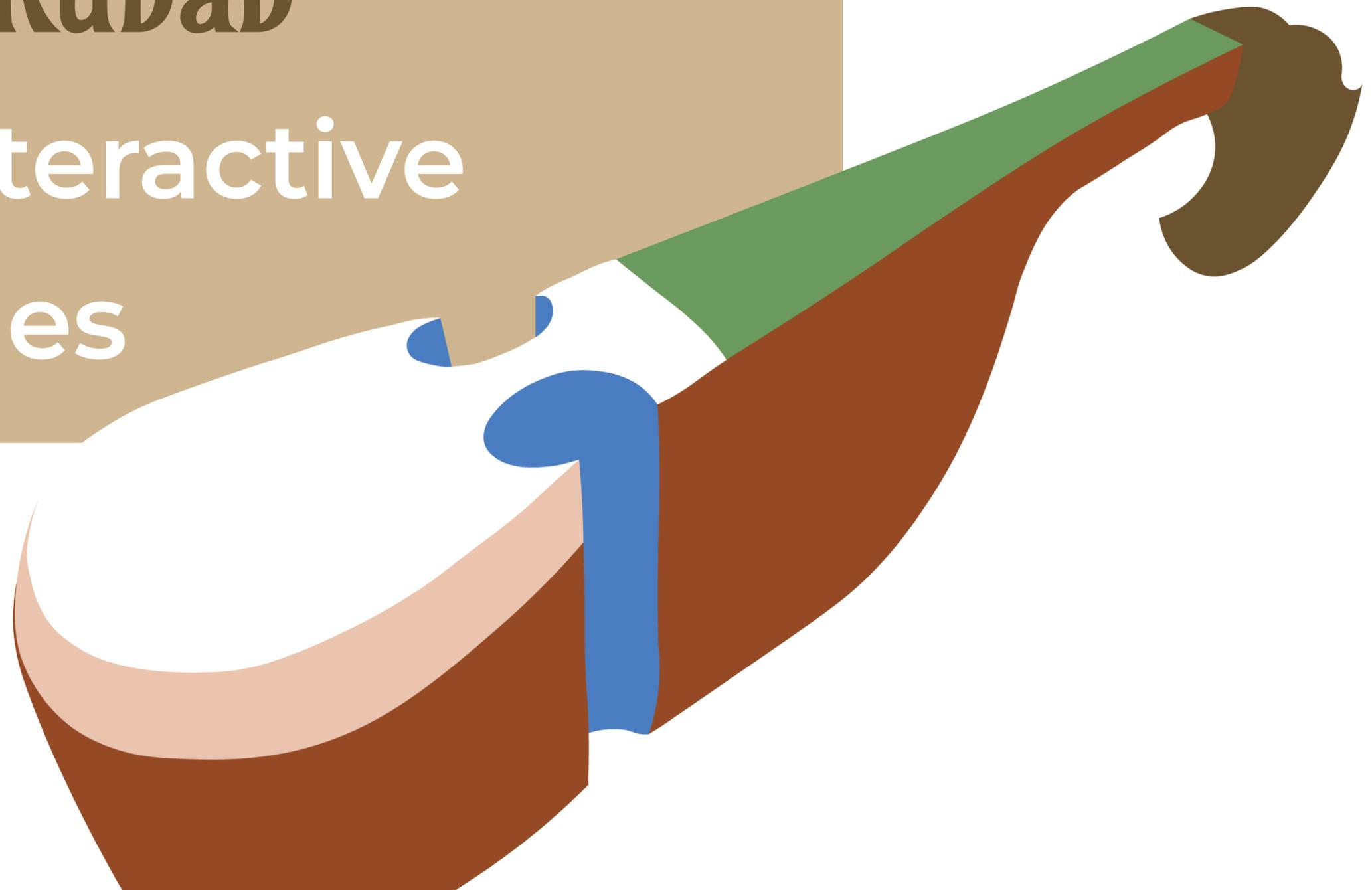
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In Collaboration with Stichting Solh



*“All that misery, true,
it's certainly part of the truth,
but that doesn't describe Afghanistan.
That's not the whole of Afghanistan.”¹*

¹ *Quote by one of the interviewed Afghan diaspora members.*

Summary

This design project explores the use of interactive technologies to preserve the endangered heritage of the Afghan rubab, a traditional instrument currently forbidden in Afghanistan. By combining Mixed Reality (MR) with Sensor-Based Embedded (SBE) technology, the project creates a hybrid interactive technology experience that conveys the rubab's most important tangible and intangible heritage. Conducted in collaboration with Stichting Solh, an Afghan-Dutch cultural foundation, the project pursued two design goals:

- *DG1: Design an interactive technology experience to meaningfully convey the tangible and intangible heritage of the Afghan rubab, for culturally interested non-Afghans to encounter the beauty of Afghan culture.*
- *DG2: Design an interactive technology experience that conveys the rubab's physical playing sensation through a combination of Virtual Reality and sensor-based embedded technology.*

Among the Afghan diaspora, the rubab is more than a musical instrument—it is a cherished symbol of Afghan beauty and identity. Promoting the rubab to non-Afghans serves as a way to highlight the richness of Afghan culture and challenge dominant Western narratives that associate Afghanistan primarily with war, oppression, and misery.

The project began with an exploration phase addressing four research questions:

- RQ1. How have interactive technologies been employed to preserve the tangible and intangible heritage of musical instruments?
- RQ2. According to the Afghan diaspora, what should be the message of the preservation project?
- RQ3. What are the essential aspects of the rubab's heritage that should be preserved (through this project)?
- RQ4. What makes a cultural encounter meaningful for the target group?

Insights from rubab player interviews, generative sessions with the target group, and conversations with members of the Afghan diaspora, and further desk research informed the refinement of the design goals and design requirements, and led to an interaction vision that informed the ideation process.

Through iterative design, prototyping, and checks on cultural accuracy with Afghan diaspora members, a final interactive system was developed. Capacitive touch sensors on the frets, and proximity infrared sensors under the strings detect user input on a physical e-rubab, which is translated into output (sound and menu selection) within an extended reality environment via Socket.IO connection. The result is an interactive Mixed Reality experience, *The Rubab Legacy*, that provides a meaningful cultural encounter with the rubab's heritage. The design was evaluated by the target group, leading to final recommendations for implementation and future development.

Acknowledgements

This graduation project would not have been possible without the generous support, time, and contributions of many.

Thank you

To my oboe teacher for introducing me to the rubab.

To Kamal Nasrati, for his dedication, enthusiasm, and trust; and for the documentary project (fig. 1) he set up around the project.

To Mohammad Mohammadi, for his beautiful rubab playing and commitment to the project.

To RP2, for his time and for sharing his knowledge.

To the Afghan diaspora members, for sharing their memories of Afghanistan.

To Raemy Abdelsalam, for filming Stichting Solh's documentary, recording rubab music, and providing high-quality footage.

To Linda van der Hout, for creating a stunning 3D scan of the rubab.

To the XR Zone staff for their dedicated teaching and guidance in Unreal Engine.

To Annemiek van Boeijen, for her advise in preparing the rubab player interviews.

To Froukje Sleswijk Visser, for her advise in preparing the generative session.

To my friends, for their help with the Arduino code and electronics.

To my friends and family, for all their support and ideas.

And, of course, to Willemijn Elkhuisen and Jeff Love.

Thank you all.

Artificial Intelligence Disclaimer

Generative AI was used for restructuring written texts, for generating the images of the Afghan people used in the prototype, and for coding. No AI was used for ideation.

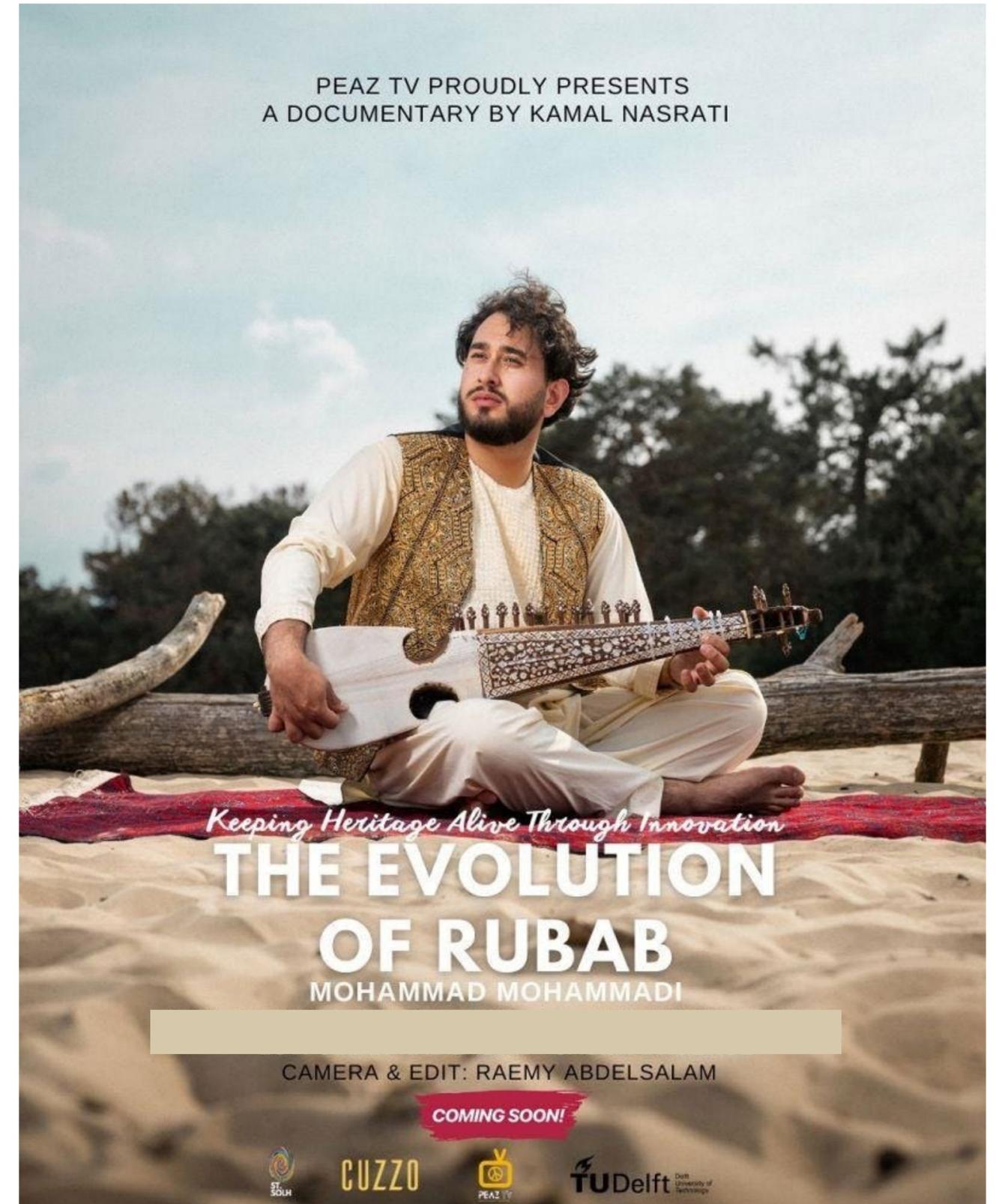


Figure 1: Kamal Nasrati's documentary poster.

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Glossary

Afghanistan

Dari: One of Afghanistan's two official languages (Ethnologue, n.d.)

(Southern) Pashto: One of Afghanistan's two official languages (Ethnologue, n.d.)

Diaspora: A group of people who spread from one original country to other countries (Cambridge Dictionary, n.d.-a).

Fall of Kabul: The 2021 event in which the Taliban regained control of Afghanistan's capital, marking a major political shift.

Rubab: A traditional lute-like string instrument and the national instrument of Afghanistan, central to Afghan music. It is also played in the neighbouring countries.

Sargam System: An Indian system of musical notation using syllables (Sa, Re, Ga, Ma, Pha, Da, Ni, Sa) to represent notes.

Stichting Solh: A Dutch-Afghan foundation located in the Netherlands promoting peace and Afghan cultural heritage.

Taliban: An Islamic political and military organization, active in Afghanistan and Pakistan (Cambridge Dictionary, n.d.-b)

Ustad: An honorific title for a master or expert, especially in music and the arts, used in South Asia and the Middle East.

Heritage

Heritage: Features belonging to the culture of a particular society, such as traditions, languages, or buildings, that were created in the past and still have historical importance (Cambridge Dictionary, 2025).

Intangible heritage of musical instruments: Practices, expressions, representations, knowledge, or skills surrounding the instrument (e.g., playing techniques, music, performance contexts).

Tangible heritage of musical instruments: The instrument's physical elements (e.g. materials, appearance).

Technology

Graphic User Interface (GUI): A way of arranging information on a computer screen that is easy to understand and use because it uses icons (= pictures), menus, and a screen that can be controlled by a mouse, rather than only text (Cambridge Dictionary, 2025).

ESP-32: A feature-rich Micro-Controller Unit with integrated Wi-Fi and Bluetooth connectivity for a wide-range of applications (Espressif, n.d.)

Meta Quest 3: An Extended Reality headset by Meta offering immersive experiences.

Socket.IO: A low-latency, bi-directional, event-based communication library between a client and server, the latter typically written in node.js. Socket.IO starts with an HTTP long-polling connection, upgrading to a WebSocket connection when possible (Socket.IO, 2025).

Sensor Based Embedded Technology: Technology with built-in sensors that detect and respond to physical changes like movement, pressure, or temperature.

Unreal Engine: 3D development software developed by Epic Games, Inc., used for creating games, simulations, and virtual environments.

Unreal Engine Plug-in: An add-on that extends Unreal Engine's core functionality, often for hardware integration or specific features.

WebSocket: A computer communications protocol, providing a bidirectional communication channel over a single Transmission Control Protocol (TCP) connection. The current specification allowing web applications to use this protocol is known as WebSockets (WHATWG, 2025).

Immersive media

Augmented Reality (AR): An enhanced version of reality created by the use of technology to overlay digital information on an image of something being viewed through a device (such as a smartphone camera) (Merriam-Webster, n.d.-a).

Virtual Reality (VR): An artificial environment which is experienced through sensory stimuli (such as sights and sounds) provided by a computer and in which one's actions partially determine what happens in the environment (Merriam-Webster, n.d.-b).

Mixed Reality (MR): A hybrid environment where real and digital objects interact in real time, combining aspects of AR and VR.

Extended Reality (XR): A collective term for Augmented Reality (AR), Virtual Reality (VR), and Mixed Reality (MR) technologies.

TU Delft specific

TU Delft: Abbreviation of Delft University of Technology.

IDE: Abbreviation of Industrial Design Engineering, one of the TU Delft faculties.

XR Zone: A TU Delft facility that supports students in using Extended Reality in their study projects, and develops new media applications.

Preface

As I began preparing my graduation project, I was interested in setting up a cultural heritage preservation project that implemented interactive technologies. Because of my background in music as an oboist, I became especially interested in preserving musical instruments. After talking about this idea with my former oboe teacher, she introduced me to the Afghan rubab, a traditional string instrument which is now under threat because of the Taliban's ban on music.

This project brings together many of my personal interests: music, culture, technology, design and history. I also wanted to learn more about the use of interactive technology within the field of cultural heritage preservation, which is an area within design that I find very interesting. Ultimately, the project became a reflection of my own interests.

I hope you enjoy reading this graduation project report.

Casijn Broerse



Introduction

Following the Taliban's return to power after the fall of Kabul in 2021, one of the laws they reinstated was the prohibition of music and musical instruments in Afghanistan (Ng, 2023; fig. 2). Among the banned instruments is the *rubab*, Afghanistan's national instrument and a symbol of its cultural identity (Al Jazeera English, 2025). As reported by newspaper *Mathrubhumi English* (2024), "the craftsmen and musicians struggle to preserve the heritage of this ancient instrument, vital to the nation's cultural identity." Under the new regime, many musicians have been threatened, forcing them to flee the country. One rubab player, now in exile in Peshawar, Pakistan, shared: "It broke my heart when the Taliban came. It felt like our music died, like it was the end for the rubab" (Voice of America, 2022).

My literature review on the employment of interactive technologies in preserving musical instrument heritage discusses projects that preserve traditional musical instruments from countries all around the world. The review concludes that Virtual Reality (VR) falls short in conveying the physical playing sensation of plucked string instruments. By combining the strengths of VR and physical sensors, a more comprehensive preservation of musical instrument heritage could be achieved.

The rubab

For this graduation project, one specific plucked string instrument was selected: the Afghan rubab. It was selected because of its currently endangered position in Afghanistan, where music (and therefore, the rubab) is forbidden under the Taliban regime, making the preservation of this traditional instrument even more relevant.

The rubab (fig. 3) is a lute-like stringed instrument, and is recognized as the national musical instrument of Afghanistan. The rubab features a carved body made from mulberry wood, with its lower section covered in goat skin. It has three main melodic strings played with a plectrum, along with a varying number of sympathetic strings (the amount depending on the instrument's size) that vibrate in harmony, contributing to its distinctive deep, resonant sound. Among Afghans, the rubab is more than just an instrument; it is a symbol of cultural identity, Afghan beauty, and resilience.



Figure 2: The Taliban burning music equipment and instruments (Ng, 2023).



Figure 3 Afghan rubab (Hussnain, 2017).

Problem statement

The project addresses the urgent risk of losing both the **tangible** and **intangible** heritage of the Afghan rubab. Tangible aspects refer to the physical features of the instrument, such as its shape and materials. Intangible aspects include non-physical elements, such as playing technique and music.

With the rubab banned under the Taliban regime, both dimensions of this heritage are now under threat.

Opportunity space

Interactive technologies, such as Virtual Reality (fig. 4) present new opportunities for preserving endangered musical instruments like the rubab, offering innovative ways to capture and engage with the cultural heritage.

This graduation project therefore focuses on the preservation of the rubab's tangible and intangible heritage through interactive technologies.



Figure 4: Virtual Reality Headset. Photograph by Marco Verch, CC BY 2.0, via cnull.de.

Initial Design Goals

The project started with these two interconnected goals:

DG1

Design an interactive technology experience that meaningfully conveys the tangible and intangible heritage of the Afghan rubab, in a way that contributes to the user's exploration of Afghan culture, for the Afghan diaspora and other people interested in Afghan culture.

DG2

Design a hybrid interactive technology experience that conveys the rubab's physical playing sensation through a combination of Virtual Reality and sensor-based embedded technology.

This secondary goal is based on the findings from the literature review in chapter 1.1, which suggests that the strengths of VR (with excellent immersive capabilities) and the strengths of sensor-based embedded technology (excelling at conveying physical playing sensations) should be combined to create a more comprehensive preservation of musical instrument heritage.

Afghan community involvement

Having selected the Afghan rubab as the subject, I began exploring who would want to contribute to this project. In the process, I met Kamal Nasrati, founder of **Stichting Solh**, a Dutch-Afghan foundation that promotes Afghan culture in the Netherlands. The foundation organises cultural events aimed at both the Afghan diaspora and wider Dutch society (fig. 5). The foundation's mission is to offer a broader and more nuanced understanding of Afghanistan — one that highlights its rich heritage of art, music, traditions, and hospitality, often overlooked in mainstream media narratives.

Stichting Solh was fond to collaborate on the project and offered to connect me with both a rubab player and several non-players from the Afghan diaspora in the Netherlands. The foundation expressed interest in adopting the outcomes of the graduation project and started production of a documentary about the rubab's heritage and this graduation project. Another valuable contribution of Stichting Solh to the design project was their evaluation of the design's cultural accuracy and guidance in avoiding unintended insensitivities or misrepresentations of Afghan culture.



Figure 5: Stichting Solh organises cultural events to promote Afghan culture.

Project overview

The structure of this graduation project report is shown in figure 6. The first part, *Explore*, answers four research questions through a series of research activities. The insights gained from this research are then used to redefine the design goals, as well as the design requirements, which are outlined in the "Exploration conclusions" chapter at the end of Part 1. This is followed by *Ideation & Prototyping* for two separate but related design goals. For Design Goal 1 (DG1), prototypes are developed and gradually refined from low to high fidelity through evaluation. For Design Goal 2 (DG2), a rapid prototyping approach is used. The outcomes of both design goals are integrated in the Final Design.

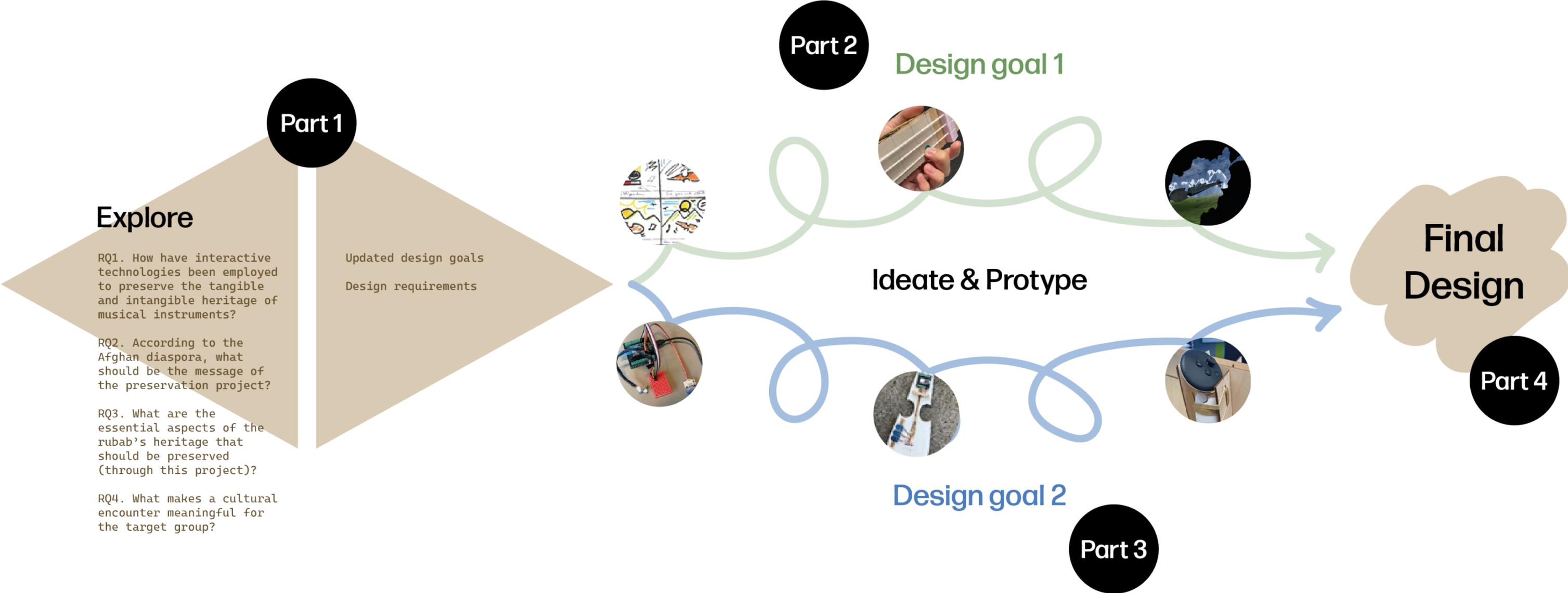


Figure 6: Project overview.

Part 1: Explore

This part presents the analysis and insights from the activities carried out in the exploration phase, and results in a redefinition of the design goals and design requirements. This part covers the following research questions:

EXPLORING THE STATUS QUO

RQ1. How have interactive technologies been employed to preserve the tangible and intangible heritage of musical instruments?

EXPLORING THE WHY

RQ2. According to the Afghan diaspora, what should be the message of the preservation project?

EXPLORING THE HERITAGE ASPECTS

RQ3. What are the essential aspects of the rubab's heritage that should be preserved (through this project)?

EXPLORING MEANINGFUL CULTURAL ENCOUNTERS

RQ4. What makes a cultural encounter meaningful for the target group?

Method

In the exploration phase, I wanted to gather insights into several key areas. The goal of this phase is to set the foundation for the design. By examining what has been done already, what the project's message should be, which aspects of the rubab should be preserved and how these should be conveyed, the design will be research-based, relevant and new.

I examined the current use of interactive technologies in musical instrument preservation projects, with the goal of identifying a research gap to guide this project (RQ1). I engaged with members of the Afghan community to understand their perspectives on the importance of preserving the rubab's heritage (RQ2). I also went out to explore the rubab's heritage, as to get familiar with the instrument myself, and to learn what are the most important aspects of its heritage that should be preserved through this project (RQ3), so the project can be feasible yet effective. Finally, I sought to understand what makes a cultural encounter meaningful for the target audience (RQ4), in order to translate the term "meaningful" in Design Goal 1 (DG1) into concrete design requirements to inform the design.

Since there is some overlap in methods used for answering the different research questions, this first chapter provides an overview of the various research activities and methods that were carried out, grouped by research method.

Literature review

A literature review was conducted to understand how interactive technologies have been employed to preserve the tangible and intangible heritage of musical instruments. The literature search was performed across three prominent databases: Scopus, IEEE Xplore, and the ACM Digital Library. The search aimed to cover studies related to interactive technologies and musical instrument heritage preservation. The review focused on four types of interactive technologies, identified in the literature: Virtual Reality (VR), Augmented Reality (AR), Graphical User Interface (GUI) technology, and Sensor-Based Embedded (SBE) technology. The review analysed 20 selected studies to evaluate the effectiveness of each technology in preserving heritage aspects such as instrument appearance, physical playing sensations, sound, and performative context.

Desk research

To become familiar with the rubab's heritage, I consulted a range of websites and documentaries (see section "Rubab heritage background sources" in References). On YouTube, I watched rubab performances to get familiar with the sound and context of playing. The sources consulted to gain insight into Afghan culture and the Afghan diaspora in the Netherlands, can also be found in References, under "Afghan culture background sources".

A key part of this research was watching a recording of the 2024 **Afghan Diaspora Dialogue** (fig. 7), a collaborative event organised by Stichting Solh and Pakhuis De Zwijger. This two-hour session featured members of the Dutch-Afghan diaspora discussing identity, culture, and the political situation in Afghanistan and its impact on the diaspora (Pakhuis De Zwijger, 2024).



Figure 7: A screenshot from the Afghan Diaspora Dialogue. Retrieved from https://www.youtube.com/watch?v=x8Y_uS676YI&t=1s

UNESCO consent of community letters

As part of the 2024 UNESCO inscription of rubab crafting and performance as intangible cultural heritage, 12 'consent of community' letters from the Afghan community were submitted (Fig. 8; UNESCO, 2024). These letters offer valuable

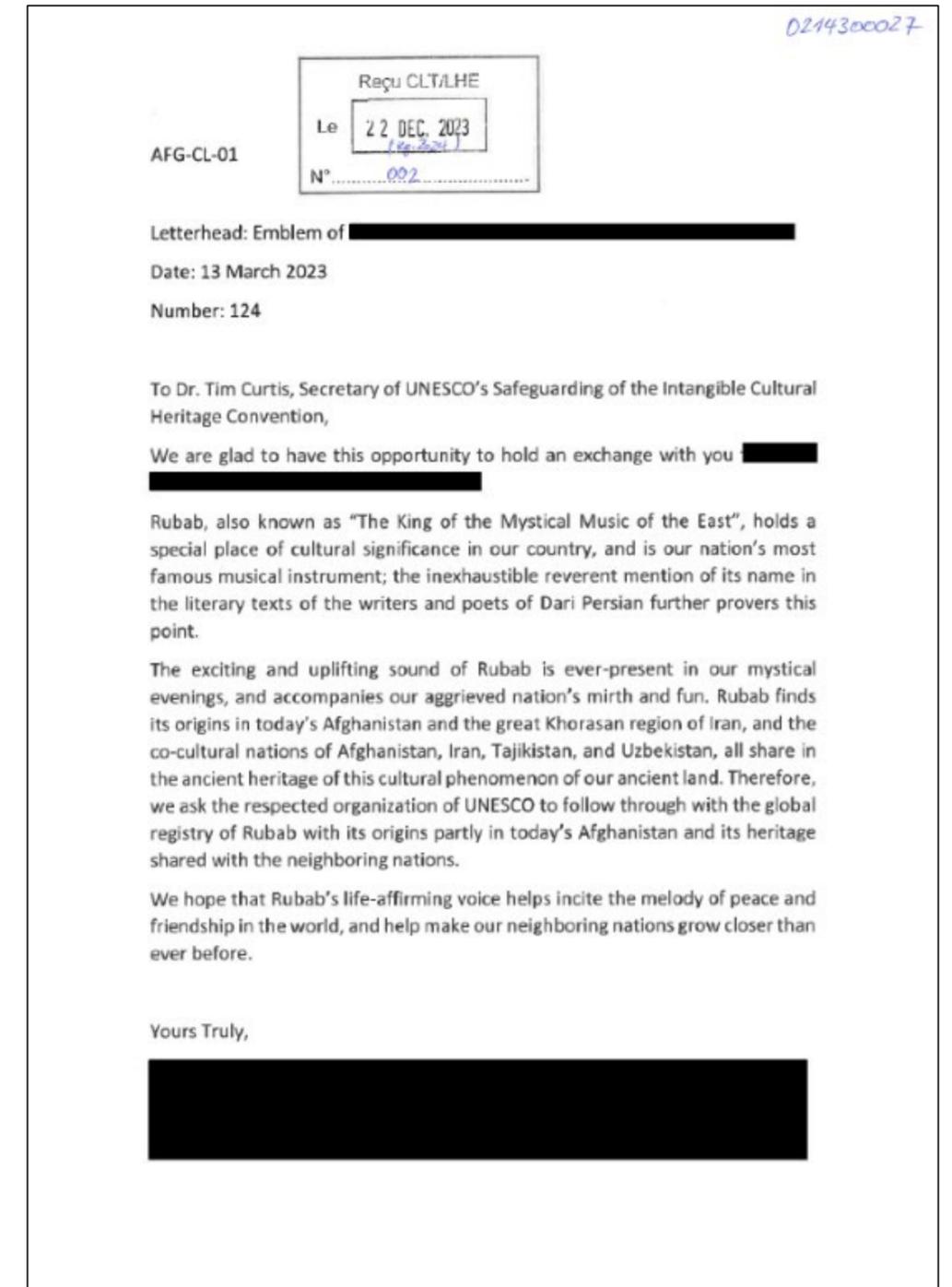


Figure 8: One of the 12 UNESCO consent of community letters.

insights into Afghan perspectives on the rubab's heritage. I analysed the letters to identify heritage aspects mentioned and, where provided, noted the reasons for their importance (Appendix A). This helped clarify which elements of rubab heritage are valued and why.

Graduation-in-one-day exercise

At the start of the project, I carried out a "Graduation-in-One-Day" exercise to explore the project scope and estimate time requirements by simulating the full process within one working day, including AI-generated mock interviews. An autoethnographic brainstorm on oboe heritage, based on my experience as an oboist (fig. 9), revealed the complexity of musical instrument heritage. This insight led to the decision that a selection of essential heritage aspects for the rubab would be needed (RQ2) to keep the project feasible. By the end of the day, I had developed a first prototype (prototype 1 in Appendix B).

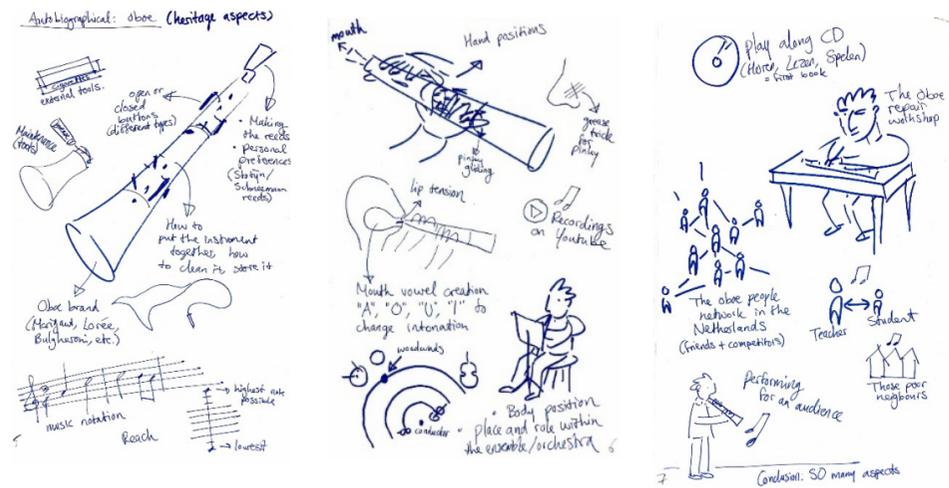


Figure 9: A collection of sketches representing different heritage aspects of the oboe.

Interviews with rubab players (RPs)

To explore the heritage of the rubab, and accurately preserve rubab culture, I conducted two interviews with rubab players (RP1 in person, RP2 via video call). I developed a set of heritage aspect cards (fig. 10) as conversation starters, as advised by Annemiek van Boeijen, Assistant Professor of Industrial Design specialising in culture-sensitive design. These cards, each representing an aspect of rubab heritage (e.g. sound), were created based on my experience as an oboist, aspects identified in the literature review (Chapter 1.1), and desk research on the rubab. Additionally, a method known as "socio-cultural dimensions" (van Boeijen, 2015) was utilised to initiate discussions about the rubab's culture and uncover hidden rules or habits

associated with it. All heritage aspect cards and the socio-cultural dimension framework can be found in Appendix C.

Participants were asked to rank the cards by importance, add any missing aspects, and draw a 'red border' to separate essential from non-essential elements for preservation, and explain their choices (fig. X). RP1 used physical cards; RP2 completed the task on a Miro board.

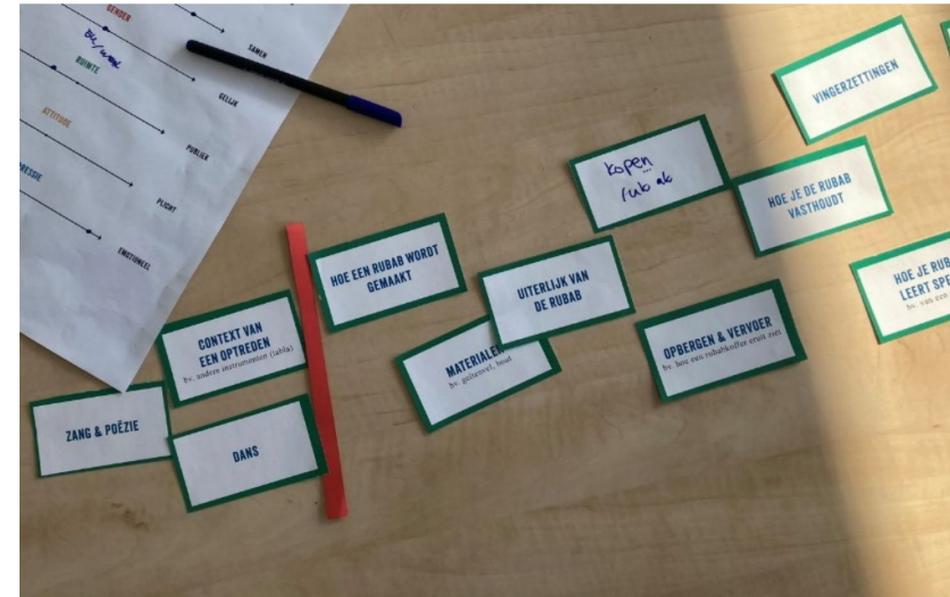


Figure 10: Heritage aspect cards and socio-cultural dimensions framework (on the left).

Rubab lessons

I took a practical rubab lesson from rubab player Mohammad Mohammadi, during which he taught me the basics of playing the instrument (fig. 11). This helped me get a basic understanding of the playing technique and physical sensation of playing the rubab.

In a separate online theoretical lesson, he introduced me to the fundamentals of the *sargam* notation system and explained the standard finger positions for playing the rubab in D major, the most commonly used key in traditional rubab music. Together, we completed a chart I had prepared to document the finger positions for the different music notes (fig. 12). For detailed chart, see Appendix D.



Figure 11: Practical rubab lesson from Mohammad Mohammadi.

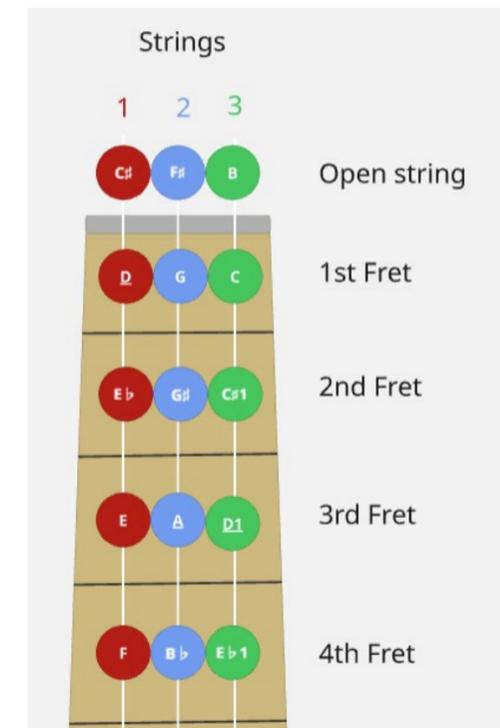


Figure 12: Fingerboard of rubab viewed from above, filled in together with RP1. The amount of circles is the amount of notes on the rubab: 15 in total.

Conversations with Afghan diaspora members

I organised a session with four members of the Afghan diaspora in the Netherlands, initially viewed as one of the target groups, all of whom (selection criteria):

- were of Afghan origin
- had grown up outside Afghanistan
- had limited familiarity with the rubab
- did not play the rubab

A balanced amount of female and male participants was recruited through social media by Stichting Solh. We met in an Afghan restaurant (fig. 13). Originally designed as a generative research session, the plan involved written reflections and crafting activities. However, once the session began, it became clear that this format was unsuitable. Participants preferred speaking freely, spontaneously sharing stories and memories over writing and silent reflection, and participants preferred a shift to non-Afghan people as the target group for the project. Adapting to the moment, I shifted the session to an open conversation format, leading to powerful, emotional insights that reshaped the direction of the project (see chapter 1.3).



Figure 13: Conversations with members of the Afghan diaspora.

Generative sessions with culturally interested non-Afghans

A generative session was conducted with six culturally interested non-Afghan participants to explore what makes a cultural encounter meaningful for this target group. The group consisted of:

- Three IDE students (age 25-26)
- One Aerospace Engineering student (age 24)
- a Tanzania-based artist (age 56)
- a psychologist (age 25)

The session drew on methodologies from *The Convivial Toolbox* (Sanders & Stappers, 2012) and *Road Map for Creative Problem Solving Techniques* (Heijne & van der Meer, 2019), and during preparation I consulted associate professor Froukje Sleeswijk Visser, who is specialised in generative design. Participants were asked to bring a past meaningful cultural encounter, and were encouraged to reflect on this memory to identify what had made those experiences meaningful. Utilising the Path of Expression framework (fig. 14) from *The Convivial Toolbox*, participants began with their memories and then transitioned to envisioning future scenarios for meaningful cultural encounters with the rubab's heritage.

Participants viewed a short video about the rubab and Afghanistan to provide context and avoid stereotypical assumptions. They brainstormed on the question 'How to create a personal connection between you and the rubab's cultural heritage?' (fig. 15) After clustering their ideas together, the group split up into three duos and crafted meaningful encounters with the rubab in the form of doll house prototypes (fig 16).

The full session plan can be found in appendix E.

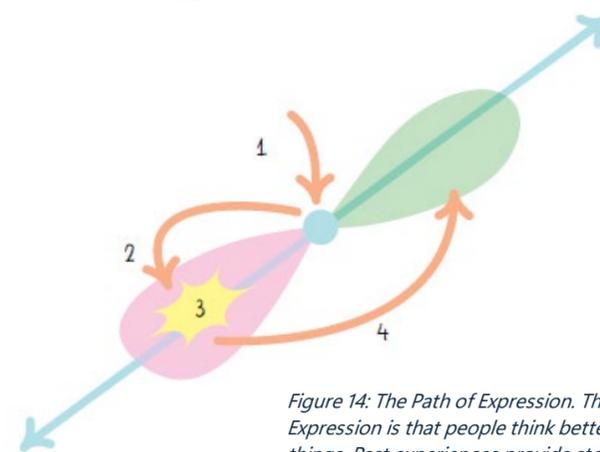


Figure 14: The Path of Expression. The idea behind the Path of Expression is that people think better in stories than in abstract things. Past experiences provide stories. Future experiences have not happened yet and are abstract. So by reflecting using stories from the present (1) and/or past (3), it is easier to move towards desired future experiences (4). Image by Sanders & Stappers, 2012



Figure 15: The participants brainstormed on the question 'how to create a personal connection between you and the rubab's heritage?'



Figure 16: The participants crafting their envisioned meaningful encounters with the rubab's heritage.

1.1 Exploring the Status Quo

This chapter concerns the following research question and sub-questions:

RQ1. How have interactive technologies been employed to preserve the tangible and intangible heritage of musical instruments?

- What types of interactive technologies have been applied to the preservation of musical instrument heritage?
- How have different interactive technologies contributed to the preservation of tangible aspects of musical instrument heritage?
- How have different interactive technologies contributed to the preservation of intangible aspects of musical instrument heritage?

Method:

- Literature review

Many musical instruments are at risk of ‘disappearing’ due to a range of challenges, including globalisation, restrictive laws that hinder musical expression, the complexity of playing techniques, and physical inaccessibility (UNESCO, 2009; UNESCO, 2021; Yu et al., 2021). Digital technologies offer new possibilities for the preservation of these endangered instruments by providing innovative ways to capture and interact with their heritage. Comprehensive preservation is crucial, as the loss of such instruments would mean the disappearance of unique and culturally rich musical traditions.

The aim of this literature review is to examine how different interactive technologies have been used to preserve the tangible and intangible aspects of musical instrument heritage, and to identify gaps in the application of interactive technology for the purpose of musical instrument heritage preservation.

The paper starts with a description of the paper’s contribution. Then, the literature selection method is explained, followed by the literature review. The discussion presents the comparative analysis of different technologies, leading to the identification of research gaps. The paper ends with a conclusion.

For clarity, all musical instrument names in the paper are italicized (e.g., *bonang*, *pan flute*).

This literature review contributes to the field of musical instrument heritage preservation by providing a comprehensive comparative analysis of Virtual Reality

(VR), Augmented Reality (AR), Graphical User Interface (GUI), and Sensor-Based Embedded (SBE) technologies. It identifies the strengths and limitations of each technology in preserving both tangible and intangible aspects of musical instruments. The review highlights VR as the most comprehensive solution, while pinpointing the challenges that remain, particularly in accurately replicating physical playing sensations. Furthermore, it emphasises that combining multiple interactive technologies could address existing gaps and enhance preservation efforts.

Method

Eligibility criteria

A systematic literature search was conducted to identify relevant studies concerning the preservation of musical instrument heritage through interactive technologies. Table 1 specifies the inclusion criteria, whereas Table 2 specifies the exclusion criteria.

#1	The paper has one of the following technology terms in the abstract, along with one of the topic I and one of the topic II terms. Technology: “interactive technolog*”, “virtual”, “virtual reality”, “augmented reality”, “extended reality”, “mixed reality” or “mixed-reality”, “VR”, “AR”, “MR”, “XR”, “embodied interaction”, “tangible interaction”, “HCI”, “human-computer interaction”; Topic I: “music* instrument”, “VRMI”, “traditional musical instrument”, “music education”, “music creation”, “instrument playing”; Topic II: “heritage”, “preserv*”, “conserv*”, “protect*”, “inherit*”.
#2	The paper is a journal article or a conference paper.
#3	The paper is written in English, Dutch, German or Swedish.
#4	The paper is published in the past 15 years (2010-2025).

Table 1. Inclusion criteria.

#1	The paper does not relate to musical heritage preservation.
#2	Access to the paper is denied.
#3	The paper is written in another language than English, Dutch, German or Swedish.
#4	The paper is not available.
#5	The paper is older than 15 years.
#6	The paper does not consider the use of interactive technology.
#7	The paper does not relate to practical implementation, but is only theoretical.

Table 2. Exclusion criteria.

Search strategy

The search strategy comprised two main stages: an initial search through online databases and a review of the papers found in the first stage.

In the first search stage, literature was identified by conducting an extensive search across three prominent databases in the field human-computer interaction: Scopus, IEEE Xplore, and the ACM Digital Library. The search aimed to cover studies related to interactive technologies and musical instrument heritage preservation. The search was conducted on January 15, 2025. The search query used was as follows: *Abstract containing (“interactive technology” OR “virtual” OR “virtual reality” OR “augmented reality” OR “extended reality” OR “mixed reality” OR “mixed-reality” OR “VR” OR “AR” OR “MR” OR “XR” OR “embodied interaction” OR “tangible interaction” OR “HCI” OR “human-computer interaction”) AND (“music* instrument*” OR “VRMI” OR “traditional musical instrument” OR “music education” OR “music creation” OR “music playing”) AND (“heritage” OR “preserv*” OR “conserv*” OR “protect*” OR “inherit*”).*

The papers found through this search were analysed to ensure their eligibility. Three additional papers were found through the state-of-the-art references in the full-text studies, and these were also included in the review.

Study Selection

The search found 27 papers based on the initial query. After applying the exclusion criteria, 17 papers were left for full review: 10 from Scopus, 1 from the ACM Digital Library, and 6 from IEEE Xplore. Together with the three additional papers, there was a total amount of 20 papers to be reviewed.

Results

Interactive Technology Types

The selected studies applied different interactive technologies to the preservation of musical instrument heritage. The interactive technologies applied can be classified into four categories: Virtual Reality (VR), Augmented Reality (AR), Graphical User Interface (GUI) technology, and Sensor-Based Embedded (SBE) technology.

Tangible Aspect Preservation

The tangible heritage aspects identified in the different technology applications are: appearance and physical properties. This section describes for each of the interactive technologies, if and how they have been employed for each aspect's preservation.

Appearance

VR has been employed to preserve the real-world appearances of musical instruments by accurately simulating their 3D shape, material and texture (Shi et al., 2019; Wu et al., 2021; Saffian et al., 2023). Within the immersive VR 3D environment, users can closely watch the instruments and even virtually 'touch' them (Shi et al., 2019; Wu et al., 2021).

AR technology has been used to merge a live recording of a player, captured via a 3D camera, and a virtual representation of the *guqin*, a traditional Chinese string instrument, thereby communicating the instrument's appearance on a screen display, although not in an immersive environment. Additionally, an educational pop-up sketchbook employed dynamic AR overlays to illustrate what different musical instruments look like (Ho et al., 2022).

Sensor-based embedded technology has not been used to preserve the appearance to the same extent as VR and AR. Instead, it primarily conveys the instrument's basic layout and look through the positioning of the sensors, and a simplified 2D representation on a connected display (Siregar et al., 2021; Hu et al., 2020; Avanzini et al., 2016). For example, Siregar et al. (2021) developed a sensor-based system that represents the layout of the *bonang* percussion instrument. While the sensors themselves do not resemble the actual *bonang*, their arrangement—two rows of six *bonangs*—is reflected in the sensor layout of the Arduino system. The accompanying smartphone application displays a simplified 2D drawing of the *bonang's* top view (Siregar et al., 2021).

GUI technology has been used to digitally represent musical instruments using 3D models (Qingtang et al., 2021; Brunt & Johnson, 2013; Zhou & Du, 2022). Through a mouse or touch controls, these 3D models can be rotated and moved, which helps the user to understand the instrument's shape and structure.

Physics

Among the four interactive technology categories, only VR has been used to simulate the physics of the real world; by including gravity and object collision detection in the virtual simulation, the physical properties and movements of the instrument in the real world can be digitally preserved (Shi et al., 2019; Wu et al., 2021).

Intangible Aspect Preservation

The intangible heritage aspects identified in the different technology applications are: playing technique, physical playing sensation, sound, performative context, music notation, musical repertoire, and background knowledge. This section describes for each of the interactive technologies, if and how they have been employed for each aspect's preservation.

Playing Technique

VR has been used to enable users to virtually play instruments within immersive 3D environments. Designed as a teaching platform, some VR systems enhance learning experiences by providing auditory, haptic, or visual feedback. For example, certain systems highlight the chime that should be played next, score performance accuracy, and offer playing tips (Shi et al., 2019; Wu et al., 2021; Syukur et al., 2023; Lyu & Zhang, 2024). Beyond teaching, VR has also been employed to provide a 'free performance' virtual instrument for those who already know how to play the instrument (Lyu & Zhang, 2024).

AR has been used to simplify the learning process for beginners, particularly the *guqin*, by reducing the required learning time (Yu et al., 2021; Zhang & Bryan-Kinns, 2022; Zhang et al., 2015). This is achieved by replacing the *guqin's* complex traditional musical notation with dynamic instructional AR visualisations on the virtual or physical instrument. Simplified symbols indicate where the user should place their fingers on the strings. Zhang & Bryan-Kinns (2022) employed a 3D camera and a projector to capture the user's playing and project instructions onto the instrument. Yu et al. (2021) used a Head-Mounted Device (HMD) to display dynamic visual instructions mapped onto the instrument. By combining AR with a physical *guqin*, these systems effectively preserve playing techniques for individuals who have access to the instrument (Yu et al., 2021; Zhang et al., 2015).

GUI-based systems have been employed to preserve the playing techniques of various instruments. For the *sanxian*, a desktop GUI offers a gamified teaching approach, guiding users from basic to more advanced techniques while providing feedback based on their performance (Qingtang et al., 2021). Similarly, the iGamelan website allows users to practice playing different instruments within the Gamelan ensemble, offering both visual and auditory feedback to support learning and improve accuracy (Brunt & Johnson, 2013). Smartphone GUIs have made instrument playing simulations highly accessible, as users can play the smartphone *pan flute* at any time and location (Avanzani et al., 2016).

Sensor-based embedded technology has been employed to create free performance instrument simulations that users can play, but it has not been widely used to teach how to play the instruments (Siregar et al., 2021; Hu et al., 2020; Avanzani et al., 2016).

However, this technology has been applied to preserve playing techniques by recording the gestures of professional Gamelan players. In this approach, accelerometers were attached to each finger to capture movement data, which was then analysed using machine learning techniques (He et al., n.d.).

Physical Playing Sensation

Virtual Reality

Various VR simulations have been developed to replicate the physical playing sensation of percussion instruments, where users "hit" virtual instruments using virtual hammers or mallets (Shi et al., 2019; Wu et al., 2021; Saffian et al., 2023; Syukur et al., 2023; Lyu & Zhang, 2024). In all these instances, users hold standard handheld VR controllers while performing the actions. According to Saffian et al. (2023), "playing with the hand controllers simulates the natural way of playing the *bonang* using a pair of mallets." Similarly, Lyu & Zhang (2024) argue that VR controllers are well-suited for mimicking the natural hand movements involved in striking a mallet and employ controller vibrations to approximate the sensation of impact (Lyu & Zhang, 2024).

Only one example in the literature describes a setup where a physical mallet was attached to a VR controller and used to strike a physical 'stand-in object,' enabling users to fully experience the tactile feedback of a mallet rebounding from a *drum's* surface (Granzow & Camci, 2020). Most VR instrument simulations found in the literature focus on percussion instruments.

In contrast, two VR string instrument systems allow users to "pluck" virtual strings in mid-air. These systems track hand gestures using a Leap Motion controller, an external optical motion-sensing device (Hariadi et al., 2017; Syahidi & Kiyokawa, 2023). However, plucking strings in mid-air does not accurately replicate the tactile sensation of plucking a string. Furthermore, in one VR string instrument system, the virtual *panting* instrument is displayed lying flat on a surface, differing from the natural position of holding the instrument, which is similar to holding a guitar (Syahidi & Kiyokawa, 2023).

Another example found in the literature involves a virtual *kompang* percussion instrument designed with Leap Motion control to capture user gestures (Leng et al., 2018). In this case, users interact by "slapping" mid-air, which fails to provide the physical sensation of actual hand slapping.

Augmented Reality

AR has not been utilised to replicate the physical sensations of playing real instruments. One AR application used mid-air plucking gestures as an input method for playing a virtual AR *guqin*, with the gestures captured through a 3D camera (Yu et

al., 2021). However, similar to VR mid-air interactions, these plucking gestures do not resemble the physical sensation of plucking a real instrument.

GUI Technology

Regarding GUI-based applications, users interact with virtual instruments via mouse and keyboard on desktop devices or through touch input on smartphones (Qingtang et al., 2021; Brunt & Johnson, 2013; Zhou & Du, 2022). These interactions do not accurately replicate the physical sensations of playing.

SBE Technology

Sensor-Based Embedded technology has been employed to approximate the physical interaction between the player and the instrument, offering a more tangible and natural playing sensation. One example involves an external device equipped with physical buttons that mimic the holes of a wind instrument. This device can be held in a manner similar to the original instrument. When the user presses a button (input sensor), a signal is transmitted via Bluetooth to a second computer, where the corresponding sound is produced. Although the user must still click with a computer mouse to simulate blowing, the act of holding the external device and pressing its buttons closely resembles the sensation of playing a real flute (Hu et al., 2020).

Another SBE technology installation replicates the blowing interaction of a *pan flute* by positioning microphones behind different holes. When the user blows into a specific hole, the corresponding microphone detects the airflow, triggering the playback of the appropriate sound (Avanzini et al., 2016). While the instrument is not held in the same way as a traditional *pan flute*, the blowing interaction effectively mirrors the experience of playing a real one.

Smartphone-embedded sensors have also been utilised to enhance the natural playing sensation. A smartphone-based *pan flute* simulation allows the user to play by simultaneously blowing air and moving the smartphone below the mouth, mimicking the physical playing interaction. The smartphone's gyroscope, accelerometer, and front camera detect the user's mouth position relative to the virtual *pan flute* pipes displayed on the screen, enabling the appropriate sound to be played (Avanzini et al., 2016).

Sound

All four interactive technology types have been used to communicate the sound of the instrument. For all virtual instruments, the corresponding tones can be heard while playing.

Since some percussion instruments give different tones depending on the place of impact, different VR systems play the sound based on where the mallet hits (Shi et al., 2019; Saffian et al., 2023; Lyu & Zhang, 2024). Some VR systems also included 'dynamic control' in their system, which means that the sound of the instrument is

louder when the speed of hitting the percussion instrument is larger (Saffian et al., 2023; Lyu & Zhang, 2024).

In addition to conveying sound, AR has been used to teach children the sounds of various musical instruments through a sound recognition quiz (Ho et al., 2023).

In different GUI applications, the sound is also communicated through videos of performances (Qingtang et al., 2021; Brunt & Johnson, 2013; Zhou & Du, 2022). The iGamelan system also plays sounds when users click on parts of the virtual instruments (Brunt & Johnson, 2013).

Performance Context

Multiple VR applications provide performance scenes to choose from, relating to the context of the instrument's performance. The scenes are simulated as 3D immersive environments (Shi et al., 2019; Wu et al., 2021). Lyu & Zhang (2024) included a very elaborate 3D immersive environment of the Confucian *chime* ceremony by 3D modelling the Dacheng Hall, a location where Confucian ceremonies take place, along with its related buildings. The musical instruments were arranged strictly according to traditional norms, combined with other ceremonial furniture and objects, thereby effectively recreating the authentic setting of *chime* playing in a Confucian ceremony (Lyu & Zhang, 2024). Saffian et al. (2023) included a 'Traditional Mode' of playing the *bonang* that can only be executed by sitting down on the floor, thereby letting the user physically experience this part of the *bonang's* traditional performance. Syukur et al. (2023) allow the user to select instruments from a variety of Gamelan instruments, thereby providing some performance context.

One of the GUI applications featured a karaoke-style play-along function with accompanying audio, enabling students to understand how their individual parts aligned with the rest of the ensemble, thereby reflecting a part of the performance context of ensemble playing (Brunt & Johnson, 2013).

AR and SBE technology have not been used to preserve the performance context.

Music Notation

VR has been used to preserve musical notation (Shi et al., 2019; Saffian et al., 2023; Syukur et al., 2023). Shi et al. (2019) incorporate a virtual book within their VR *chime* playing experience, with musical notation to follow. In the VR *bonang* simulation, the musical notation of a traditional melody is displayed, thereby familiarizing the user with the musical notation and some musical repertoire of the instrument (Saffian et al., 2023).

The virtual AR *guqin* implemented the explanation of the original *guqin* musical notation on a screen display. This adds to the preservation of the musical notation and the user's understanding of it.

All GUI systems found in literature include music notation to aid in learning the instruments. The Sanxian system displays musical notation as part of its guided learning process, helping users understand the music they are playing (Qingtang et al., 2021). Similarly, the Gamelan system provides notation to guide users through the pieces, allowing them to practice traditional Gamelan music (Brunt & Johnson, 2013).

Sensor-based embedded technology has not been used to preserve the instrument's musical notation.

Musical Repertoire

Lyu & Zhang (2024) state that VR enables users to engage with music in a more interactive and participatory manner. Indeed, different VR systems provided musical repertoire, often traditional tunes, to virtually play (Saffian et al., 2023; Lyu & Zhang, 2024; Syahidi & Kiyokawa, 2023). One VR Gamelan game even incorporated an extensive collection of 40 different Gamelan compositions (Syukur et al., 2023). Different AR and GUI applications also implemented musical repertoire to play (Yu et al., 2021; Qingtang et al., 2021; Brunt & Johnson, 2013). GUI technology has also preserved musical repertoire through videos of performances (Zhou & Du, 2022). Sensor-based embedded technology has not been used to preserve the instrument's musical repertoire.

Background knowledge

One paper describes how a VR object, either the virtual musical instrument or a related object in the VR simulation, can be grasped by the user to get a detailed object description (Wu et al., 2021).

In one of the AR applications, Yu et al. (2021) implemented several pieces of *guqin* music that can be played, each with corresponding scenic background pictures or videos that related to the music pieces, thereby preserving some of the instrument's cultural context.

All GUI applications identified in the literature offer users access to cultural and historical information about the instruments (Qingtang et al., 2021; Brunt & Johnson, 2013; Zhou & Du, 2022). The iGamelan system, for instance, includes videos, pictures, and textual information about Gamelan culture and performance practices (Brunt & Johnson, 2013). The *sanxian* system provides modules that explain the instrument's history, structural characteristics, and music theory, enabling users to gain a comprehensive understanding of the instrument and its cultural significance (Qingtang et al., 2021).

One system that used sensor-based embedded technology did communicate background knowledge, but only through the combination with a touchscreen (GUI technology) that allowed users to access textual and audio-visual information about an ancient *pan flute* (Avanzini et al., 2016).

Discussion

Table 1 shows for each of the four interactive technologies for which aspects they have been used, and my classification on how accurately the technologies have preserved the different aspects:

- “√” indicates that the technology has been used to preserve the specific aspect.
- “X” indicates it has not been used for that specific aspect.
- Green background indicates that the technology’s employment has resulted in an accurate preservation of the heritage aspect.
- Yellow background indicates that the technology’s employment has resulted in a limited preservation of the heritage aspect.
- Orange background indicates an inaccurate preservation.

		VR	AR	GUI	SBE
Tangible Aspects	<i>Appearance</i>	√	√	√	√
	<i>Physics</i>	√	X	X	X
Intangible Aspects	<i>Playing technique</i>	√	√	√	√
	<i>Physical playing sensation</i>	√	√	√	√
	<i>Sound</i>	√	√	√	√
	<i>Performance context</i>	√	X	√	X
	<i>Music notation</i>	√	√	√	X
	<i>Musical repertoire</i>	√	√	√	X
	<i>Background knowledge</i>	√	√	√	X

Table 3: Technology employment for different musical instrument heritage aspects (√=preserved, X=not preserved) and their preservation accuracy (colour).

VR has been the most comprehensive technology. It has been used for the preservation of all heritage aspects. All tangible aspects and most of the intangible aspects have been preserved accurately through the use of VR. Its immersive capabilities enable users to interact with virtual instruments in an almost lifelike environment. Notably, VR has been widely used to simulate percussion instrument experiences, with a focus on replicating mallet striking interactions. Some attempts have been made to simulate interaction with string instruments using mid-air gestures, but these implementations fail to accurately replicate the physical sensations of playing. This points to a notable gap in the exploration of accurate physical playing sensation interactions for non-percussion instruments in VR.

AR has been primarily used for educational purposes, effectively enhancing learning experiences by overlaying instructional visualisations on physical instruments. However, AR has not been used to simulate the physical sensations of playing instruments, or to preserve performance context or the instrument’s physical properties other than (limited) appearance.

GUI technology has proven useful in digitally representing musical instruments and supporting learning through interactive interfaces. It effectively preserves aspects such as musical notation, musical repertoire, background knowledge, and playing technique, but lacks the ability to replicate accurate physical playing sensations.

SBE technology is the technology that most accurately conveys physical playing sensations through the use of physical components and sensors. However, its use has been limited in conveying appearance (inaccurate), and most of the aspects preserved through the other technology types, have not been preserved through the use of SBE technology, or only in combination with GUI technology.

Each interactive technology has demonstrated strengths in particular areas. VR excels in immersion, accessibility and comprehensive preservation, AR in enhancing real instrument learning. GUI technology excels in offering structured educational content, and SBE technology in providing tactile experiences that come close to the physical playing sensation. Still, the described gaps and limitations remain.

Future research and design projects could benefit from integrating multiple technologies to address these gaps. By combining VR’s immersive environments, which excel in appearance preservation, with SBE technology’s tactile components and sensors, the realism of playing experiences could be significantly enhanced and a more accurate preservation could be achieved. Moreover, incorporating VR or AR with SBE technology could offer a more informative experience.

Limitations of the study

This literature review offers important insights into the use of interactive technologies in the preservation of musical instrument heritage. However, there are a few limitations to consider. The review focused on studies from three specific databases (Scopus, IEEE Xplore, and the ACM Digital Library), which may not have captured all relevant research from other sources. Additionally, the timeframe of 2010 to 2025 was chosen to focus on recent developments, meaning older studies were not included, though they may still offer some valuable perspectives.

Conclusion

The comparative analysis of VR, AR, GUI, and SBE technologies in preserving musical instrument heritage highlights the strengths and limitations of each approach. VR has emerged as the most comprehensive solution, offering high accuracy in

preserving both tangible and intangible aspects through immersive experiences. However, challenges persist in accurately replicating physical playing sensations for non-percussion instruments. AR has demonstrated effectiveness in educational applications, enhancing learning experiences through instructional overlays, yet falls short in replicating physical sensations and performance contexts. GUI technology excels in structured educational content but, too, lacks the capacity to accurately simulate playing sensations. SBE technology offers the most accurate representation of physical playing sensations but remains limited in preserving other heritage aspects.

Future research should explore “hybrid” solutions that combine the immersive capabilities of VR with the physical components and sensors of SBE technology, to create more realistic playing simulations. Additionally, integrating AR or VR with SBE technology could result in more informative experiences. Exploring such combinations of interactive technologies may lead to a more comprehensive and accurate preservation of musical instrument heritage.

This conclusion led to the formulation of Design Goal 2: Design a hybrid interactive technology experience that conveys the rubab’s physical playing sensation through a combination of Virtual Reality and sensor-based embedded technology.

1.2 Exploring the Why

This chapter concerns the following research question:

RQ2. According to the Afghan diaspora, what should be the message of the preservation project?

Methods:

- Session with four members of the Afghan diaspora
- Afghan Diaspora Dialogue
- Interviews with two rubab players
- UNESCO Consent of Community letters

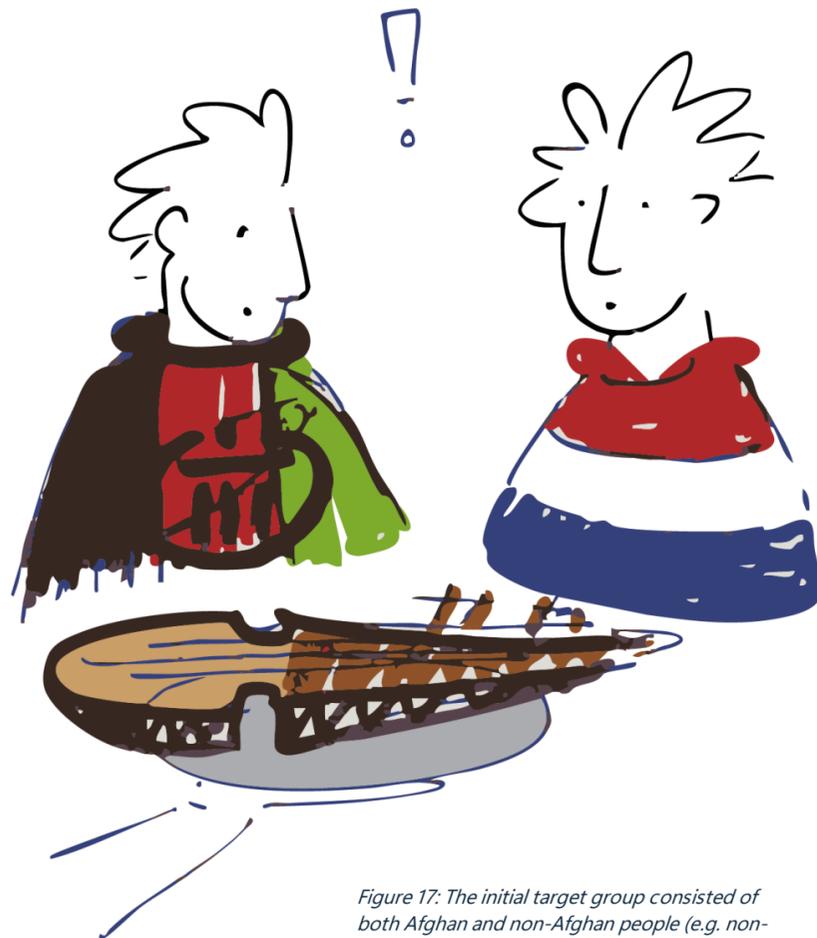


Figure 17: The initial target group consisted of both Afghan and non-Afghan people (e.g. non-Afghan Dutch)

Initial target groups

At the start of the project, the intention was to design an experience that would target both Afghans and non-Afghans (fig. 17). This included members of the Afghan diaspora and non-Afghans with an interest in culture. The idea was that promoting the rubab in countries like the Netherlands, where there are no restrictions on music, could help preserve the rubab's cultural heritage.

For Afghans living outside their home country, the design could offer a way to reconnect with their cultural roots, especially for those who may feel a sense of disconnection from their cultural background. For non-Afghans, an introduction to the rubab could provide a richer perspective on Afghanistan, beyond the focus on war and hardship.

Refocusing the target audience

The conversations with Afghan diaspora members (ADM 1-4) revealed that while younger members of the Afghan diaspora may be less familiar with the rubab, the instrument is still present in their collective memory:

ADM2: "I think every Afghan knows rubab, but I think only the new generation, so the kids who were born from ... 2010, that they are starting to know the rubab less and less."

ADM1: "Maybe not by name, but definitely the sound ... I think that generation won't listen to the [rubab] music attentively or explicitly, because it's already familiar to them in the back of their minds."

Although the younger diaspora may not actively listen to the rubab, it remains embedded in family traditions and the soundscape of Afghan weddings and gatherings. Thus, participants felt that introducing the rubab to Afghan youth, while valuable, was not the most urgent goal.

Instead, they advocated strongly for preserving and sharing the rubab's heritage with non-Afghans, to change the way Afghanistan is perceived:

ADM1: "I think it would be much nicer to attract people who know absolutely nothing about rubab and introduce precisely those people to the instrument, to the whole history of rubab, so that people become more and more familiar with rubab than the group that knows it already."

ADM2: "And through rubab also gets acquainted actually eventually with Afghanistan. To associate Afghanistan not only with war and terrorism and misery, but also with beautiful things, with music."

Preserving a symbol of Afghan beauty

Participants spoke passionately about how Afghanistan's beauty — its music, landscapes, food, and hospitality — is overlooked in the global West:

ADM2: "When you think of Afghanistan, when you think of Afghans, an average Western person thinks of terrorism, of Taliban ... The beauty of Afghanistan, the decent people, the hardworking people, the beautiful culture, the warmth ... you don't see that anywhere ... All that misery, true, it's certainly part of the truth, but that doesn't describe Afghanistan. That's not the whole of Afghanistan."

ADM4: "Most people have the image [of Afghanistan] of the bombed-out cities ... But it is so immensely rich in landscape ... that combination with [rubab] sound and that landscape ... did give me some peace just now."

The rubab, as described by members of the Afghan diaspora, is more than just an instrument; it is a symbol of Afghan beauty, identity, and resilience. Its sound evokes pride, nostalgia, and a deep emotional connection to the homeland. This symbolic weight makes its preservation essential. In a global context where Afghanistan is often reduced to images of conflict and crisis, the rubab offers a way to share a more nuanced view of the country. As one participant put it:

ADM3: "A lot of Afghan cultural heritage has been taken from us, except the dirty geopolitics, yes, we are in the middle of that."

In the spirit of the Dutch saying "unknown makes unloved" (*onbekend maakt onbemind*), the goal remains to preserve and protect the heritage of the rubab, but the preservation takes the form of cultural promotion to non-Afghans, deploying the rubab as a symbol of Afghan beauty.

A broader desire to share outwards

This desire to present a fuller image of Afghanistan to non-Afghans is also expressed in broader community dialogues. During the Afghan Diaspora Dialogue, host Sodaba Abibzay noted:

"I really notice that we Afghans ... in addition to what you do, tell extra about your history, yourself, your country, that's kind of in all of us, we all want to propagate it and bring it out, and I think it also has to do with that maybe sometimes there's misconception of what Afghanistan is, who Afghans are, and that we're struggling with that a little bit."

Psychologist and storyteller Shah Tabibi explains this desire to share heritage outwards as:

"...I also think that storytelling is also perhaps a result of that displacement we were just talking about, as a psychological effect of finding yourself, and wanting to define yourself."

In one of our meetings, Kamal Nasrati from Stichting Solh also captured the sentiment of introducing non-Afghans to the rubab:

"The rubab is Afghanistan. How wonderful would it be if even non-Afghans would think that when they hear it?"

Conclusion

These insights led to a refocus of the target group. The design will now target only culturally interested non-Afghans, as a way to reveal the richness of Afghan culture, deploying the rubab as a symbol. According to the Afghan diaspora, there is a misconception in the West about Afghanistan as solely a country of conflict and crisis, and promoting the rubab's heritage can contribute to a more nuanced understanding of Afghan culture (fig. 18 and 19).

Regarding my concerns about possible cultural appropriation, there appears to be no resistance within the Afghan community towards non-Afghans learning the rubab—in fact, it is welcomed. Rubab Player 2, for instance, praised American musician John Baily for his dedication to learning the instrument, and the UNESCO letters celebrate Ustad Mohammad Omar's (a valued rubab player and teacher from the past century) contributions in teaching the rubab to American students. Some members of the Afghan diaspora even suggested integrating the rubab into Dutch music education, alongside instruments like the piano and guitar.

With this in mind, the project aims to create an experience for non-Afghans that preserves the rubab's heritage, sharing the beauty of Afghan culture.



Figure 18 and 19: In the global West, Afghanistan is often associated with war and conflict, and its beauty (e.g. its nature and music) is often overlooked. Image sources: Al Jazeera English, 2012 (up); Habibi, 2021



1.3 Exploring the Heritage Aspects

This chapter answers the following research question:

RQ2. What are the essential aspects of the rubab's heritage that should be preserved (through this project)?

Method:

- Interviews with two rubab players
- UNESCO Consent of Community letters
- Session with four members of the Afghan diaspora

Towards a selection of heritage aspects

The graduation-in-one-day exercise included an autoethnographic brainstorm on the cultural heritage of the oboe, drawing from my own experience as an oboist. This revealed the wide range of heritage aspects tied to the oboe and led to the realisation that the rubab, also a musical instrument, likely has a similarly rich heritage. This insight made it clear that preserving *all* aspects of the rubab's heritage would not be feasible within the scope of this project. A focused selection was therefore necessary.

In order to make this selection of essential heritage aspects, I organised the rubab player interviews and the session with the Afghan diaspora members, and read the UNESCO letters., providing both player and non-player perspectives on the rubab.

I extracted quotes related to the rubab's heritage from the letters and audio transcripts, then grouped them thematically using *on-the-wall* analysis (Sanders & Stappers, 2012, p. 207). While light in analytical depth, this method suits the small sample size and provides meaningful, design-relevant insights (Sanders & Stappers, 2012, p. 207).

The resulting insights, along with all their supporting quotes, are included in Appendix **F**.

Clustered Heritage Aspects

This section presents each of the identified heritage aspects, grouped into distinct themes of rubab heritage:

- Theme 1: Cultural-historical context
- Theme 2: Learning to play
- Theme 3: Physical and performative aspects of playing
- Theme 4: Construction, materials & maintenance
- Theme 5: Performative context

Each aspect—or combination of aspects—is presented alongside a visual icon, the corresponding insight(s), a significance score, and one quote that illustrates the connection between the insight and the underlying data (all supporting quotes can be found in Appendix F).

The significance score, shown as a visual scale, reflects the importance of each aspect within the rubab's heritage. These scores are derived from the insights gathered about each aspect. Figure 20 displays the significance symbols and their meanings.

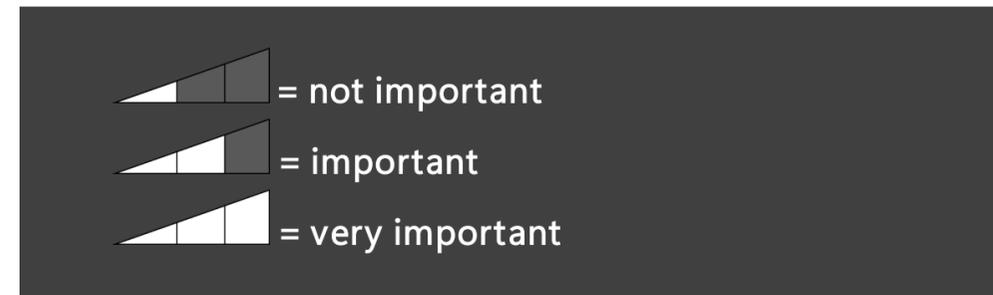


Figure 20: the different significance score options and their meanings.

The **ADVANCED** label (short for *Advanced Player*) indicates that a particular aspect is only relevant at a higher level of rubab playing, as opposed to for beginners or non-players. This distinction is important when selecting design criteria, as the intended design is not aimed at advanced players. Whether an aspect qualifies as "advanced" is determined based on related insights, supporting quotes, contextual information, and the playing level of those who mentioned it.



A part of Afghan identity

The cultural significance of the rubab is a very important aspect. For Afghan people, all over the world, the rubab evokes pride and emotional connection to their roots. It therefore holds great cultural significance for the Afghan community and is an important part of the Afghan identity.

UNESCO Letter #2: "...Rubab acts as a solid foundation for the authentic music of my nation ... The people of Afghanistan know this instrument as they know their own flesh and blood"



The Sultan of Rubab: Ustad Mohammad Omar

Ustad Mohammad Omar (1905-1980), nicknamed the King/Sultan of Rubab, is considered an important figure in the history of the rubab, because of his contribution to the development and promotion (teaching rubab in the USA) of the instrument. He still serves as an example for rubab players.

UNESCO Letter #11: "Master Mohammad Omar, who has the title of "King/Sultan of Rubab" in Afghanistan and the Indian subcontinent, brought the evolutionary process of this instrument to the level of perfection..."



History (other than the relation to Afghanistan)

Although knowing the rubab's history is a must for rubab players, there is not much information available about the rubab's origins. The historical relation to Afghanistan seems to be the most important part of the history.

RP1: "The history of the rubab isn't very well documented, as in, they can't say, 'It originated at this time, this person created it,' and so on."



The relation to Afghanistan

Highlighting the rubab's relation to Afghanistan is considered very important for Afghan people, because they are proud that the Rubab is Afghan heritage. The rubab's relation to Afghanistan is considered important because the Afghan people have experienced much loss and they want to cherish and protect their remaining cultural heritage against cultural appropriation by others. Among Afghan people, some see the rubab as solely Afghan heritage, while others see it as part of a shared cultural heritage with countries that were once part of the Greater Khorasan region.

RP1: "But it's like hey, it's really Afghan. The techniques come from rubab players from Afghanistan. The best rubabs are made in Afghanistan. So that one is very important yes."

ADM3: "A lot has been taken away from us... A lot of Afghan cultural heritage has been taken from us, except the dirty geopolitics, yes, we are in the middle of that."



Regional diversity in rubab playing

One of the interviewed rubab players emphasised the importance of preserving Afghanistan's regional diversity in rubab playing, as it reflects the richness of Afghan culture, despite the unfortunate divisions between ethnic groups.

RP1: "To demonstrate that what Afghanistan is known for—being a war-torn country and all that—it also has this culture ... And to show that in that Afghanistan we have, and in that music we have, everyone, every taste, every population group, and ethnic group is represented, each in their own way. Yes. So, I would want to include that as well."



A symbol of Afghanistan's beauty

For Afghan diaspora members, the rubab is a symbol for the beauty of Afghan culture. Preserving the rubab's heritage is important because through the beauty of the rubab, non-Afghans can learn that Afghanistan is more than a war-torn country, and has a beautiful side too. Showing this beauty is important to the Afghan community, because it can counter the prejudices and stereotypes about Afghanistan and Afghan people they encounter.

ADM2: "And through rubab also gets acquainted actually eventually with Afghanistan. To associate Afghanistan not only with war and terrorism and misery, but also with beautiful things, with music."



Historical literature & poetry

Historical stories, literature and poems about the rubab and rubab players are highly valued because they underscore the historical relationship between the rubab and Afghanistan.

UNESCO Letter #7: "Historical research has shown that the Rubab instrument has been mentioned in the works of Persian-speaking thinkers, poets and mystics since the ancient past and this proves that this instrument has been historically used in the region that is today's Afghanistan, and also those of Iran, Tajikistan and Uzbekistan."



Face-to-face teaching

The personal interaction between student and ustad, where they sit in front of each other during the rubab lessons, used to be central to the learning process, but this is disappearing. The personal interaction is valued by players.

RP2: "He [his ustad] sits in front of me, he writes for me, and he tells me what I have to write in my book, in my notebook, yeah ... And in Afghanistan, a lot of people learn in front of each other ... meet his teacher personally."



Playing from memory **ADVANCED** and Music notation

Afghan rubab players mostly learn and play music from memory, as many musicians in Afghanistan, especially older generations, cannot read or write. Hindustani (Sa, Re, Ga, Ma, Pa, Dha, Ni, Sa) or Western (e.g. C D E F G A B C) music notation is used for teaching, but there is no single, official system. Since compositions are rarely written down, Afghan music is mainly passed down through personal teaching rather than documents. This explains why music notation is not considered an important heritage aspect.

RP2: "But this repertoire of composition, we don't have any book for that."

Theme 2: Learning to play



The ustad-student relationship

Having a good ustad (master) to learn from is highly valued among rubab players, because rubab players have a lot of respect for (their) ustads; they are their idols and examples. Still, rubab players also learn their skills from

YouTube these days, without an ustad.

RP1: "To become a student of an Ustad ... And then I can truly say, you know, that I am learning from him and that I am his student ... Then it takes on even more colour, scent, and shape, so to speak."



The instrument's difficulty

The rubab is a difficult instrument to play, and some skills, such as playing scales and tuning, take years of practice, and are too difficult to learn in a short time. Both players and non-players I spoke to, mention that the rubab is a difficult instrument.

RP1: "Depending on the note you press, you choose your scale. That is tricky, it really takes years to understand and do this, so to explain it now can be a bit much and confusing."

Theme 3: Physical and performative aspects of playing



How to correctly hold the rubab and plectrum

If you want to learn how to play, you need to know how to correctly hold the rubab and the plectrum, because only then you can start learning to play.

RP1: "After you know how to hold it, you can start that process [of learning to play the rubab]."



Playing the rubab (the basics)

To preserve the heritage of the rubab, it is essential that people continue to learn and play the instrument – especially in light of the ban on music in Afghanistan. Encouraging people to simply try playing the rubab is key; mastering it is not the priority. By learning the basics and experiencing the instrument firsthand, individuals are introduced to the rubab, and a foundation for further learning is established.

RP2: "I would like to offer an open opportunity to anyone interested from anywhere in the world to learn or experience it [the rubab]."



Finger positions

You can only play music when you know how to play the notes, and for that you need to know where to put your fingers on the frets.

RP1: "So the first [note] is the first [string] from above and then first fret. So all the way to the left ... yes, a bit more to the left ... And then the third [string] ... And then you need to practice these patterns so your fingers get used to them."



The physical playing sensation

When properly tuned, the physical sensation of playing the rubab, touching the strings and feeling the vibrations, is described as 'wonderful' and 'truly satisfying'.

RP1: "Yes, so if your rubab is properly tuned, and you're holding it, and you touch the string, you just feel it—you hear it and you feel it. Yes, it vibrates along, even through the wood. Yeah, okay, it's perfectly in tune, and that's wonderful. It sounds really strange, but it's truly satisfying."



Tuning the rubab **ADVANCED**

Knowing how to tune the rubab is very important for rubab players, because without tuning your instrument sounds bad and you cannot play. Tuning takes years of practice.

RP1: "Tuning the rubab is, I think, one of the most important things. Because if an instrument isn't tuned, it's useless."



Functions of parts **and** Names of Parts

Understanding the **functions of the different parts** of the rubab is important for understanding and playing the instrument. The importance of naming its parts varies between players.

RP1: "In order to best play/understand your own instrument, you also need to know it. And that includes what everything is called and how everything works."



Materials **and** Maintenance **ADVANCED** **and** Storage & Transport

As a rubab player, it is **important to know how to maintain the instrument**, because it just "needs to be done". In order to maintain it, you need to know its parts and materials, and use a **proper bag** for storing and carrying the instrument around.

RP1: "You need to understand its parts ... like, what is this made of? How does it wear down? And so on, in order to maintain it."



Materials  and

How to recognise a quality rubab **ADVANCED**

The wood is an important indication of the rubab's quality. **Afghan mulberry wood** is considered the best wood, and can be recognised by its straight stripes. This is important to know when buying a rubab, and mainly important for more advanced players, as beginners do not necessarily need a quality instrument.

RP1: "So ultimately what produces the sound is the cohesion of materials ... so if you don't use the right wood ..."



How a rubab is made

For rubab players, the art of rubab crafting is very important, because without rubab crafters, there would be no rubabs to play on.

RP2: "if you want to keep the instruments, music instrument rubab in your music genres, you need the rubab makers."



Appearance  and Decorative elements 

By the overall looks, the appearance, the instrument can be recognised as a rubab, so appearance is an essential aspect. While the rubab's **decorative elements** (e.g. mother-of-pearl inlays) are not essential for its sound, they are **valued as a nice extra** and may hold **personal and cultural significance**; beads can add a personal touch to the instrument, and from the wood carvings you can tell who crafted the rubab.

RP1: "How beautiful it is and the decorations are all just nice, just extra."



Etiquettes of appropriate repertoire & context combinations **ADVANCED**

and Audiences, settings and purposes of rubab performances 

Rubab players carefully choose the music they play based on the audience, setting, and purpose of a gathering. Music is deeply emotional for many Afghans, and certain songs require a fitting atmosphere, such as playing nostalgic pieces by candlelight in the evening. Understanding the context, whether a prayer, classical setting, or festive gathering, is essential in selecting the right music.

RP1: "When you get invited [to play], and you know there will come around twenty elderly people, then you know they won't get up and dance ... You need to activate their memories ... It's really important when you go somewhere, to know your audience, why the gathering is organised, and that way you choose what you will play."

Theme 5: Performative Context



The standard combination of melody & rhythm

The rubab's melody and a percussion instrument's (Zerbaghali/Daira/Tabla) rhythm belong together.

RP2: "If the people play the rubab, they also want to find a percussion instrument ... It's two parts. One musical instrument is you play the melody and one instrument is your percussion instrument. And both together, it comes always together."



The rubab's sound and Music

The rubab's characteristic sound is a very important aspect of the rubab's heritage, because it is 'heart-touching', brings happiness, and brings nostalgic memories from the past, to Afghan people all over the world who recognise the rubab's sound. The characteristic rubab sound is more important than the music played, since there is no specific music only played on rubab.

UNESCO Letter #4: "...its exciting sound promotes happiness in happy and friendly gatherings of the people of this land."



A sense of peace

The rubab can provide a sense of peace and calm to the player and the listener.

RP1: "Playing the rubab gives me a sense of calm and a feeling that I can reconnect with myself for a moment."

ADM4: "Yes, and that combination with [rubab] sound and that landscape, that did give me some peace just now."



Improvisation in playing **ADVANCED**

Improvisation is an important part of playing the rubab, because it gives **new colour** to the music, adds a **personal flavour**, and it keeps the music interesting.

RP1: "Because, you know, the thing is, if you play a song that has already been played twenty times by twenty other rubab players, at some point, people might think, 'Huh? I've heard this so many times before.' So they always say, if you play something by someone else, try to add your own flavour to it, so that others will think, 'Oh, this is the ... version' or whoever's version."



Sufi whirling dance

For non-players more than players, dance is a significant part of the rubab's heritage. They value the combination of rubab music and dance, specifically the Sufi whirling dance, which is related to 13th century Afghan poet Rumi.

One of the interviewees mentions that the combination of rubab music, dance and poetry provides a sense of inner peace.

UNESCO Letter #7: "The notes of Rubab excite the Sufi dancing whirling dervishes..."
ADM0 (non-player): "...a combination of dance, music and poetry. And that gives you a certain trance it seems. They then start dancing in circles. That gives you such a different experience of life. It's just a certain tranquillity. I think nothing on this globe can almost compete with that. To find your inner peace that way."

Selection criteria

I used the following criteria to determine the aspects relevant for this project:

- Significance score: very important
AND
- Expertise level: non-advanced (not **ADVANCED**)

Aspects only relevant for 'advanced players' were excluded, in relation to the design goal, which does not target advanced rubab players, but non-players to be introduced to the rubab's heritage. The remaining aspects are relevant for both non-players and beginner players, which is interesting for the target group members who would like to experience what it is like to play the instrument (beginner level).

With the eye on project feasibility, only those aspects with significance score 'very important' are included in the selection. This leaves a selection of aspects that are relevant for the target group, and very important parts of the heritage.

Only one of the 'important' level aspects has been included, namely the physical playing sensation. This is related to the literature review in chapter 1.1 (Exploring the status quo), which concludes that a secondary goal of this design project is combining VR technology with micro-electronics to convey the instrument's physical playing sensation.

Final selection

Applying these criteria led to the following collection of relevant rubab heritage aspects to convey in the to be designed VR experience. They are presented in alphabetical order:

Very important and not advanced:

- Appearance
- Finger positions
- How a rubab is made
- How to correctly hold the rubab & plectrum
- Materials
- Part functions
- Playing the rubab (the basics)
- Rubab as part of Afghan identity
- Rubab as symbol of Afghanistan's beauty
- Sound of the rubab
- The rubab's relation to Afghanistan

Important and not advanced:

- The physical sensation of playing the rubab

1.4 Exploring meaningful encounters

This chapter explores the design research question: What makes a cultural encounter meaningful for the target group?

Method:

- o Generative sessions with culturally interested non-Afghans

It presents findings from a generative session with culturally interested non-Afghans, conducted to uncover the elements that contribute to meaningful cultural encounters. Unlike Afghans, who often have a deep emotional and personal connection to the rubab, non-Afghans typically lack this inherent bond. The session helped understand how to design a cultural experience that fosters such a personal connection for this audience, making the introduction to the rubab's heritage meaningful despite their unfamiliarity.

As described in the Method section, the session drew on the Path of Expression framework (Sanders & Stappers, 2012). Participants reflected on past cultural encounters and then ideated future scenarios that could foster a personal connection with the rubab. Through activities including memory sharing, brainstorming, and physical prototyping (via dollhouse models), the session generated insights into what makes a cultural encounter a meaningful one.

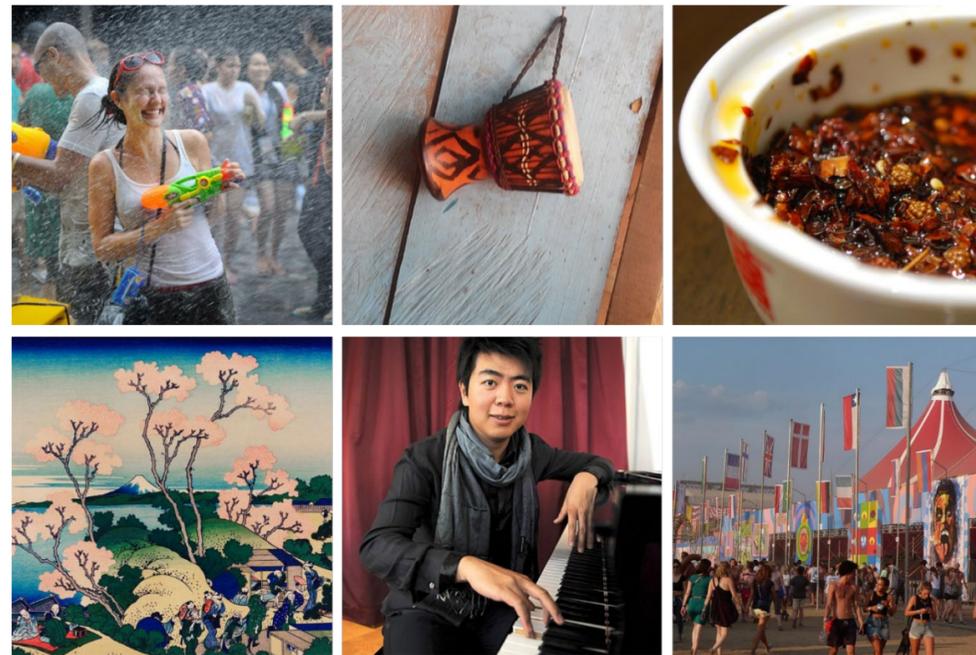


Figure 21: Each of the participants brought a different memory of a cultural encounter. Image sources from left to right: Bouch, 2011; Bayelharriet, 2016; Alpha, 2010; Hokusai, n.d.; Nikeush, 2010; Andor, 2015.

Key Insights from Cultural Memories

Each participant brought a personal memory of a past cultural encounter to share with the group: a photo of a Songkran water pistol fight in Thailand, a mini-djembe, a memory of a Chinese cooking course with new flavour encounters, a booklet with Hokusai prints, A CD of pianist LangLang, and a flag from the Hungarian Sziget festival (fig. 21).

Each participant shared with the group what had made this cultural encounter meaningful. From their reflections, several recurring themes emerged (see fig. 22, full details in Appendix G). These insights proved valuable to guide the ideation for Design Goal 1 (see Part 3).



Figure 22: Recurring themes for meaningful cultural encounters.

Brainstorm outcomes

In response to the prompt “How to create a personal connection between you and the rubab’s cultural heritage?”, participants proposed a wide range of ideas (see Appendix H). I clustered all suggested ideas into six thematic categories:

Category 1: Story-telling



A rubab fairytale

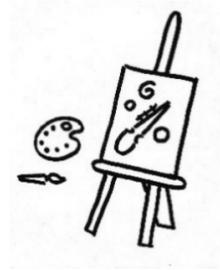
Category 2: Create



Make your own rubab



Composing for rubab

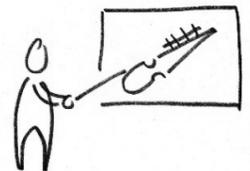


Using the rubab in your artwork

Category 3: Education



General ‘learning’



Educational programmes about the rubab



Learning about Afghan culture

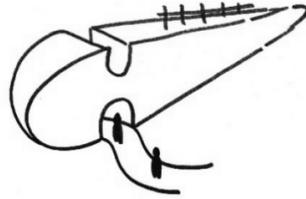


Observing rubab expert demonstrations

Category 4: Setting the scene



Create an atmospheric setting/ambience



Walking through a building-sized rubab

Category 5: Connect



Connect rubab with your own culture



Get to know the rubab player



Speechless communication and connection

Category 6: Experience



Rubab concert



Dancing to rubab music



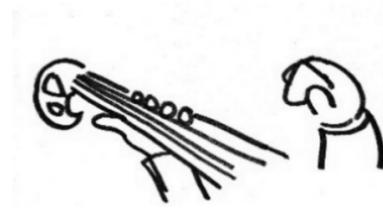
Rubab and food



Listen to a rubab music playlist in your own time



Multi-sensory experiences



Play the rubab:

- Lessons
- Try the rubab
- Hold the rubab

Prototypes: Dollhouse Designs

Each pair of participants created a small-scale prototype of a meaningful encounter with the rubab. Three distinct concepts emerged:

1. Inside the Rubab: The Instrument's Journey

Visitors walk through a building-sized rubab, following the stories of a single rubab's various owners via puppet scenes that depict the instrument's crafting, sale, and journey out of Afghanistan. The immersive experience engages all the senses, including tasting Afghan food, making and playing the rubab, and interacting with giant strings to produce sounds. This design fosters a personal connection by placing visitors inside the rubab, allowing them to 'feel part of the instrument'.



Figure 23: A visitor looking at one of the puppet scenes.



Figure 24: Inside the rubab: the instrument's journey dollhouse prototype.

2. The Rubab Playground

A playful, physical environment where visitors interact with oversized rubab components — pulling strings, jumping on sound boxes, climbing. The concept promotes joy, discovery, and group participation. A contrasting silent space with wool encourages rest and reflection. The designers explain that personal connection with the rubab's heritage is created by letting the visitors discover the instrument in a fun way, by letting the visitors be part of the instrument, and let different people play the huge instrument at the same time.



Figure 25: A user pulling the strings of the rubab.

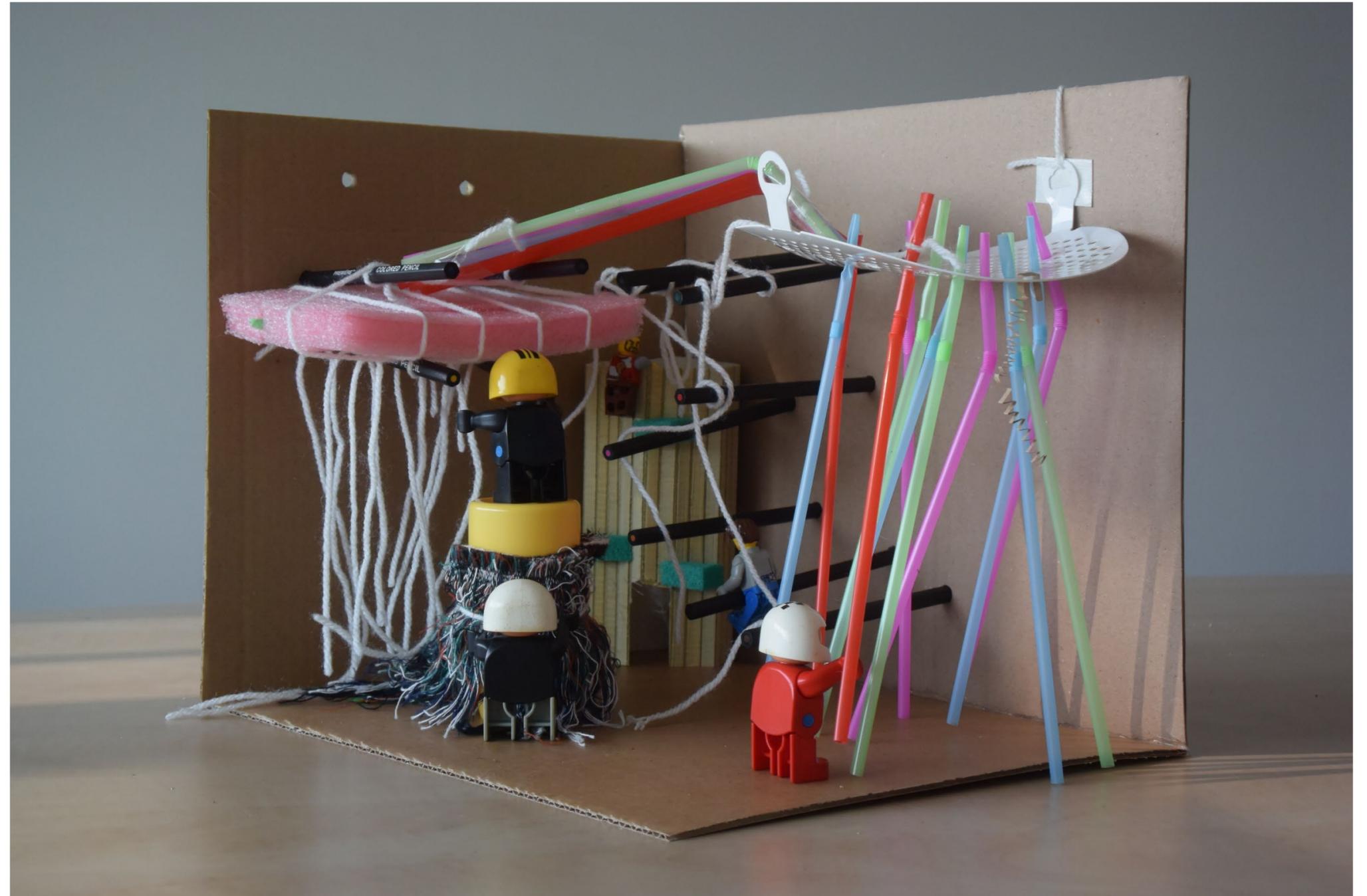


Figure 36: The rubab playground dollhouse prototype.

3. Emotional Imagination

In this minimalist experience, visitors enter a dark room with only a rubab and a bench. Listening to the instrument's sounds, they are encouraged to close their eyes and imagine a tranquil Afghan valley, depicted in the dollhouse with sheep, a starry sky, and a campfire. By providing very little impulses, the visitor's imagination is encouraged. The design fosters a personal connection by creating an **intimate, emotional setting**. One of the two designers, a psychologist, explains why: 'We know that memories are stored better when emotion is involved.'



Figure 27: The rubab, tent, campfire and sheep.



Figure 48: Emotional imagination dollhouse prototype.

Common Characteristics Across Doll House Designs

Despite differing formats, all three designs shared the following features:



Embodied interaction

In each design, users physically engage with the rubab or its representation (giant strings or a giant rubab).



Emotional engagement

Whether through joy, empathy or contemplation, all designs evoke emotional responses.



Multi-sensory experiences

Each design activates multiple senses, all include sound and touch



Personal creation

Users either create sounds, movements or imaginative worlds.



Afghan cultural context

Afghan heritage is embedded through materials, stories, or landscape.

This concludes the exploration of RQ4. The analysis of the memories, brainstorm and dollhouse designs have led to a collection of insights that have been used to inform the design phase of Design Goal 2 (see Part 2).

Exploration conclusions

This chapter concludes Part 1: Explore. It redefines the design goals, based on the insights retrieved in the exploration phase. It lists the identified requirements for the to be made design, and presents the interaction vision. These conclusions inform the designing (Part 2 & Part 3).

Refined design goals

DG1

Based on the insights from the exploration phase (part 1), the primary design goal has been refined:

Design an interactive technology experience to meaningfully convey the tangible and intangible heritage of the Afghan rubab, for culturally interested non-Afghans to encounter the beauty of Afghan culture.

In this updated design goal, the target group has been changed to culturally interested non-Afghans instead of both Afghans diaspora members and non-Afghans. Secondly, the aim is altered to let them “encounter the beauty of Afghan culture”, instead of the more general initial aim to let them “explore Afghan culture” (see initial goal in the introduction of this report).

DG2

The secondary design goal mostly stays the same, based on the literature review’s conclusion (Chapter 1.1).

Design an interactive technology experience that conveys the rubab’s physical playing sensation through a combination of Virtual Reality and sensor-based embedded technology.

Design requirement summary

This section summarises the design requirements and wishes identified during the exploration phase (part 1).

Requirements

- The design must be feasible with the interactive technology combination of Extended Reality and micro-electronics.
- The design must provide an culturally accurate representation of Afghan heritage.
- The design must address the following heritage aspects of the rubab:
 - Appearance
 - Finger positions
 - How a rubab is made
 - How to correctly hold the rubab & plectrum
 - Materials
 - Part functions
 - Playing the rubab (at any level)
 - Rubab as part of Afghan identity
 - Rubab as symbol of Afghanistan's beauty
 - Sound of the rubab
 - The physical sensation of playing the rubab
 - The rubab's relation to Afghanistan
- The user's interaction with the design must be:
 - **Calming**
 - **Rewarding**
 - **Guiding**
- The to be designed experience should have the following characteristics:



New experiences
The encounter provides a new experience, thereby expanding the participant's worldview



Active participation in a cultural phenomenon
The encounter allows for physical engagement (e.g. through dancing, a water pistol fight, or playing music), making it immersive and memorable.



Inspiration
The encounter prompts future creative work or activities (e.g. an art work)



A shared experience (with strangers)
The encounter provides a moment shared with strangers (from the culture in question)



Relate it to your own life
The encounter allows those encountering to compare/relate (aspects of) the cultural phenomenon with what they know from their own lives



Embodied interaction
In each design, users physically engage with the rubab or its representation (giant strings or a giant rubab).



Emotional engagement
Whether through joy, empathy or contemplation, all designs evoke emotional responses.



Multi-sensory experiences
Each design activates multiple senses, all include sound and touch



Personal creation
Users either create sounds, movements or imaginative worlds.



Afghan cultural context
Afghan heritage is embedded through materials, stories, or landscape.

Part 2: Ideate & Prototype DG1

This part describes the ideation and concept development processes for DG1:

Design an interactive technology experience to meaningfully convey the tangible and intangible heritage of the Afghan rubab, for culturally interested non-Afghans to encounter the beauty of Afghan culture.

In the first chapter, the ideation process is described, including the interaction vision. The second chapter describes the iterative development process, from low fidelity to high fidelity prototypes, and user evaluations.

2.1 Ideation

Interaction vision

The ideation started with setting the interaction vision: a design method that draws on an unrelated scenario or metaphor that embodies desired interaction qualities, analyses their affordances within that scenario, and uses them to inspire ideation for the intended design (Pasman et al., 2011).

The rubab evokes a sense of peace for both players and listeners within the Afghan community (see heritage aspects in chapter 1.3). This interaction vision embraces that feeling of peace and calm, thereby opposing the association of violence and war many non-Afghans have with Afghanistan. Moreover, it provides an analogy that combines the characteristics of meaningful cultural encounters, identified during the generative research session with the target group (see chapter 1.4):

The interaction should feel like working in a community garden

Interaction qualities & their affordances:

- *Calming*
Ambient nature sounds of wind, water, birds, leaves and soil | the greenery around you | low-stimulation environment | presence of others nearby | the overall quiet | the outdoors | the slow pace of nature | room for mistakes
- *Guiding*
Guidance from experienced gardeners | instructions on what to do | vegetable labels | the presence of experienced gardeners | the provided information | the possibility to ask questions | seasonal cycles | gardening plan | the freedom to choose your own plants | the rules of nature
- *Rewarding*
Visible growth of plants | The harvest | A sprouting seed | compliments from others | small tasks to complete | beautiful plants and flowers | the relaxed feeling after working in the garden | The results of your contribution



Figures 29 & 30: The interaction should feel like working in a community garden. Image sources: Umphreys, 2020 (up); Neil, 2018 (down).

Generating ideas

For each requirements (see Exploration conclusions in Part 1) and for each interaction vision quality, a 'How-to' (H2) question was formulated (e.g., *How to convey part functions of the rubab?* or *How to create a calming encounter with the rubab's heritage?*).

To generate ideas, I used two methods from *Road Map for Creative Problem Solving Techniques* (Heijne & van der Meer, 2019):

- Brain-writing on post-its
- Visual stimulation excursion using *Dixit* image cards: identifying intriguing characteristics in unrelated images and using them as stimuli to spark non-obvious ideas.

Ideas for each H2 question were grouped using the book's **spontaneous clustering** method. I then developed three sketch storyboard concepts by combining selected ideas using the **hits and dots** method (intuitive selection of the most promising ideas). Each concept took a different approach, resulting in three distinct directions (see next chapter).

All ideas and idea clusters can be found in appendix I.

2.2 Prototyping

Lo-Fi concept storyboards

The first three concepts 'prototypes' were rough storyboard sketches. In this section, the concepts are discussed, together with their feedback by the target group.

Evaluation by the target group

I showed the three concepts to people from the target group, individually, and got their feedback:

- One Dfl student, age 25, female
- One IPD student, age 26, female
- One retired social worker, age 61, female
- One architect, age 62, male

After viewing a concept, they shared their opinions, what they liked, what they didn't understand, what they didn't like. After all three concepts were shown, they were asked to compare the three, and indicate which concept they preferred, and why. Their feedback led to a collection of pluses and minuses (Appendix J) for each of the concepts, together with improvement opportunities (i.e., consequences of the minuses and suggestions by the participants). The evaluation feedback is summarised for each concept in the following sections.

Concept 1

The user sits on an Afghanistan-shaped rug with Afghan flag print, wearing a VR headset and holding the e-rubab device. They are guided through a structured narrative (like a book) in three chapters:

1. *The Rubab*
2. *Afghanistan*
3. *The Duet*

Progression through the chapters is based on correctly playing notes on the rubab. Visual cues—coloured dots on the fretboard—indicate finger positions to guide the user. Chapter titles appear overlaid with Afghan script in the background, visually reinforcing the connection to Afghanistan.

In the experience's first chapter, the user is introduced to the rubab's functions by a virtual rubab tutor and plays their first notes. Once these are completed, the map-shaped rug beneath them levitates and moves through a giant rubab-shaped gate into a virtual representation of the Afghan mountains, marking the beginning of Chapter 2.

Concept 1 uses large-scale, opera-like scenography—such as the floating rubab and monumental gate—to evoke a sense of awe and the sublime. The contrast between darkness and light enhances this atmosphere, highlighting the rubab as a symbol of Afghan beauty. The experience is designed to be calming by using minimal stimuli (darkness), repeated interactions, and natural landscapes.

In the experience's "Chapter 2", the rubab's materials are personified: a goat represents the goat skin, and a tree represents the mulberry wood. The user collects these elements by playing the correct notes. These materials are then transformed into a giant rubab, which ascends into the clouds, leading to the final chapter—*The Duet*—where the user performs together with the giant rubab.

See figure 31.

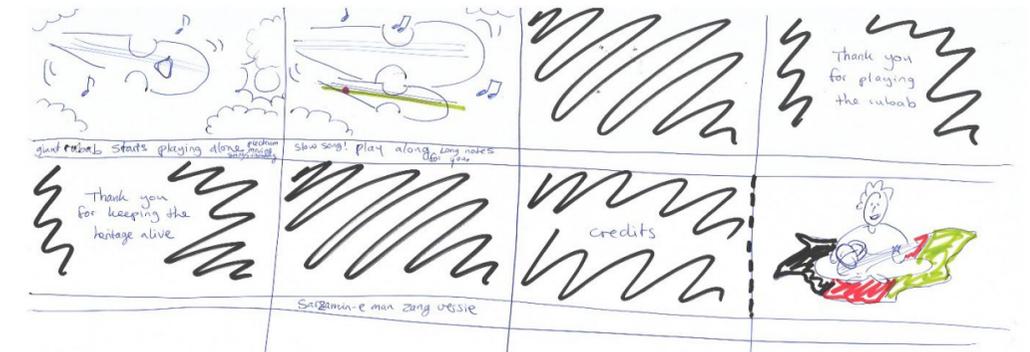
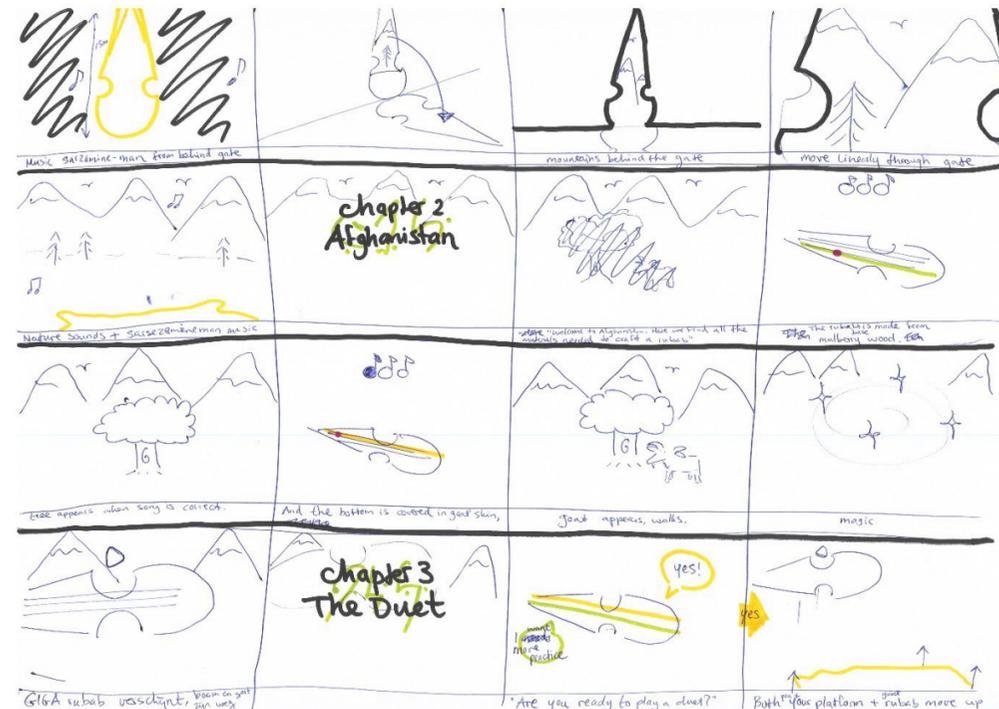
Evaluation concept 1

Concept 1 is praised for its effective use of humour and a calming, pleasant atmosphere. Elements such as the goat, mulberry tree, mountains, and magic contribute to its charm. The structured progression and use of the rubab sound at the introduction are positively received. Strong cultural grounding is achieved through Afghan text, chapter divisions, and the map of Afghanistan. Learning to play is well-supported with visual cues, and the interaction with the virtual teacher is appreciated. Ambient features like the rubab-shaped gate, changing light, and physical rug are valued.

However, the use of the term 'chapter' evokes associations with lengthy texts. The experience lacks an initial narrative or clear motivation for learning to play the rubab, making it less engaging for some. Its linear structure limits user autonomy, and the sole male rubab player excludes gender inclusivity. Compared to other concepts, it evokes less emotional resonance. Additionally, sitting on the rug resembling the Afghan flag may be culturally insensitive.

Suggestions for improvement include: allowing users to see their hands while playing, increasing choice and narrative clarity, including a female rubab player, replacing the term 'chapter' while maintaining structure, enhancing emotional depth, and redesigning the rug to retain the country's shape without the flag.

Figure 31: Concept 1 storyboard.



Concept 2

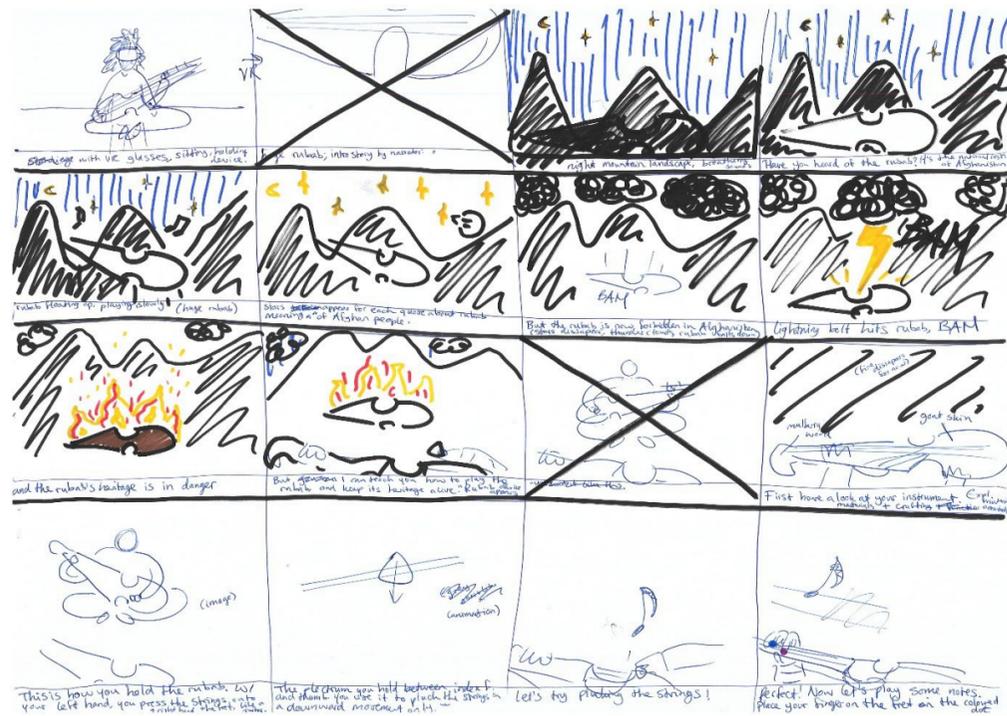
The user sits on the floor, wearing a VR headset and holding the e-rubab. They begin in a star-lit mountain landscape, with calming breathing sounds. A narrator introduces them to the rubab, and a huge rubab appears. More stars gradually appear in the sky, each accompanied by a quote from an Afghan person sharing what the rubab means to them, conveying the rubab's cultural significance.

When the narrator reveals that the rubab is now banned in Afghanistan, thunderclouds roll in, the music stops, and the rubab falls to the ground, is struck by lightning and catches fire. The narrator then directly calls upon the user to actively engage them: "I can teach you how to play the rubab, and keep its heritage alive."

The user begins to play, each note weakening the fire, visualized as a classic boss-level life bar. As the flames diminish, the rubab is restored, and the user is rewarded: the music returns, the sun rises, and the voices of the Afghan people can be heard again.

See figure 32.

Figure 32: Concept 2 storyboard.



Evaluation concept 2

Concept 2 is praised for its strong emotional and symbolic impact. The idea of saving the rubab through playing is seen as meaningful, and the introduction featuring prohibition and fire effectively establishes motivation and urgency. The experience is engaging, focused, and feels concise yet powerful. The act of extinguishing the fire offers a clear, tangible sense of progress, making it accessible and rewarding, especially for non-musicians, due to its emotional rather than technical emphasis.

However, the absence of other characters limits social connection, and the experience appears non-repeatable. A more hopeful or uplifting message is suggested. The many coloured dots (used as frets notation) are confusing and the transition from emotional experience to technical learning is abrupt. The lack of traditional or cultural context makes it feel more like an experience than an educational tool.

Suggestions include: reframing the goal as reviving the rubab rather than extinguishing fire to convey a more positive message; incorporating dynamic changes such as standing during the fire scene and sitting to play; and adding a hopeful transition, for example showing generational continuity through rubab playing. Additional recommendations are to include human characters, allow users to revisit sections (particularly the playing part), strengthen Afghan cultural context, simplify the fret feedback system, and create a smoother transition into the learning phase.

Concept 3

The user begins the experience standing and wearing a VR headset. They enter a fully dark virtual space with minimal visual stimuli, creating a calming atmosphere. ASMR-like sounds—ticking, crackling, and scratching—are heard, made from recordings of the rubab’s materials. A spotlight appears, revealing a wiggling rubab. When the user picks up the rubab (the e-rubab device), it begins to play soft, melodic music.

Three tiles then appear on the floor, each representing a different aspect of the rubab’s heritage: **Play**, **Afghanistan**, and **Parts & Functions**. Footstep visuals guide the user to step onto one of the tiles to select a level. This design offers *guided freedom*—the user chooses the order of activities instead of following a fixed path.

Within each level, the user continues to make choices by plucking one of the rubab’s three strings—for example, selecting a question to ask Afghan people or choosing a song to play. Menus are limited to three options to avoid overwhelming the user with choices, maintaining a calming interaction while still allowing agency.

Information is presented as written text throughout the levels.

In **Parts & Functions**, the rubab is shown through an animated assembly of its individual components.

In **Afghanistan**, the connection to the country is emphasized with a 3D globe that zooms in on Afghanistan, helping situate it geographically. Then, they meet several virtual Afghan representatives (offering a *shared experience with strangers*), who can answer their questions (again, three questions to choose from).

In **Play**, the user can choose from three songs, a mix of Afghan and Western songs, providing recognition by the user from what they know from their own lives (in the case of Western users, in this example):

- Für Elise (Beethoven)
- Sarzamin-e man (Traditional Afghan)
- Make You Feel My Love (Adele)

The user can decide at any moment to stop and remove the headset. There is no designated closing sequence.

See figure 33.

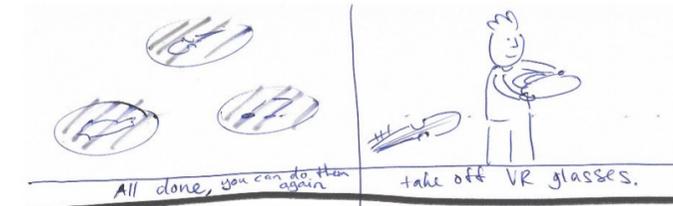
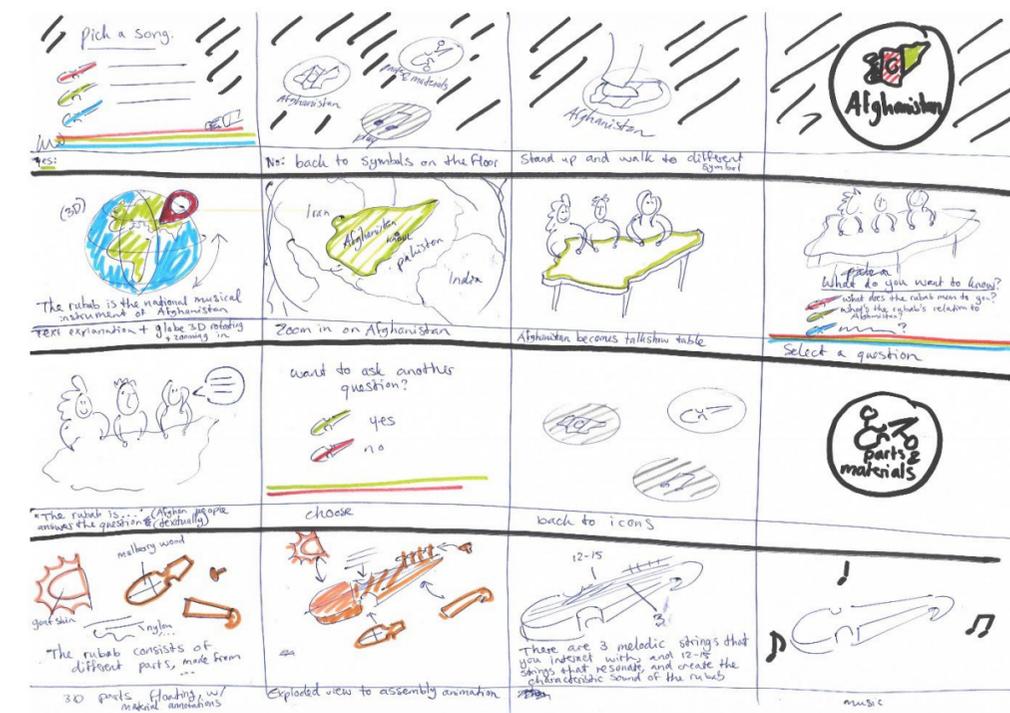
Evaluation concept 3

Concept 3 is valued for its personal and human approach. Conversations with Afghan characters offer emotional connection and cultural representation, giving a face to Afghanistan. The interactive tile-based interface is praised for being playful, intuitive, and allowing users to explore at their own pace. Song selection via strings is seen as simple and enjoyable. The inclusion of diverse musical pieces appeals to a wide audience, and the option to return and continue learning enhances the experience’s longevity. The ability to include a range of character types (e.g. age, gender) supports inclusive representation. The central space with tiles and rubab music creates a sense of cohesion and continuity, contributing to the feeling of a rewarding experience.

However, the concept lacks a strong narrative hook or sense of urgency, making the purpose of playing unclear. The open structure, while offering freedom, may feel aimless or overwhelming without more guidance. Users indicated they may struggle with a lack of clear progression or motivation. Additionally, the rubab sound effects at the start feel disconnected from the experience.

Opportunities for development include: adding a clear storyline and motivation to anchor the experience; improving structural guidance to support user navigation and progression; and ensuring authentic representation of Afghan people.

Figure 33: Concept 3 storyboard.



Lo-Fi enacting prototype: concept 4

This concept combines the strengths of concepts 1-3, identified through the evaluation. To test this new concept, I had participants physically enact the interactions (interaction walkthrough), enabling them to actively experience the concept from a user's perspective rather than relying on sketches or descriptions. Having them enact the concept allows for testing the interactions in more detail, and helps in finding usability issues based on users' interactions with the system (Arvola & Artman, 2007).

A slideshow prototype was created, featuring visual animations, voice-over narration, and sounds, supported by physical props: printed floor tiles with footsteps for users to step on, and a cardboard e-rubab (non-electronic) for them to 'play'. During the enactment, transparent sheets with coloured dots were placed on the rubab's frets to simulate the virtual interaction overlay.

Fig. 34-40 show selected images of the prototype. The complete storyboard can be found in appendix K.

The experience begins in the physical space, where the user sees a map of Afghanistan (2 meters tall) and a pedestal holding the e-rubab device (fig. 34).



Figure 34: The physical space, with e-rubab device on a pedestal.

By putting on the VR headset, the user enters a starry Afghan mountain landscape (conveying the beauty of Afghanistan). A female narrator's voice (in line with Stichting Solh's mission to empower Afghan women) introduces the rubab's cultural significance and its current endangered status, symbolised by thunderclouds, a lightning strike and a burning rubab (fig. 35). The user is invited to learn about the rubab to keep its heritage alive.

The experience unfolds across three levels accessed by stepping on virtual circle-shaped floor tiles (fig 36). The tiles turn gold when its level has been visited. The levels are:

1. **Afghanistan:** Users engage with Afghan people sharing personal connections to the rubab through selecting questions by playing strings on their e-rubab (fig. 37).
2. **Play:** Users learn to hold and play the rubab, guided by coloured dots on the instrument's frets to play songs, with options to play freely or choose new songs (fig. 38).
3. **Parts & Functions:** the narrator tells about the rubab's materials and components (represented by living materials, such as a goat representing goat skin (fig. 39). They answer a quiz question on the function of the rubab's sympathetic strings.

The experience concludes after all levels have been explored: the fire fades, the rubab rises, joyful rubab music plays, and a sunrise marks cultural preservation, before the credits roll (fig. 40).

Figure 35: Burning rubab scene.



Figure 36: Virtual floor tiles to select the different levels.



Figure 37: Afghanistan level with pop-up menu.



Figure 39: Parts & Functions level.



Figure 40: Sunrise after all levels have been played.



Figure 38: Playing the notes on the cardboard model of the e-rubab with "virtual" overlay dots.

Evaluation Enacting prototype

Evaluation was conducted with:

- 5 members of the target group, individually:
 - Dentist, 28, male
 - IDE student, 26, female
 - Product designer, 25, female
 - Double bass student, 24, male
 - Psychobiologist, 25, female
- My graduation supervisory team
- Kamal Nasrati (Stichting Solh) and 1 rubab player (both Afghan)

For the target group, I asked what they liked, disliked, and found confusing. They also rated the experience (1–5) on the interaction qualities *calming*, *guiding*, and *rewarding*, and explained their ratings. For Stichting Solh and the rubab player, the focus was on conceptual feedback, cultural accuracy (e.g., Dari translations), and identifying any unintended cultural insensitivities.

Figure 41 shows photographs from the evaluations with the target group. Figure 42 shows an image from the evaluation session with Stichting Solh and Rubab Player 1.



Figure 41: Photographs of target group participants testing the prototype.

Feedback by the target group

This concept is widely praised for its high interactivity and engaging user experience. Participants appreciated actively plucking strings, making choices via the instrument, and the freedom to select from three tiles. The fret-dot cues were well understood, and the combination of cultural education with hands-on play was highly valued. The background music added atmosphere and emotional depth, while the humorous goat character was a standout element. The intuitive string-based choice system and pleasant voice narration were also noted positively. The experience's accessibility to all ages, the calming yet engaging pacing, and the rewarding elements such as applause and visual feedback contributed to its appeal. Sitting during play was comfortable, and the option for freestyle playing was welcomed.

Areas for improvement include clarifying the instructions on using the plectrum, which many participants overlooked initially. The reason why the rubab is forbidden in Afghanistan was repeatedly noted as unclear and should be better explained. Some found the ending abrupt and desired longer or more flexible playtime. Audio balance needs adjustment to reduce distracting sounds, and clearer feedback on string selection during menu navigation was requested. The goat's movement in the Parts & Functions section was considered too slow, causing some confusion. The text balloons in the Afghanistan level were considered confusing, since there was no text in them.

Additional feedback

Additional feedback from Stichting Solh and Rubab Player 1 emphasized avoiding stepping on the Afghan flag for cultural sensitivity, refining the tile icons for clarity, ensuring purely Afghan musical content, and providing accurate translations in both Pashto and Dari. They suggested adding more Afghan songs, better highlighting instrument parts during explanations, extending the introduction for greater context, and adding traditional Afghan clothing. The current "lightning strike" was seen as too definitive; moreover, the focus on the current prohibition was feared to be too much tight to current events, making the experience outdated if the Taliban regime were to fall tomorrow. The minimalist design was praised by Stichting Solh, and the use of English was valued.

Supervisory team feedback highlighted positive pacing and interaction design but recommended more natural, conversational voiceovers, more difficult quiz answers, and adaptation to Mixed Reality (pass-through instead of full Virtual Reality) for comfortable use in public spaces. Suggestions included making tiles three-dimensional, enhancing Afghan aesthetic resonance, and using the country's shape instead of the flag to avoid political sensitivity.

See Appendix L for detailed feedback.



Figure 42: Photograph of Kamal Nasrati from Stichting Solh and Mohammad Mohammadi (RP1), testing the prototype.

Feedback implementation in the final design

For the final design, which was prototyped in high fidelity (Part 5), the feedback on the lo-fi enacting prototype was incorporated as follows:

General

- All music in the final design is now performed by an Afghan rubab player, with permission. Some music pieces have changed, while maintaining the music's tone (e.g. calm, happy).
- Pass-through has been added, **shifting the experience from Virtual Reality to Mixed Reality**. This allows users to see their surroundings, making users feel more comfortable in public spaces, which I find very important. To retain the immersive quality of VR (in line with DG2), an Afghanistan-shaped portal with a depth effect displays an immersive Afghan landscape. The pass-through has been set to black and white, so the colours in the surroundings do not distract the user too much.
- Pashto text was added in all title pages.

Intro

- The fire metaphor was considered too definitive and has therefore been replaced by a thunderstorm metaphor (more temporary than fire). The thunder still conveys a sense of threat, helping to maintain urgency and motivate users to learn about the rubab.
- Instead of 2D tiles, 3D floating objects were added to step into for level selection.
- The introduction narration was extended with more focus on the rich diversity of Afghanistan.
- Some voice-over texts were rewritten, combining poetic tone with a more informal tone. Still, AI was used for voice generation, because this took less time than hiring voice actors for this prototype.
- The plectrum is mentioned earlier on, and more explicitly

'Afghanistan' Level

- An older Afghan man was added to the character images in the Afghanistan level. Two of the four characters now wear traditional Afghan attire (selected by Stichting Solh), and two wear Western clothing, helping Western viewers relate through familiar dress (supporting meaningful connection, see chapter 1.4) as well as showcasing Afghan attire.
- A more general question on political challenges faced by the rubab was added, replacing the earlier "why currently forbidden" question in the Afghanistan level.
- Instead of text balloons—which proved confusing—light emitting bars are now used in the Afghanistan level to indicate which character is speaking.

'Play' Level

- Easier songs with less repetitive notes were selected.
- The previous symbol for 'Play' (music notes) was replaced by a rubab for icon clarity, and the symbol for 'Parts & Functions' (a rubab with annotations) was replaced by loose parts of the rubab.
- The 3D rubab model has been made partly transparent, so users can view where they place their fingers on the frets, since current hand tracking technology is not accurate enough yet (see chapter 4.3).

'Parts & Functions' Level

- The Dari title of "Parts & Functions" was corrected, and
- In the Parts & Functions level, when the parts are mentioned by the narrator, they are now highlighted (yellow) on the rubab that the user is holding.
- The quiz answers have been made more difficult, and less obviously wrong

Finale (after all levels have been played)

- In the finale, a transparent video overlay of a rubab player performance has been added, providing footage of a person playing the rubab and adding another human element to the experience, and a festive element to the finale.
- Although users indicated they would like to have the option to keep exploring before the end animation, this would disrupt the intended flow and narrative, and potentially extend the experience indefinitely, something that I do not find suitable for a public setting where other museum or library visitors may want to try out the experience as well. The current experience takes around 15 minutes and that should be long enough

Part 3: Ideate & Prototype DG2

This part outlines the development of the e-rubab, an electronic hardware device designed to replicate the physical sensations of playing the traditional rubab. It describes the development process for DG2:

Design an interactive technology experience that conveys the rubab's physical playing sensation through a combination of Extended Reality and sensor-based embedded technology.

The first three chapters each describe the development of one aspect of the e-rubab:

- 3.1 Input sensors
- 3.2 Shape
- 3.3 Hybrid technology connection

3.1 Input Sensors

This chapter discusses the scope of the physical playing sensations and discusses the most important prototypes developed for DG2. These prototypes and insights can be found in Appendix B.

Scope of physical playing sensations

During a lesson with RP1, I had the opportunity to play the rubab at an ultimate beginner's level. This provided an initial understanding of the physical sensations involved in playing the instrument. Based on this autoethnographic experience, I noted down the sensations I had while playing (fig. 43):

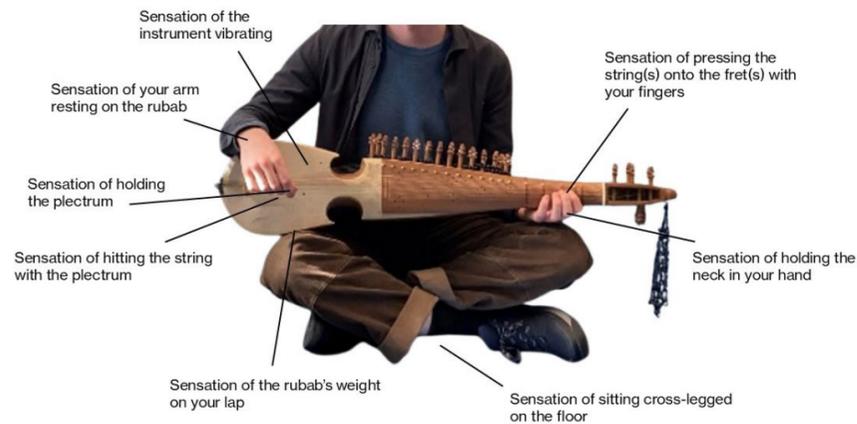


Figure 43: The sensations I had while playing the rubab.

Playing the rubab is comparable to playing the guitar. It is held with the neck in the left hand, where the index, middle, and ring fingers press the strings against the frets. The right hand holds a plectrum between the thumb and index finger, plucking any of the three melodic strings in a downward motion. The instrument rests on the player's lap, typically while seated cross-legged on the floor. While playing, you can feel the instrument vibrating.

"So if your rubab is properly tuned, and you're holding it, and you touch the string, you just feel it—you hear it and you feel it ... it vibrates along, even through the wood." – RP1

Based on this quote by RP1 on the rubab's physical playing sensation, the following key sensations of playing the rubab were identified:

- Touching the strings
- Feeling the instrument's vibrations

These sensations in relation to the physical rubab are shown in figure 44. Since pressing the string onto the fret, and plucking the string with a plectrum are both related to the sensation of 'touching the strings', these were included in the scope:

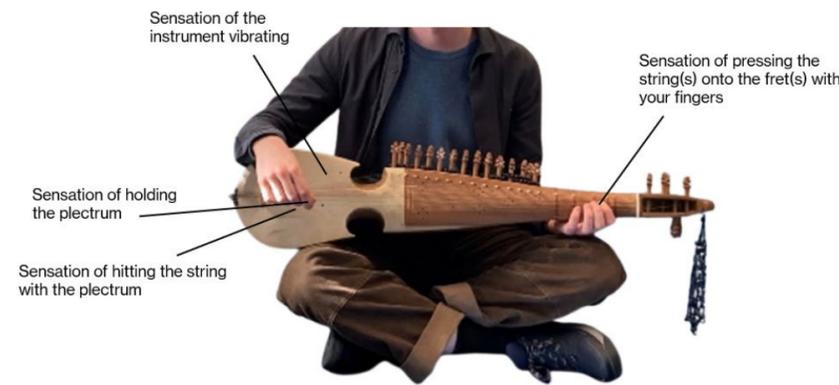


Figure 44: The sensations related to 'touching the strings'

Replicating sensations through hardware

I explored how each of the selected sensations could be mimicked using hardware and micro-electronics. The table below outlines the initial hardware set-up. Given the time constraints of this project, priority was placed on user input (plucking and pressing the strings) while output (vibration) was not included in the prototype but is recommended for future development.

Sensation	(Initial) mimicking method
Plucking strings with plectrum	Incorporate real nylon strings and a plectrum, with Force Sensitive Resistor (FSR) sensors on each string to detect force and identify the string played.
Pressing strings onto frets	Use real strings combined with 12 touch sensors (four frets per string) to detect finger placement.
<i>Instrument vibration</i>	Use of haptic vibration motors at contact points between the e-rubab and the body.

Sensor prototypes

The development of the user input sensor design was done by rapid prototyping: trying things out and learning from the insights gathered. The first prototype was a piece of wood with fake sensors (fig. 45). I increased complexity with each prototype.

Prototype 1 was used to present the initial concept to the XR Zone staff and get their technical feedback. They urged me to determine the number of sensors needed, since there are limits to pin capacity on different Microprocessor Units (MPUs). This resulted in the consultation with a rubab player to determine the amount of sensors needed: 12 fret sensors (4 frets per string).

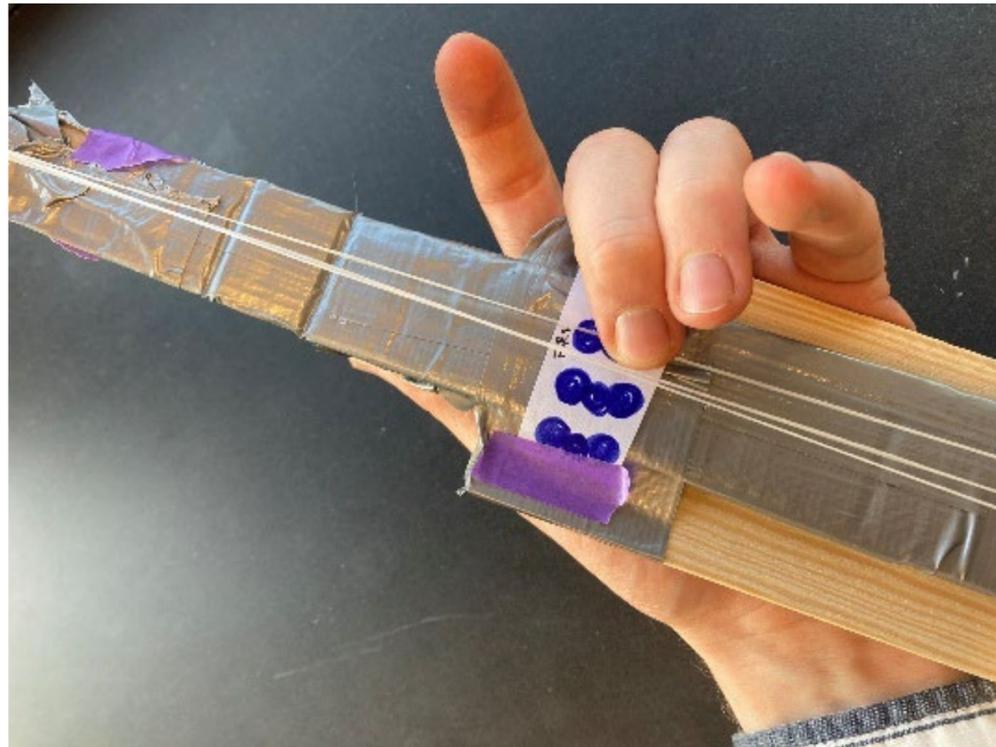


Figure 45: Prototype 1.

Prototype 2 (fig. 46) used a single elastic string, one button as the string input, one touch sensor as the fret input, and a buzzer for sound output, all connected to a Seeeduino Lotus 1.1 board. The combination of the touch sensor and string effectively simulated pressing a string onto a fret. However, the system only produced sound when both inputs were active, whereas plucking the string alone should also generate sound, as with an open string on the rubab. The Seeeduino Lotus was found to be unsuitable due to its limited input capacity and lack of wireless communication. The ESP32 was chosen as a better alternative, offering more inputs, Wi-Fi connectivity, and support for custom-shaped capacitive touch sensors that better match the fret layout than standard circular sensors.

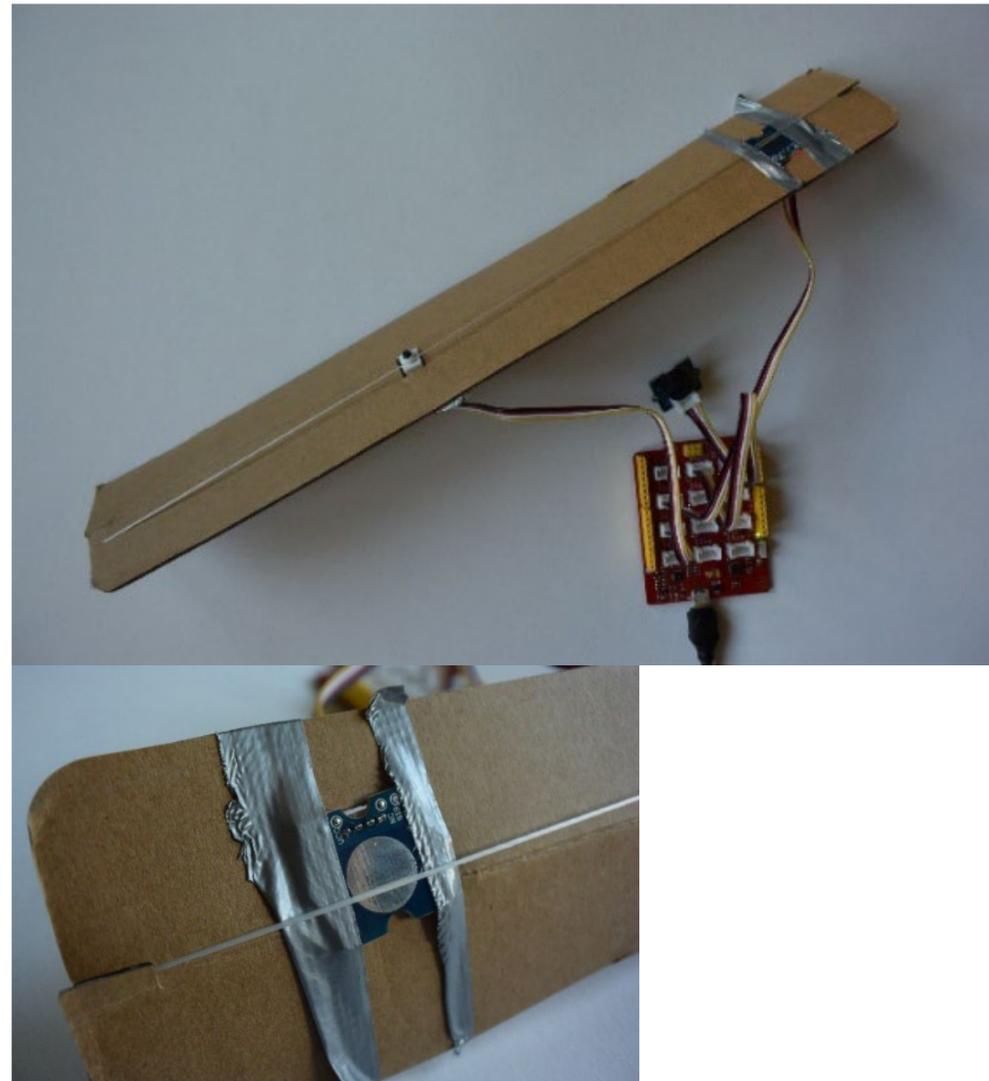


Figure 46: Prototype 2 is a simplified set-up with sensors and buzzer.

Prototype 5 (fig. 47) revealed that the ESP32 supports only 9 touch pins (see pink coloured 'TOUCH' pins in figure 48), which is insufficient for the required 12 sensors. Additionally, these pins require a manually defined threshold to determine input states (HIGH/LOW). As a result, an MPR121 breakout board was introduced in *Prototype 6* (fig. 49). It connects to the ESP32 — maintaining Wi-Fi capability — and provides enough capacitive touch inputs for all 12 fret sensors. Another advantage of the MPR121 is that it has a default threshold value that works well for touching the frets, so no manually set threshold is needed, unlike the ESP32.

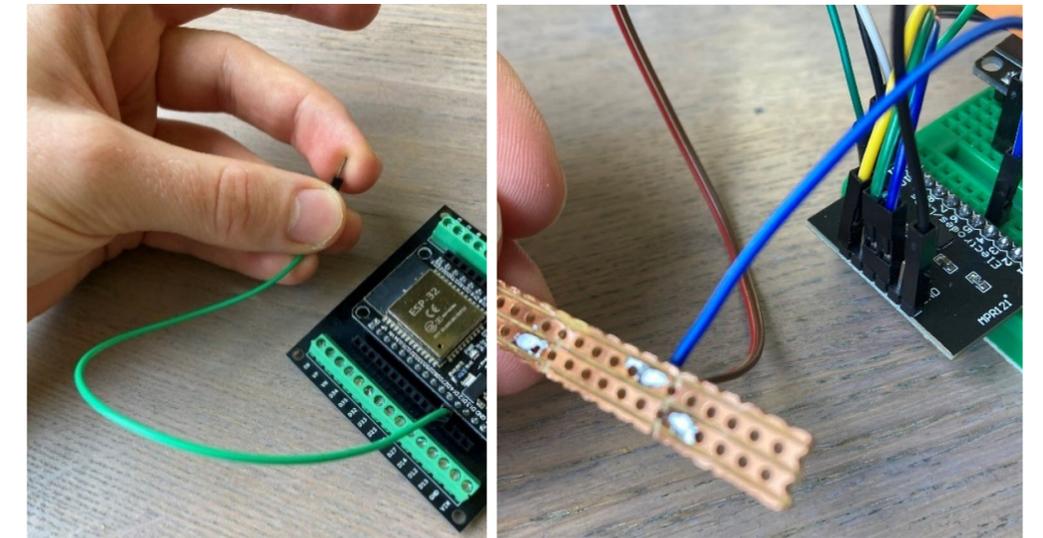


Figure 45: Prototype 5 was a test of the capacitive touch capabilities of the ESP32.

Figure 49: Prototype 6 incorporated the MPR121 breakout board (black, on the right) in combination with a custom made capacitive touch sensor.

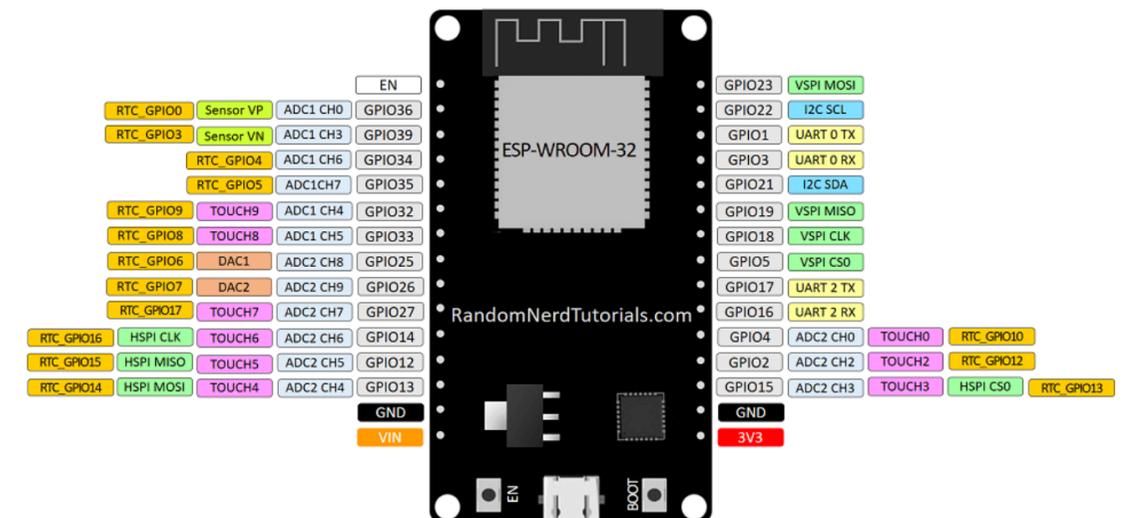


Figure 48: ESP32-Wroom Pinout diagram. Source: <https://esp32.com/viewtopic.php?t=9875>

Prototype 8 (fig. 50) was the first to combine all sensor components. It included:

- a wooden rubab-shaped board
- three nylon guitar strings (as used on the traditional rubab, per RP1)
- a custom-shaped printed circuit board (PCB) fretboard (fig. 51) with a copper layer, divided into 12 capacitive touch sensors (connected to an ESP32 via an MPR121)
- three Force Sensitive Resistors (FSRs) placed under wooden blocks beneath the strings (fig. 52).

The fretboard worked well and accurately detected finger positions. The FSRs, however, were unreliable: firmly plucking one string triggered the other two sensors as well, resulting into incorrect HIGH readings for the other two snare sensors. Because of this instability and the need for constant calibration, the FSRs were unsuitable for detecting which string was played (a key function for both note detection and menu selection in the XR application). As a result, the FSRs were removed and replaced with three touch sensors for the time being, allowing testing to continue while prototyping in Unreal Engine.



Figure 50: Prototype 8.

Prototype 9 (fig. 53) implemented infrared (IR) proximity sensors (fig. 54), which proved significantly more reliable than the previously used FSRs and were therefore adopted in the final design of the e-rubab. These sensors work by detecting reflected infrared light: when the string is at rest above the sensor, it reflects the light back, indicating a LOW signal. When the string is plucked, it moves away from the sensor, reducing the reflected light and resulting in a HIGH signal. This clear contrast enabled consistent and accurate detection of string selection.

For optimal performance, the strings needed to reflect sufficient infrared light. To ensure this, a light-coloured piece of cable insulation was added around each nylon string, just above the sensors, as lighter colours reflect more infrared light than darker ones.

The infrared sensors work effectively and accurately, although at first, when played, they sent their signal two to three times, because of the string vibrating too much before it was still in balance above the sensor again. Therefore, a few nails were added, blocking the vibration, resulting one signal being sent per string plucked.

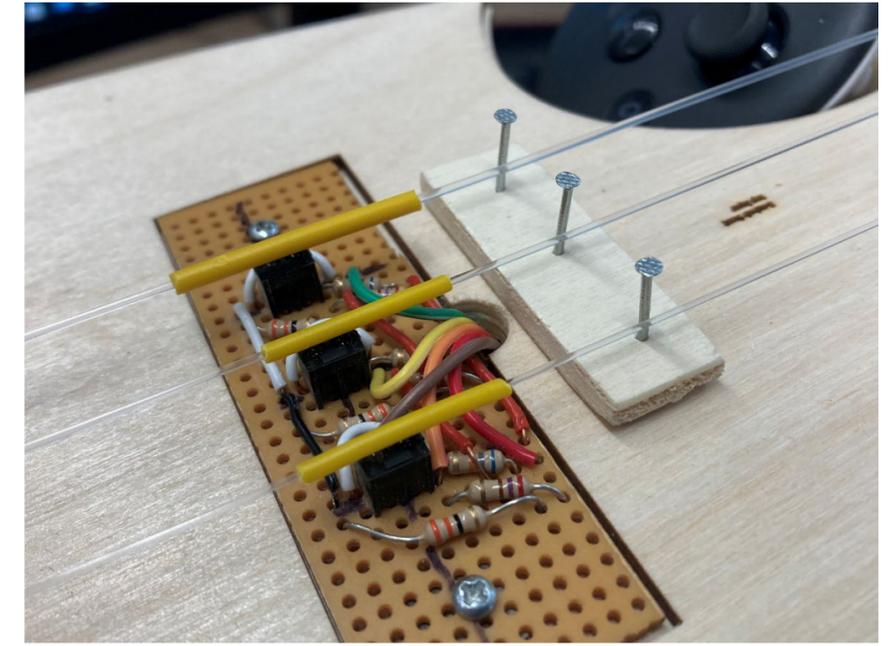


Figure 54: Close-up of prototype the IR sensors (black), and the vibration blocking nails.

Figure 52: Three Force Sensitive Resistors.

Figure 51: The fretboard of prototype 8.



Figure 53: Infrared sensors with yellow insulation around the strings.

3.2 Shape

This chapter discusses the development of the e-rubab's shape design.

Conveying appearance

Since the rubab's appearance emerged as an essential part of its heritage, and conveying its appearance is a key requirement (see Part 2) the e-rubab was designed to maintain the instrument's traditional shape. This is especially important as users will likely see the e-rubab before wearing the VR headset.

The e-rubab therefore has the characteristic silhouette of the original rubab (fig. 55), and includes the three melodic strings and plectrum for playing. However, it does not include tuning pegs and sympathetic strings, which are instead presented in the virtual rubab model.

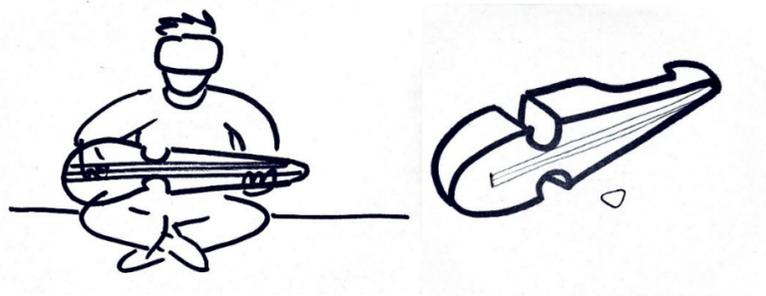


Figure 55: The e-rubab has the characteristic silhouette of the rubab.

For the enacting prototype (see Chapter 3.2), a simplified, cardboard version of the rubab shape was created (fig. 56) for participants to use during the tests. Its minimalist form was well-received by Stichting Solh and worked effectively within a fully immersive VR setting. However, based on feedback (see chapter 3.2), the experience shifted from full Virtual Reality to Mixed Reality using pass-through, allowing users to see their physical environment. This change revealed that the simplified model lacked accurate angles and proportions, resulting in parts not aligning well with the virtual rubab model.



Figure 56: Cardboard prototype of the e-rubab, in use (above) and next to a real rubab (down).



In response, the next iteration featured a more accurate 3D representation of the rubab's shape, based on a 3D scan of one of the original rubabs borrowed for the project (see Appendix M for 3D scanning documentation).

Based on the 3D scan, the essential shape of the rubab was translated into a 3D assembly model composed of parts suitable for laser cutting and manual assembly (fig. 57). This version preserved the minimalist aesthetic while more closely matching the virtual model, as its measurements were taken from the same 3D scan file used for the virtual rubab. The body was constructed from birch wood. The technical drawing and laser cut file are included in Appendix N.



Figure 57: Wooden hi-fi e-rubab.

3.3 Hybrid technology connection

This chapter discusses the development of the connection between the two interactive technologies used: Mixed Reality and SBE technology (the sensors in the e-rubab).

Socket.io server

The user generates input through the use of sensors, and the data of these sensors should be communicated to Unreal Engine to generate the right output: sounds and choice selection. In the Arduino code, running on the ESP32, the input of the fret sensors and string sensors is combined into a single message per note played, for instance 'S1_F2' (String 1, Fret 2).

Using the socket.io plugin for Unreal Engine, I created a connection between the ESP32 and Unreal Engine using a Socket.IO server, as advised by the XR Zone staff in response to prototype 1 (Fig. 45). The set-up of the socket.io connection (Fig. 58) consists of three parts:

- The Socket.IO server running
- ESP32 with built-in Wi-Fi, with connected sensors, acting as a Socket.IO Client sending messages to the Socket.IO server based on the sensor input
- Unreal Engine with Socket.IO plugin enabled, and subscribed as Client to the Socket.IO server events

How to set up the Socket.IO server is described in Appendix O.

The Arduino code running on the ESP32 can be found in Appendix P.

Appendix Q contains the settings for the Unreal Engine Socket.IO Plugin.

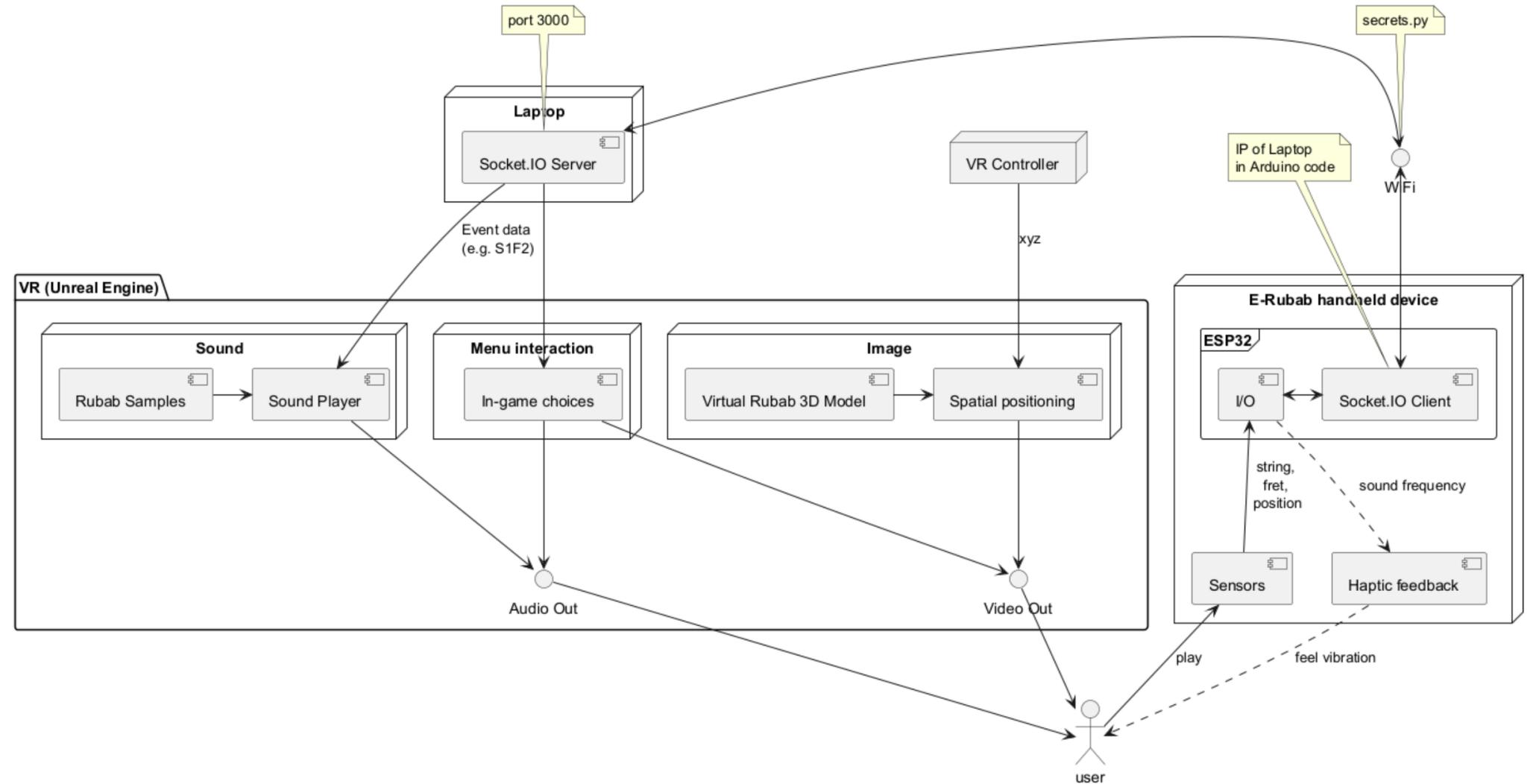


Figure 58: Diagram showing the different components of the hybrid technology system and their connections.

4.2.2 Visual alignment

Another part of integrating the hybrid technology setup is ensuring that the movements of the physical e-rubab align accurately with those of the virtual rubab model. This alignment was achieved by attaching a Meta Quest 3 VR controller to the e-rubab (fig. 59) and positioning the virtual rubab's connection point accordingly within the 'VR pawn' blueprint in Unreal Engine. The positioning is quite a lengthy process because of the limited orientation movement features in Unreal Engine, but can be done through trial and error (fig. 60).

Because the VR headset and controller are part of the same system, the headset can track the controller's orientation with high precision. As a result, the virtual rubab model accurately follows the controller, with only occasional minor lag. At times, it requires a brief movement to 'wake up' the system so that the controller is recognised and the virtual model realigns correctly again. An alternative approach would be to embed a gyroscope and accelerometer in the e-rubab and transmit the sensor data via the socket.io server. However, for the purposes of this project, the VR controller was sufficient.

Finger positions

Both the Meta Quest 3 and the Vive Focus Vision (two types of XR headsets tested) support hand tracking, but the current technology of these headsets is not precise enough to reliably detect the left hand when part of it is obscured by the neck and frets of the e-rubab. As a result, the virtual hand's finger positions are displayed inaccurately, making precise placement on the frets unreliable. Therefore, hand tracking was omitted. Since a pass-through virtual environment was used, which also shows the physical surroundings, the virtual rubab was made partially transparent. This allows the user's real hand to remain visible on the frets, enabling more accurate finger positioning (fig. 61).



Figure 57: By mounting the VR controller to the e-rubab, the virtual rubab can be aligned with the e-rubab in movement and position.

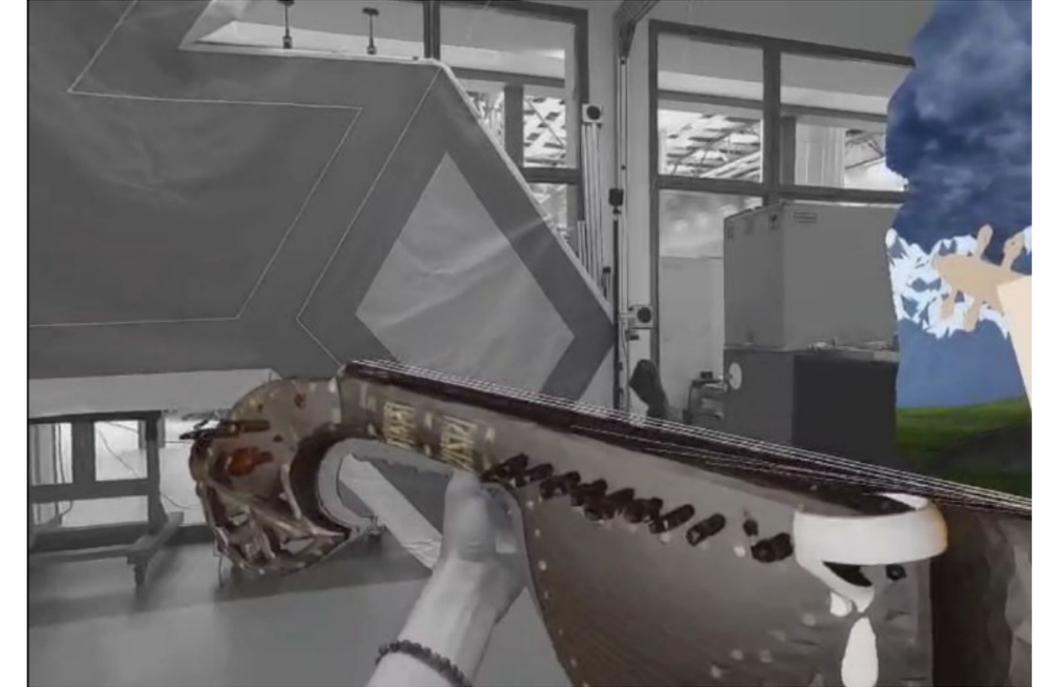


Figure 60: With pass-through enabled, both the virtual rubab and the e-rubab can be visible, so visual alignment is important.



Figure 61: By making the virtual rubab model somewhat transparent, the user can see their real fingers on the e-rubab's fret board.

Part 4: Final Design

This part describes the design of the final prototype, its evaluation and recommendations.



The Rubab Legacy

4.1 Final Design: The Rubab Legacy

This chapter describes the final design of this graduation project: its different parts, its narrative, interactions and functionality. This is the design of the final prototype.

General set-up

The designed system (fig. 62) consists of:

- a physical e-rubab device, with built-in touch sensors and infrared sensors, and Wi-Fi connectivity
- an Mixed Reality experience running on a Meta Quest 3 headset.
- A Socket.IO server running on an a PC.
- A bench with an Afghan rug and wall sticker with image and text (fig. X).

Adapting to Afghan politics

There are two versions of the Mixed Reality experience:

- one for during the Taliban regime (speaking in present tense about the Taliban)
- one post-Taliban version (past tense), if the regime were to fall.

This is done because from the feedback on concept 2 (see Part 3), it was found that by relating the experience to current events, specifically the prohibition of the rubab in current Afghanistan, users felt motivated to learn about the rubab, feeling a sense of responsibility. However, Stichting Solh requested the design to not be bound to current politics. By offering two versions, both insights are addressed.

Only a few audio files differ between the two versions (for scripts, see Appendix R), so no changes to visuals or interactions are needed. This ensures the experience remains relevant in case of a regime change, while maintenance is kept to a minimum. In the event of a regime change, the second version can simply be loaded.



Figure 62: The Rubab Legacy

Physical surroundings

Figure 63 shows an impression of the physical (i.e., non-virtual) space where the design will be used. There is an Afghan rug on the floor, with footsteps on the rug to indicate starting position. This creates a comfortable seating experience for sitting cross-legged on the floor, and offers a nod to Afghan heritage.

The physical e-rubab and plectrum are placed on a bench, which can be used as a seat by those who prefer not to sit on the floor. A visual of the Afghan landscape on a mural sticker conveys the beautiful landscape, and Afghan text (the word 'rubab') on the wall, and the question 'have you ever heard of the rubab?' The idea behind this set-up is to make the user curious by not giving away too much of the content, while still setting the scene using landscape imagery, the Afghan rug, the e-rubab and Afghan script.



Figure 63: Impression of the physical space.

E-Rubab device

This device is a 1:1 scale model in the shape of a real rubab, made from laser cut wooden (birch plywood) panels (fig. 64, fig. 65). It includes:

- 3 nylon strings;
- 12 custom-shaped capacitive touch sensors (fret sensors), sensing which fret is being pressed;
- 3 proximity infrared sensors, one under each string (string sensors), sensing which string is being plucked;
- 3 pieces of yellow insulation wrapped around the nylon strings, just above the infrared sensors;
- An ESP32 with Wi-Fi connectivity, running Arduino code that 'sends' the sensor input to the Socket.IO server;
- An MPR121 board between the ESP32 and the fret sensors;
- A rechargeable 3.7V Li-Po battery;
- A Meta Quest 3 VR controller, attached to the E-rubab body using a rubber band.



Figure 64: E-rubab in use.

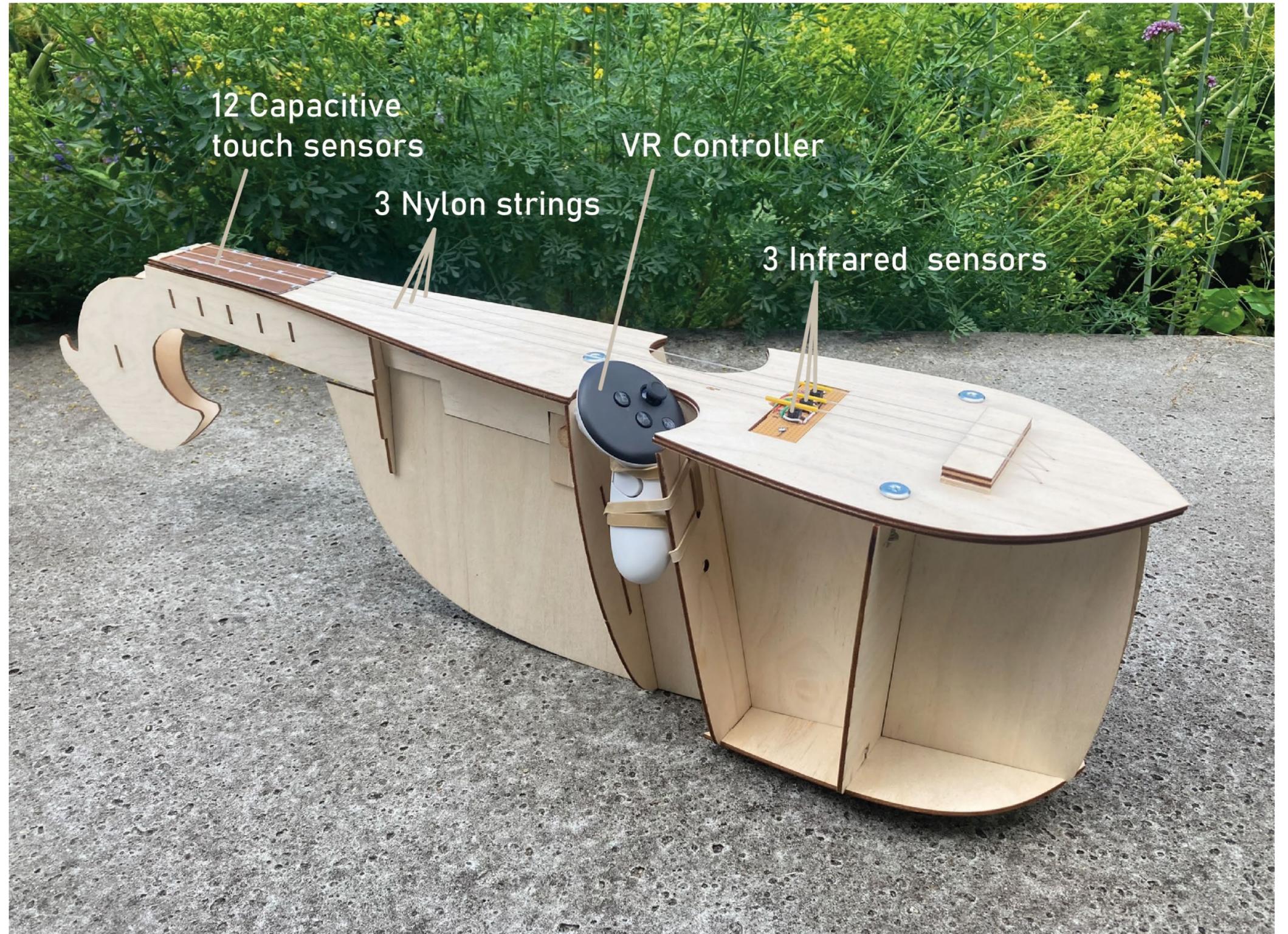


Figure 65: Final design e-rubab.

Mixed Reality Experience

[This link leads to a video of the full walk-through of the final prototype.](#)

After putting on the XR headset, the user sees a portal in the shape of Afghanistan and begins with an introductory animation accompanied by a voice-over, accompanied by rubab music. The narrator tells about the rich diversity of Afghanistan, both in landscape and culture, and informs the user that the rubab is currently forbidden in Afghanistan. This sense of threat is visually reinforced by a Afghan landscape, shifting from a calm starry night to a thunder storm with lightning (fig. 66), as a giant rubab slowly descends to the ground, in a position resembling a ship-wreck. This scene conveys a sense of urgency to motivate users to learn about the rubab.

The voice-over then invites the user to pick up the e-rubab (fig. 67) and explore the rubab's heritage. Once the introduction concludes, three interactive tiles appear on the floor (fig. 68). By stepping onto a tile, the user can select one of three levels: Afghanistan, Parts & Functions, or Play.

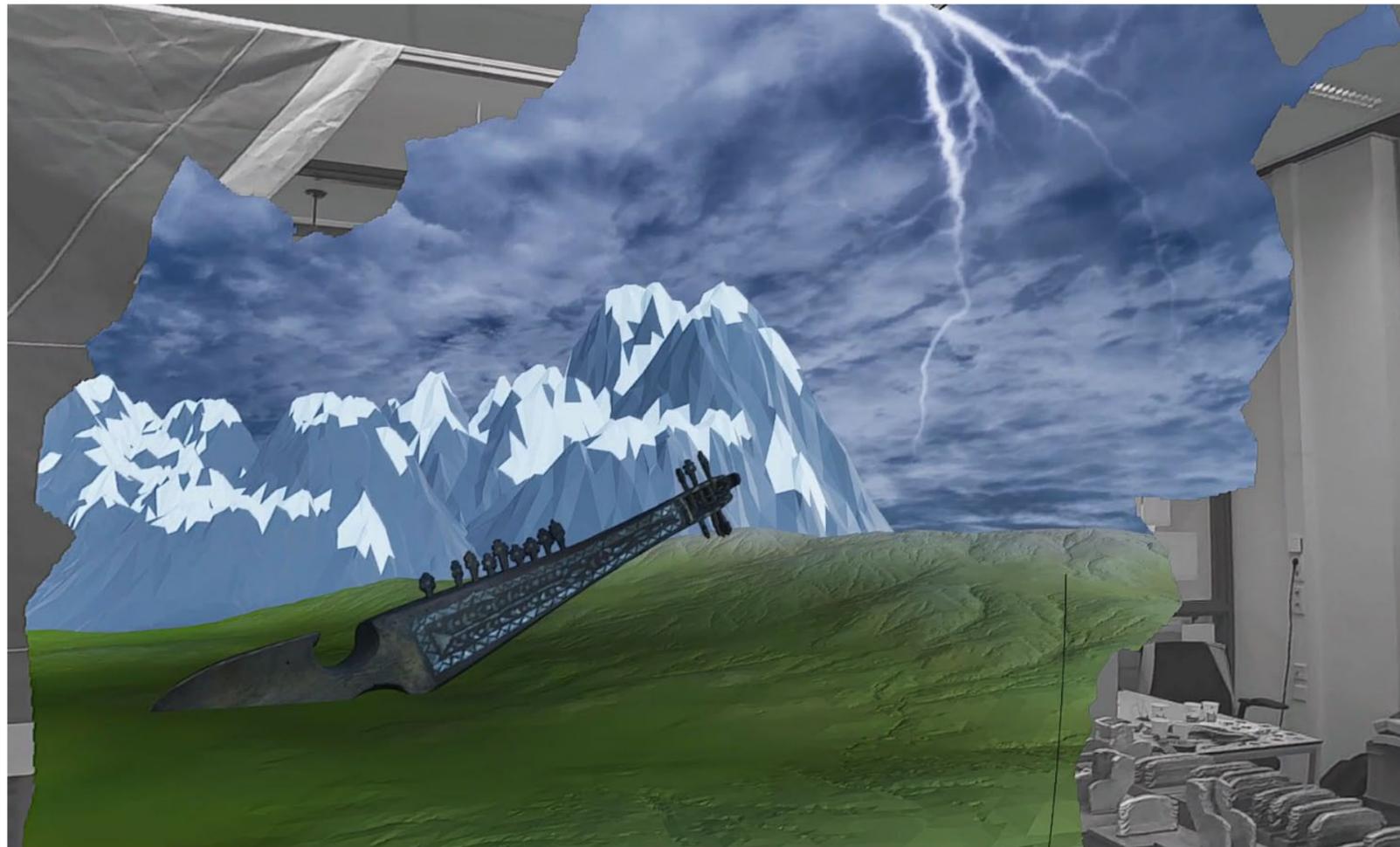
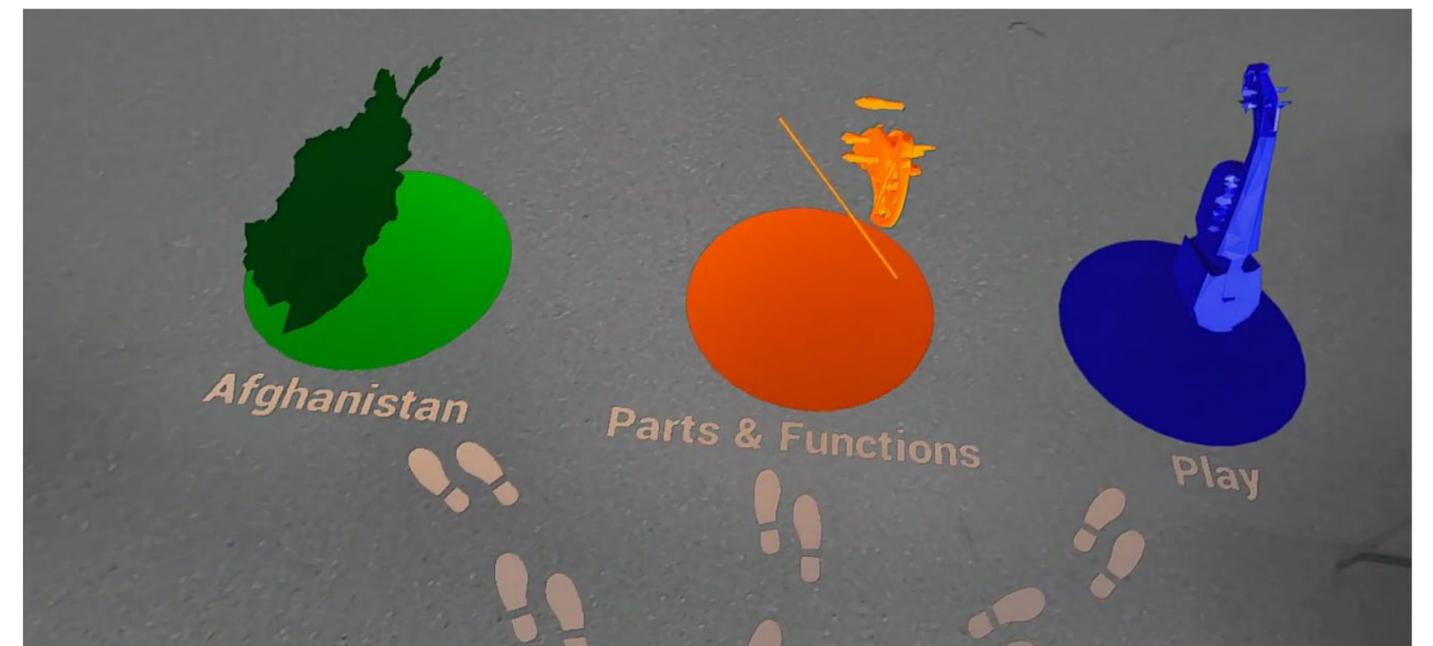


Figure 66: Afghan shaped portal with landscape.

Figure 67: Afghan shaped portal with landscape.



Figure 68: Interactive tiles on the floor that lead to the three levels.



In the **Play** level (fig. 69), users can choose a song—either a familiar Western tune (Do-Re-Mi or Frère Jacques) or an Afghan piece: Sarzamin-e man. This encourages both cultural connection and cross-cultural exploration.

Users can select the menu options by plucking one of the three strings on the e-rubab (which are coloured using a virtual overlay, with the same colours depicted in the choice menu) (fig. 70).

To play the selected song, users follow a blue dot on the virtual fretboard overlay of the e-rubab they are holding (fig. 71). They can hear the notes that they play through the headset. After they finish a song, the user is rewarded with an applause, and then prompted to choose whether to play another song, play freely without guidance (with a one-minute timer), or exit the level.

Figure 70: Menu options, with the coloured strings to pick from.



Figure 69: Play level.



Figure 71: Following the blue dot (virtual overlay) on the fret.

In the **Afghanistan** level (fig. 72), the user encounters four characters positioned across a map of the country. They represent the Afghan people. Users can select questions to ask them by plucking one of the three strings on the e-rubab (which are coloured using a virtual overlay, with the same colours depicted in the choice menu), and in response, each shares a personal story that highlights the rubab's cultural significance and its connection to Afghan identity.

Two of the four characters wear traditional Afghan attire (selected by Stichting Solh), and two wear Western clothing, helping Western viewers relate through familiar dress (supporting meaningful connection, see chapter 1.4) as well as showcasing Afghan attire.

Light emitting bars (fig. 72) are used to indicate which character is speaking.

Questions a user may select are:

- What does the rubab mean to you?
- What is the relation between the rubab and Afghanistan?
- Which political challenges has the rubab faced over the years?



Figure 72: Afghanistan level

In the **Parts & Functions** level (fig. 73), the user hears a narrated explanation of the various components of the rubab and their functions. As each part is described, it is visually highlighted (virtually) on the rubab they are holding (fig. 74). The materials used—mulberry wood and goat skin—are represented virtually by a 3D tree and a goat. The voice-over then poses a quiz question about the function of the sympathetic strings. If answered correctly, the narrator elaborates on how these strings affect the rubab's sound, with an audio comparison between versions with and without sympathetic strings to demonstrate their impact on the sound.



Figure 73: Parts & Functions level, with tree and goat.



Figure 74: Parts are highlighted in yellow when described by the narrator.

After all levels have been completed, the user returns to the Afghanistan-shaped portal for the **finale**. The sun rises, and the voice-over thanks the user for keeping the rubab's heritage alive.

As part of this finale, the giant rubab ascends to the sky (fig. 75), and a video overlay shows a joyful rubab duet performance (fig. 76).

When the concert concludes, the experience ends as the credits roll.

Figure 76: Rubab concert during the finale/outro.

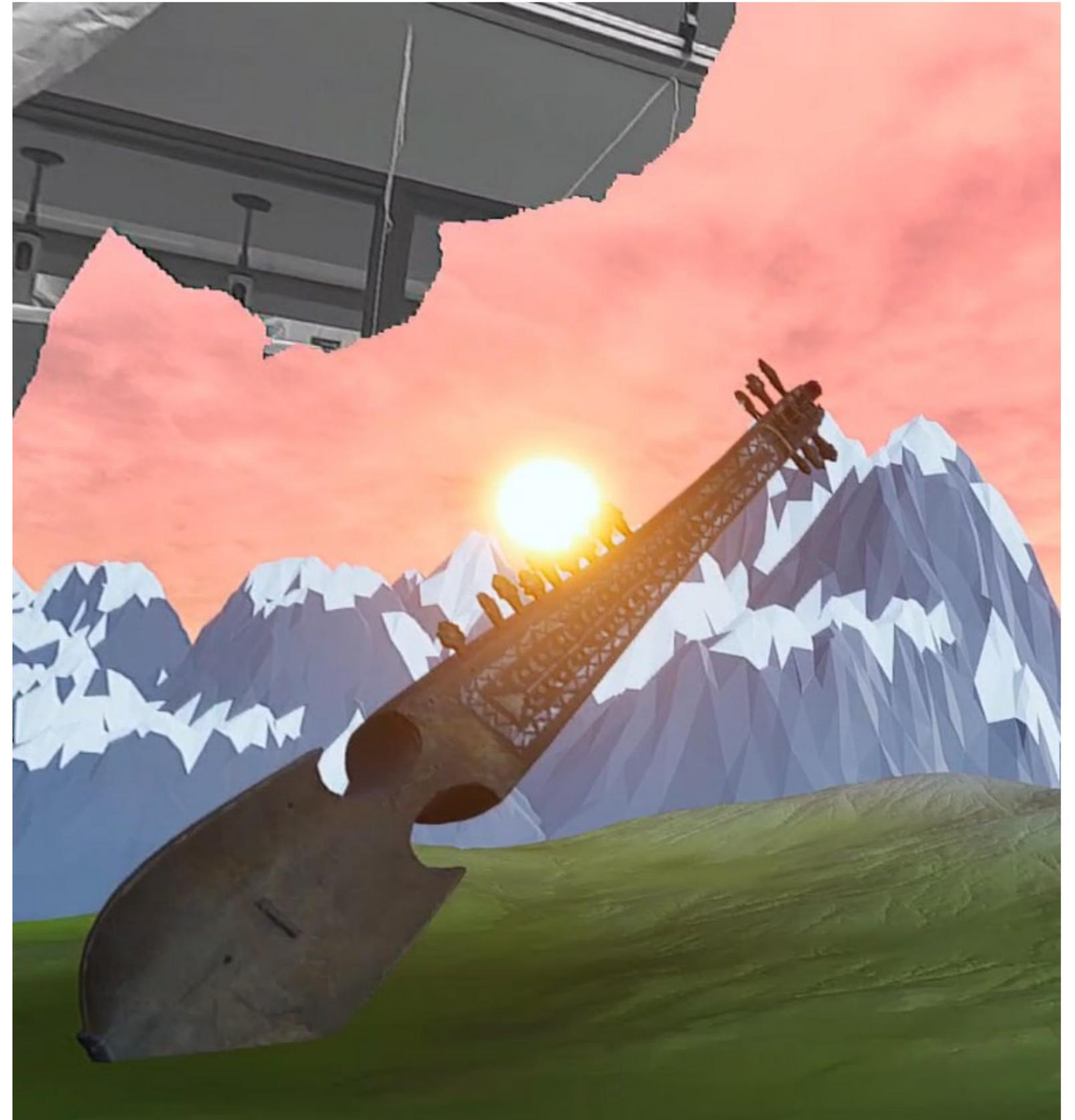


Figure 75: Giant rubab floating up.

4.2 Final Design Evaluation

This chapter discusses the evaluation of the final design. It was evaluated with:

- 6 members of the target group, individually:
 - Geography teacher, age 25, male, no prior experience with VR, no experience with playing string instruments
 - Linguistics student, 26, female, little experience with VR, no experience with playing musical instruments
 - Crisis communication officer, 26, female, no prior experience with VR
 - 3 IDE students, 24-26, male (1 of them with prior VR experience)
- 1 Rubab Player.

Method

The target group evaluation sessions consisted of the following activities and questions:

- Explanation of Meta Quest 3 headset volume buttons
- Question beforehand:
 - *What is your perception of Afghanistan? Why?*
 - *Have you used Virtual Reality before?*
- Display and explanation of the picture of physical library context (see fig. 63)
- Full run-through of the MR application with functioning e-rubab (participants were observed)
- Questions afterwards:
 - *How would you describe the experience you just had? Why?*
 - *What did you like? Why?*
 - *What did you not like? Why?*
 - *What did you find confusing or unclear? Why?*
 - *How calming did you find the experience, on a scale from 1-5 (1 being not at all, 5 being very much)? Why?*
 - *How guiding did you find it (1-5)? Why?*
 - *How rewarding did you find it (1-5)? Why?*
 - *What did you learn during the experience?*
 - *What is the most surprising thing you learned about Afghanistan through this experience?*
 - *To what extent does the experience introduce you to the beauty of Afghan culture? Why (not)?*

- *How do you feel about holding a physical instrument?*
- *How do you feel about the standing and sitting interactions?*

The rubab player evaluation was only about the playing sensation of the e-rubab with virtual overlay, due to time limitations during a long documentary shooting day.

Rubab player feedback

RP1 indicated that the shape and weight of the e-rubab device were spot on:

"It feels like I'm just holding a proper rubab, and it sounds good too."

The sound is clear and the material of the strings is accurate, but to truly resemble the rubab, they need to be tightened quite a bit more: *"Right now, the strings are so loose that I'm already touching the other string ... and they're a bit too sensitive now to play properly."*



Figure 78: One of the participants testing the prototype.

Target group feedback

General feedback

- Most participants described the experience as fun.
- The goat was once again valued as a highlight, that adds a touch of humour to an overall quite serious topic.
- It turned out necessary to inform the participants how to use the sound volume button of the Meta Quest 3 headset, especially since 5 of them had little to no experience with Virtual Reality, giving them control on the sound volume (when the sound is too loud, this can be experienced as stressful [one participant had this]).
- The narrative voice was valued as clear and comforting.
- The visual animations really added to the experience; the tree and the mountains were considered beautiful and something nice to look at while listening (M);
- One participant noted that they would have liked an exit button available at all times, and that that button could lead to the end animation earlier on, because they found it important that people get the chance to see that final concert video, even if they do not want to play all levels.
- One participant even subtly danced along to the final music concert, and tapped the rhythm with their foot.
- For some of the participants, the XR technology was quite overwhelming and new, since they had never tried XR before.
- The amount of information provided was good, not too much, not too little, and the pace was good.
- Four out of six participants did not take the plectrum, and played the rubab using their fingers. They simply did not notice the instruction to get the plectrum, although it was mentioned twice. A more visual instruction could help.
- Although some did not notice it, the misalignment between virtual and physical rubab was considered troublesome by most participants.
- Several participants mentioned that they were surprised that a musical instrument could be so political.
- One of the participants had difficulties reading the pop-up menus. Because the text is attached to the user's headset, it moves along with where they look, and he explained that he reads by moving his head instead of his eyes, and

therefore struggled reading the menu options. It would be better if the text was set in one position in space, instead of moving along with the headset.

- The rug was considered inviting to sit down on, as well as a clear boundary of where you can walk.
- The strings were too sensitive at times, and sometimes unintendedly triggered the next menu option already. One participant got stuck in a loop of the same story in the Afghanistan level because of this.

P4: *"I thought it was really good that you get a complete picture of what the instrument means. Besides its cultural significance, it also shows what the country has been through. And you get the sense that you yourself become more a part of it, because you really step into that world and actually get to play with it yourself."*

Level Afghanistan

The visual highlights that marked who is speaking, were clear. Moreover, the use of generative AI for creating the images of "Afghan people" was also valued, and even preferred over real people by some, explaining that too realistically animated human figures often have something uncanny over them, whereas these AI generated figures put the focus on the rubab's story instead of the individual person.

Some extra images of Afghanistan would have been a great addition to the humans in the Afghanistan level, one person explained. They were positively surprised to encounter humans in the Afghanistan level.

Multiple participants indicated that the voice of the elderly man did not fit well, because the voice sounds a lot younger than what he looks like.

Level Parts & Functions

In this level, three participants did not notice the yellow highlights on the rubab parts, because they were looking at the tree instead, and you need to actively look down at your instrument to see the highlights. This led to confusion when the quiz question was asked, as these participants did not understand what 'strings' the question referred to. The other three, however, saw the yellow highlights right away.

One of the participants explained that they found it difficult to understand how the resonating strings worked, and would have like a bit explanation, not even technical, but just a mention of cause and effect would suffice, he said.

Level Play

Many participants needed a hint before they understood what to do during the Play level, and waited for instructions by the narrator, which did not come. More guidance is needed here. Two participants even asked if they should press the title text that says 'Play'. Once they received a subtle hint that they should look at the frets, they saw the blue dots and followed these. The blue dot (communicating where to place the finger on the frets) was understood by all once noticed. All participants managed

to finish the songs they chose, some even played very well, but some others commented that they did not recognise the song they had selected in their playing, and one considered this a stressful experience. An example of what the melody should sound like would be a good addition, as well as a virtual rubab teacher that could provide more guidance in playing, participants suggested. It should also be gently feedbacked when one is (repeatedly) making a mistake.

One participant explained they would have preferred the sound of the rubab coming from the direction of the rubab, instead of a 2D sound, as is now. He found it confusing that he heard the rubab sound 'above his head', and it would be clearer if the sound really came from the rubab you're playing, he suggested.

The misalignment of the virtual strings with the physical strings led to confusion for almost all of the participants as to where exactly to place their fingers, making it difficult to play the correct note/ select the right option. One participant even 'peeked' underneath the edge of the VR headset to find the correct position.

Three of the participants (without guitar experience) had not understood the correct way of holding the e-rubab while playing, and played the frets using their thumb instead of index and ring fingers (fig. 79). The other players did play the frets correctly, although they too had no prior experience playing the guitar.

Menu Selection

All participants understood the menu selection interaction right away, and plucked the coloured string of their choice for each of the menus. However, the misalignment of virtual and physical rubab led to confusion as to which string they had plucked. The menu selection interaction using the strings of the e-rubab was praised, since they are already part of the instrument itself.

P1: *"you don't need anything else than the instrument itself."*

P3: *"I really liked that I could control the whole system using the three strings, which are already part of the instrument; that was very well done."*

P4: *"I thought it was really cool that you could also make choices and play using the guitar—all those things combined!"*

One participant explained that it would be helpful if the menu would show which options they had already selected before (for instance, the questions in the Afghanistan level).

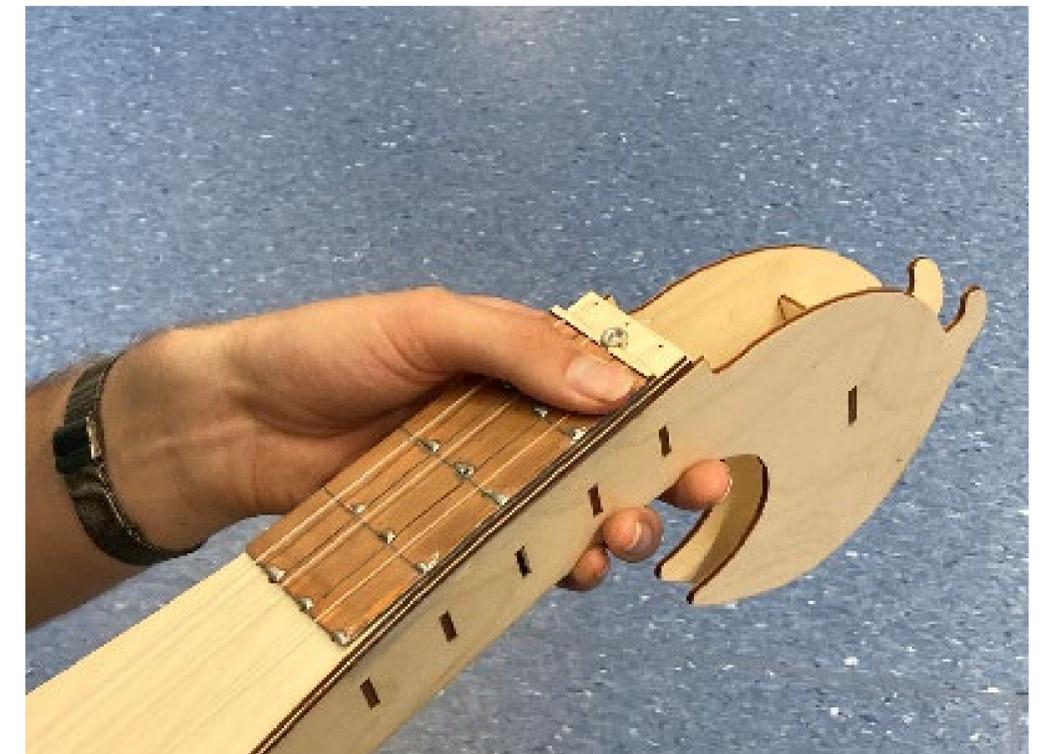
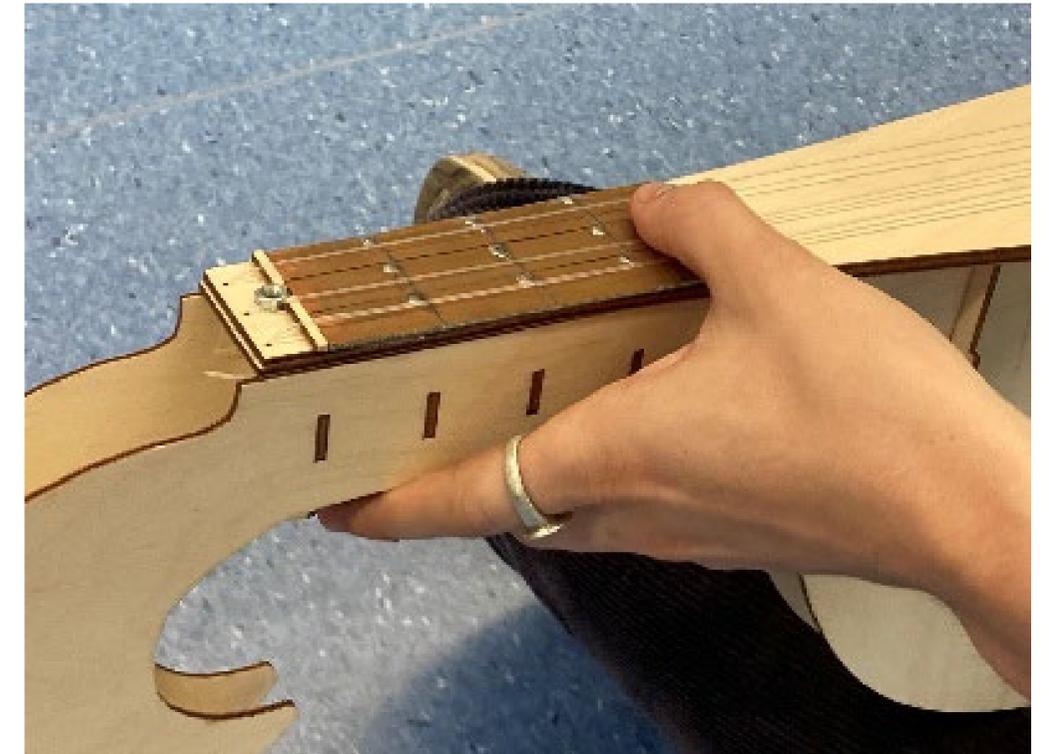


Figure 79: Several participants had not understood how to correctly hold the rubab while playing.

Interaction vision qualities

Calming: The slow-paced music was considered beautiful and calming. The overall ambience, the “pretty things to look at” (landscape, goat and tree), listening to the stories, and the voices too led to the experience being very calming for most participants (score average: 3,5 out of 5). One participant explained that the British accents with slow pacing reminded him of relaxing documentary narration, and more specifically BBC documentaries, which he found generally calming. Another participant described the experience as meditative:

P4: *“You really step into another world, and with the music you hear and the stories being told, I found it somewhat meditative in a way. It truly takes you out of your own world for a moment, and my own world can be a bit stressful at times.”*

The parts where they had to play the instrument, however, were considered less calming and somewhat hectic. Participants suggested that this could be solved by adding more guided, comforting, instructions for when the wrong notes are being played, and reducing the sound volume of wrong notes, as to reduce dissonance in music, and improving alignment of virtual and physical rubab.

One participant mentioned that he found XR technology not so calming, since it was new to him and conveys a lot of information to process.

Guiding: The experience was considered very guiding as well (score average: 4,3 out of 5) because of the narrator telling you what to do, how to hold the instrument, and visual cues such as the coloured strings. It was clear what you could do, and how to navigate. You’re taken by the hand through the story and get to learn the instrument. The three paths were clear, as well as the three strings for the three options. Only during playing, there was a lack of guidance. Other elements that were considered guiding were the footsteps; A clear beginning and end; and the repeated starting and stopping of the different levels that helped anticipate how long each will take.

It was valued by many that there was no fixed order of doing things, but instead have the option to choose what interests you, a certain autonomy. Therefore, the playing without guidance option was also valued. One participant explained that if there had been no autonomy, but a set order of things, there would be little advantage over a video format.

Rewarding: (score average: 4 out of 5); Contributing to keeping the heritage alive by playing was considered rewarding, just as gaining new knowledge through the stories told by the Afghan people. The experience running smoothly was also valued, as things appeared by themselves, and you did not need to wait very long. One participant mentioned their progress in playing as rewarding. The final video of the rubab performance was also considered rewarding, since you first get an idea of the instrument, trying to learn it by your self, and then you end with how it really is

played, resulting in a sense of climactic build-up. Other elements considered rewarding (and satisfying) were the applause after playing a song; the transition from explanation in the intro to actively participating yourself; the sense that your actions influence the output of sounds and visuals.

It was described as very interesting, especially since beforehand you have no idea what the rubab is, and the word on the wall in the physical space is unfamiliar, and therefore mysterious. It is rewarding to then find out what the rubab is.

P3: *“I don’t play guitar, and I don’t play the rubab either, yet you still get the feeling that you’re doing something, and it gives you a result. So you feel like what you’re doing is actually good.”*

P3: *“I walked in here, put that thing on my head, and it started—you get completely drawn into the whole story. The entire experience really felt like a moment set apart. It’s a kind of pause, but in a different way. Just like when you go to the theatre—you walk into the auditorium and then back out again, and at the end you think, wow, what have I just experienced? You need a moment to process it all. And that’s not a bad thing—it just takes a bit of time. That feeling is really rewarding.”*

P4: *“Playing was really fun. It made me feel like I was contributing in some way. I really enjoyed the stories too, that feeling of “oh, I get to hear this story” and that I’m gaining new knowledge. Those are fulfilling things: you contribute something and you gain new knowledge.”*

Introduction to the beauty of Afghan culture

One participant indicated that he was surprised by the value and love that the Afghan people feel for their own country, even when they live abroad. By conveying the meaning that the rubab holds for the Afghan people, together with a tangible rubab, the “beautiful” music, and the landscapes, a rich ambience is created that gives the idea of a rich culture as well. The greenery, such as the tree, and the overall colourful design also helped in creating a “richer impression of the country”, another participant explained. Two participants explained that they valued that there was no judgment passed, which they liked, but that the experience merely facilitates cultural appreciation. Some quotes from the participants:

P3: *“As I understood it, the rubab is a central symbol within the culture, and **the fact that there’s more than just the rubab—that it’s part of something bigger—means there’s so much more to discover.** It communicates a kind of richness of Afghan culture. It’s not just about the rubab on its own, but about it being part of a whole way of life.”*

P4: *“You really get a good sense of how beautiful it is. I think because of the different regimes, the oppression that has happened there, and people being forced to leave, a lot of it has, maybe not disappeared, but started to fade ... It’s made very vivid. With*

the images, the tree it’s made from, the goat of course, but also the decorations on the rubab itself, and then actually seeing people who are speaking directly to you.”

P5: *“If I knew someone from Afghanistan now, I’d ask them if they know the rubab. I’d be curious to hear what they have to say about it.”*

P5: *“I do think it was well-balanced, especially because it didn’t pass judgment—and that’s something you see all too often, like, “this is beautiful, but they hate women,” for example—but that wasn’t the message here, and I really appreciated that. **I liked that it was about cultural appreciation.** It wasn’t like, “wow, we should all start playing the rubab here out of solidarity.” I was glad that wasn’t suggested. It simply presents it—without pushing you to do anything—and that’s a good thing.”*

P5: *“I think it’s beautiful how an entire world forms around such a static object [the rubab].”*

P6: *“The origin of the instrument, the stories, and the overall setting with the music and the video showing how it’s played and its role in society, all of that helps you understand that **it’s really something ancient and unique, and not just some kind of guitar.**”*

P6: *“**It’s nice to have an older and more original image [of Afghanistan] for once, rather than just the past 20 years, which tends to overshadow everything.** I also found it funny that there was a tree involved, because that doesn’t really fit with my image of Afghanistan—which just shows that my view isn’t entirely accurate, based only on the idea of a desert that’s been bombed flat.*

P6: *“It made me think of *The Kite Runner* by Khaled Hosseini. That also shows someone growing up there, the pre-war situation, when things seemed better—greener and more peaceful than they do now. **You get a fuller, more nuanced picture.** This experience gives you a bit of that as well. And maybe in reality trees do get bombed too—but still, **that greenery, and the whole presentation being quite colourful, all adds to giving you a richer impression of the country.**”*

The concert video in the finale was praised as ‘really beautiful’ too. The rubab floating up to the sky was interpreted by one of the participants as a metaphor for the rubab being part of something bigger, something connecting, almost religion-like.

Physical instrument

Some participants (M); indicated that they were scared to break the e-rubab prototype, since they knew that it was a (graduation) prototype, and because it looked fragile.

Participants indicated that the physical instrument added to the experience, as it conveys how big the instrument is, and adds a sense of reality to the virtual experience, as well as a playing interaction closer to real playing, and makes you feel

part of the rubab. The heavy weight of the e-rubab also conveyed a certain sense of value of the rubab, one participant added.

P1: "With a VR experience, you may get a somewhat abstracted image of reality—something that creates a bit of distance from the real world—but when you're holding something physical that represents the instrument, it almost adds up to the real experience, I think."

P2: "Compared to just a digital version, it's nice that you can actually touch something and feel what's happening. When it's completely virtual, you're basically just grabbing at thin air."

P3: "It's really great to have something physical in your hands. There's no better way to tell a story than by combining it with a physical experience like this."

P4: "I think a virtual rubab on its own would be a bit of a shame. With this, you really feel more like you're part of it because you can actually feel it in your hands. If it were purely imaginary, it would feel like something's missing."

P5: "A custom controller like this is really effective for this kind of experience—if you want to take it seriously ... It helps with your suspension of disbelief; like in theatre, where you forget for a moment that everything is pretend. With this too, I thought: I've got this thing in my hand now."

Walking-sitting interactions

All participants understood the walking interaction right away, and selected the levels by stepping onto the level 'tiles'. However, some participants (M; J) experienced difficulties with the tiles; One participant walked too far that they exited the virtual boundary, resulting in missing all visual animations of one of the levels, and was scared that they would not have enough walking space later; another participant forgot that they could also walk back a few steps, and stood uncomfortably close to the virtual objects because they had walked too far.

One of the participants (N.) wanted to remain seated after doing the Play level, and tried to select the menu tiles using his hands and feet, but was confused when it turned out he had to use his head instead (since it was set that the menu tiles' collision boxes need to collide with the headset for collision to be detected in Unreal Engine).

One other participant valued the diverse character of the walking and sitting interactions, explaining that it also marked different parts of the experience as if they were chapters. She ended with the Play level, and therefore ended seated, which she felt was very natural, and even relaxing, for the final concert. Another participant (Ja.) also ended sitting down, and really valued the sense that he was sitting in a circle together with the two musicians in the video, who were also in cross-legged position, just like he was, and felt a sense of cozy togetherness because of that.

Two participants preferred sitting on the provided chair (M.; K;) instead of sitting cross-legged on the floor (R; N; J; J;). They considered sitting on the chair less risky, and were afraid that they might break the e-rubab while sitting down, since they would need to hold it in one hand only to be able to sit down on the floor. Staying seated was preferred overall, and some suggested using the hands for navigation instead of walking. Although it is considered fun to walk, it is troublesome when you are holding an instrument to stand, then sit down, and then stand up again to walk. Ideally, one participants suggest, you would sit in cross-legged position throughout the whole experience.

Once sitting on the floor, two participants mentioned that it was a lot easier holding the rubab while sitting, because of its proportions. Although they valued the way of selecting a level by walking, they would have liked to be seated while watching the video animations. One of them did not like the switching between standing and sitting, and therefore remained seated throughout the whole experience. Another participant was unsure if switching between standing and sitting was comfortable.

Another participant suggested to start standing, and sit down after the introduction as to physically 'commit' and take the rest to sit, play and learn.

Sitting cross-legged was valued and conveyed the "Afghan way" of playing:

P3: "The fact that you're meant to sit cross-legged also says something about how it's supposed to be played. In the West, the guitar is usually played sitting on a chair, but the rubab isn't. That says something about that place, and about the way of life there."

P4: "It was also nice to play sitting cross-legged, since that's how it's often played—that makes it feel a bit more realistic, I think."

Pass-through

The surroundings being still visible (pass-through) was valued, because that way there is still a connection with the real world, and contact with the people around you is still possible. It could even lead to funny situations, one participant noted, since you can comment what you see to your family members or friends and make them imagine what you are seeing, and making them curious to try it out as well.

The Afghanistan shaped portal was also valued by many, correctly interpreted as the shape of Afghanistan. One participant described it as a window to Afghanistan, as if you could walk right in, and be there.

4.3 Recommendations

Design recommendations

Based on the feedback from the final design evaluation, my design and research recommendations are:

1. Alignment of virtual and physical rubab:

- Resolve the misalignment between the virtual and physical rubab to improve finger placement accuracy on the frets and strings. The current prototype uses a semi-transparent virtual rubab to allow users to see their own fingers. However, alternative methods for guiding finger placement should be explored to identify the most user-friendly approach. For example, instead of relying on a transparent virtual rubab, the system could visualize the user's current finger positions alongside the desired positions (e.g., using a blue dot) to clearly indicate where to move next.

2. E-Rubab design

- Adjust the string tension on the e-rubab to more closely match the tighter tension of a real rubab. Use the existing terminal block (fig. 80) for tightening, or implement an alternative mechanism if necessary. Increasing string tension may also reduce excessive string vibration, possibly preventing the infrared sensor from picking up double signals. This hypothesis should be tested. If confirmed, the current prototype's dampening nails may no longer be needed and can be removed. Otherwise, finetune the IR sensor code.
- Make the e-rubab device more robust to reduce the user's fear of breaking it, and to make it durable for use in the public space.



Figure 80: Terminal block used to tighten the string.

3. Playing the rubab:

- Ensure that the rubab sounds are 3D sounds instead of 2D, and come from the direction of the instrument to enhance the realism of the playing experience.

- Provide more visual instructions (e.g. animation or video) for using the plectrum, as many participants did not notice the audio instructions about the plectrum, and therefore do not use it.
- Offer more guidance (how to play, and how to correctly hold the rubab) and feedback during the Play level to help users learn to play the rubab. Include audio of the melodies before playing the tune to let the user know what the song should sound like, and provide gentle feedback when a mistake is made. Possibly include a virtual rubab player in the level.
- Reduce the sound volume of wrong notes, or only play the sound of the correctly hit notes, to make the playing experience more calming and less musically dissonant.

4. Seated interaction:

- Start the interaction standing, and after the intro animation, invite the user to take the e-rubab and sit down on the bench or floor, cross-legged. Let the users stay seated throughout the whole experience, increasing ease of holding the instrument.
- Replace the current walking-based level selection with a seated interaction, for instance using the hands (with hand-tracking) to select one of the three rotating 3D level icons, displayed in front of them instead of on the floor.

5. Menu navigation:

- Set the menu options' text in a fixed position in the virtual space rather than having them move with the headset, to improve readability.
- Provide visual feedback to show which menu option has been selected.
- Provide visual feedback to show which menu options have already been selected before.

6. Images of Afghanistan:

- Add more images/videos of Afghanistan to provide a richer cultural context in the Afghanistan level, and to further convey how the rubab is embedded in Afghan cultural events.

7. Exit button:

- Provide a virtual exit button that is available at all times, allowing users to end the experience. The button should lead to the finale with the rubab performance as part of the closure.

8. Highlighting rubab parts

- Since users sometimes do not notice the yellow highlighted rubab parts in the current Parts & Functions level, because they need to actively look down to the rubab in their hands, and may be distracted by the goat and tree. Make the yellow highlights stand out more, for instance by adding another virtual rubab that floats in front of the user, and display the highlights on that rubab instead of on the one they are holding.

9. Refine voices

- Use real Afghan people to record the voices (of the narrator and the voices in the Afghanistan level), to enhance the authenticity and decrease synthetically sounding voices. Keeping the British accent and the tone used will help in keeping the calming effect the current voices have. The current AI-generated voices were used to save time and costs during prototyping.
- Make sure to record the audio tracks for both version of the MR-experience: the version to be used during the Taliban regime (present tense about Taliban), and the post-Taliban version (past tense).
- Make sure that the voices used align well with the age and looks of the AI-generated image of the Afghan people in the Afghanistan level.

10. Refine 3D rubab model

- Improve the layout of the sympathetic strings in the virtual rubab blueprint within Unreal Engine, and add the missing tuning pegs. The scanned rubab was missing parts—an advantage in this case, as it had no strings, making it easier to model these directly in Unreal Engine. But for a more accurate appearance, the missing parts (tuning pegs) should be added and correctly modelled. Loose tuning peg 3D meshes are included in the Unreal Engine project file but have not been added yet.

11. Accelerator & gyroscope instead of VR controller

- Instead of the VR controller, implement an MPU-6050 accelerator and gyroscope, connected to the ESP32, and test whether it is capable of smooth alignment as well. If so, the VR controller can be removed from the e-rubab, resulting in a cleaner look and reduced maintenance (since changing the batteries now requires recalibration each time). If the VR controller turns out to still be a better option than accelerator and gyroscope, make sure it is more sturdily mounted to the e-rubab, and batteries can be easily replaced without the controller changing position.

12. The rubab's physical playing sensation

- Research whether a vibration motor in the e-rubab would further enhance the physical playing sensation mimicking, to convey the sensation of feeling the vibrations while playing.
- Make sure that the weight of the rubab remains similar to that of the current wooden e-rubab / a real rubab.

13. XR headset instructions

- For users unfamiliar with XR technology and/or the XR headset used, make sure to include instructions on how to change the sound volume of the specific headset used.

14. Physical space

- Make sure that it is clear that the Afghan script word for rubab (on the wall sticker), means rubab. This can be done by using the same distinctive colour for the word rubab in both the Dari/Pashto translation, and the word rubab in the question "Have you ever heard of the rubab?"
- Attach the Afghan rug not only on the floor, but also on the bench, so both users who sit on the floor and those who prefer to sit on the bench have the same sensation of sitting on a rug, which adds an element of Afghan culture to their sensation (fig. 81).

15. Two versions of the MR experience

- Make sure to program two different versions of the MR application: one that uses present tense about the Taliban regime, and one that uses past tense for the Taliban regime (the only difference is a few audio tracks). This way, the experience will not get outdated if the Taliban regime were to fall any time soon, as it will be only a matter of selection the other version.

16. Practical implementation

- Research is needed on how and when to best charge the e-rubab's battery, taking into account that electricity may be switched off at night in library and museum buildings.
- While further developing the design, organising a co-design or input session with library and museum employees will be a valuable way to gain insights into practical implementation challenges.
- The final prototype runs on Unreal Engine via a separate PC, connected to the headset with a USB cable. To maintain the high rendering quality (which is typically lost when running the application directly on the headset) it will likely be necessary to continue using an external PC (which can then also run the Socket.IO server). This PC could be integrated into the bench design.
- Stable Wi-Fi connection at the intended location of use should be ensured.
- The design is to be used in libraries, museums and possibly music or culture festivals. Suggestions would be musical instrument museums with rubabs in their collections, such as Museum Vosbergen; or the WonderFeel Festival, a yearly outdoors festival that welcomes many culturally interested people to listen to both Western and non-Western classical music performances.

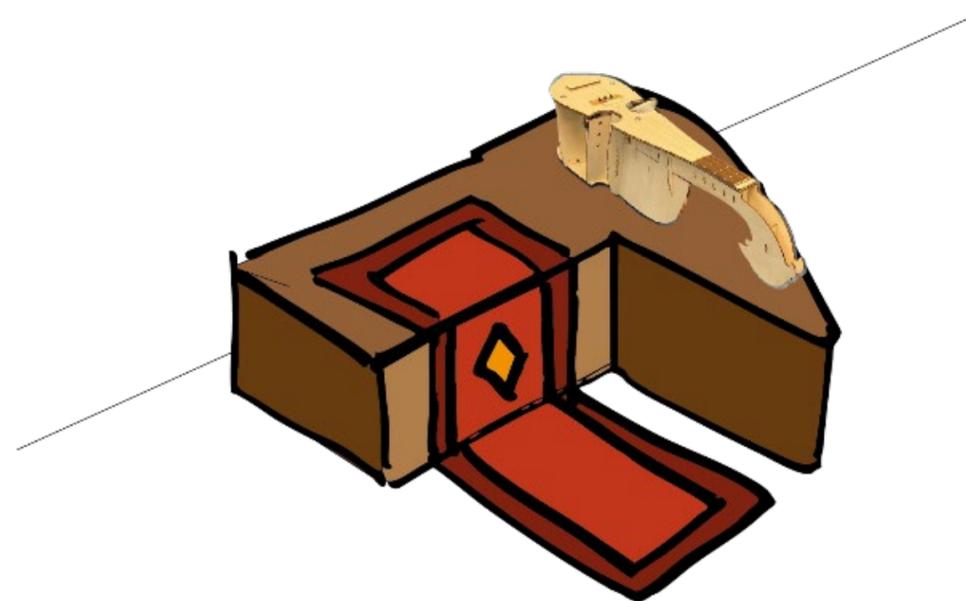


Figure 81: Bench redesign with Afghan rug attached to both floor and seat, and area to put the e-rubab..

Conclusion

Conclusion

Research and design objectives

The project initiated from a literature review on musical instrument heritage preservation through interactive technologies. This review revealed a research gap within this domain: the physical playing interaction of plucked string instruments had not yet been conveyed comprehensively using interactive technologies. It postulated that a more comprehensive preservation of the musical instrument heritage could be achieved by combining Virtual Reality (VR) technology with Sensor Based Embedded (SBE) technology, thereby combining the immersive qualities of VR with the strength of SBE technology to convey physical playing interactions.

For this graduation project, one specific plucked string instrument was selected: the Afghan rubab. It was selected because of its currently endangered position in Afghanistan, where music (and therefore, the rubab) is forbidden under the Taliban regime, making the preservation of this traditional instrument even more relevant. This led to definition of the following design goal:

Design an interactive technology experience that conveys the rubab's physical playing sensation through a combination of Virtual Reality and sensor-based embedded technology.

Another design goal was formulated addressing the goal of the preservation effort, based on the Afghan communities' desire to promote the rubab outwards, to non-Afghans:

Design an interactive technology experience to meaningfully convey the tangible and intangible heritage of the Afghan rubab, for culturally interested non-Afghans to encounter the beauty of Afghan culture.

Key Findings

Meaningful cultural encounters

The (generative) research into what makes a cultural encounter meaningful for culturally interested non-Afghans led to the following requirements for meaningful cultural encounters. The encounter should:

- provide new experiences

- inspire for future creative work or activities
- involve active participation in a cultural phenomenon
- include a shared experience (with strangers)
- allow those encountering to compare/relate (aspects of) the cultural phenomenon with what they know from their own lives
- involve embodied interaction
- include emotional engagement
- involve multi-sensory experiences
- facilitate personal creation
- embed cultural context, through materials, stories, or (landscape) images.

These insights apply to any cultural encounter and were integrated into the design of the cultural encounter with the rubab's heritage.

Essential aspects of rubab heritage

Through consultation of the Afghan community (rubab players, non-players, and UNESCO letter writers), the following scope of essential rubab heritage aspects was defined:

- Appearance
- Finger positions
- How the rubab is made
- How to correctly hold the rubab & plectrum
- Materials
- Part functions
- Playing the rubab (at any level)
- Rubab as part of Afghan identity
- Rubab as symbol of Afghanistan's beauty
- Sound of the rubab
- The physical sensation of playing the rubab
- The rubab's relation to Afghanistan

These insights only apply to the Afghan rubab, and not to other musical instruments.

Hybrid technology: XR & SBE technology

A hybrid interactive technology experience was designed and prototyped. The XR application was created using Unreal Engine, running on a Meta Quest 3 headset.

The sensors used on the physical representation of the rubab, called the e-rubab, were:

- 12 custom-shaped capacitive touch sensors (fret sensors), sensing which fret is being pressed;
- 3 proximity infrared sensors, one under each string (string sensors), sensing which string is being plucked.

These sensors were placed on a rubab-shaped wooden base (scale 1:1) with 3 nylon strings, as used on a real rubab, and the strings were played with a plectrum. According to Rubab Player 1, this effectively mimicked the playing interaction of the instrument. However, to further refine the experience and better replicate the authentic sensation of playing the rubab, the strings should be tightened more firmly. Additionally, the infrared sensors were either overly sensitive, or the looseness of the strings caused notes to be triggered too easily and repeatedly, resulting in multiple sounds being produced instead of a single, intended note.

Communication between the physical sensors and the XR application was handled by a Socket.IO server. The input of the sensors, connected to an ESP32 microcontroller unit, were transmitted in string form (message events) over Wi-Fi via the Socket.IO server to an Unreal Engine Socket.IO plugin, where these signals were received and transformed to output in the form of either sound or menu selection. This led to low latency wireless communication and a well functioning hybrid technology system.

Conveying the beauty of Afghan culture

During evaluation of the final prototype, most target group participants indicated that the design introduced them to the beauty of Afghan culture, because of (some of) the following elements:

- The rubab being presented as a cultural symbol
- The stories of Afghan people about the rubab's cultural meaning, and the love they express for Afghanistan
- Landscape imagery and a big green tree (associated with fertility), opposing the image of Afghanistan as "a bombed desert"
- The vibrant colour palette used, opposing the often war-torn imagery of Afghanistan
- A "fuller, more nuanced picture" of Afghanistan provided

- The absence of (Western) political or moral judgment, and focus on cultural appreciation
- The beautiful music
- The tree and the goat, making the rubab more vivid
- The fine decorations on the (virtual) rubab
- The “rich ambience” (created through music, stories, landscapes, and tangible rubab), giving the idea of a rich culture as well
- The tangible sensory interaction with the handheld, making the rubab feel real and alive
- The symbolic finale with rubab concert, sunrise and ascending rubab; interpreted as a metaphor “for the rubab being part of something bigger, something connecting, almost religion-like”.

Significance

The key insights described are important for different reasons.

The insights into what constitutes a meaningful cultural encounter proved highly valuable during the ideation phase, as they clarified the interpretation of the term *‘meaningful’* within the design goal. These insights helped to break down the abstract notion of meaningfulness into concrete design requirements. For each of these requirements, specific ideas could be developed, ensuring that the design addressed them directly. This approach not only strengthened the design process within this project but may also offer a useful framework for other designers aiming to create meaningful cultural encounters in different contexts, for a similar target group.

The selection of essential aspects of rubab heritage is relevant only for the Afghan rubab, and not for other instruments, since it is a tailored approach in collaboration with the Afghan community. It provided a workable scope for this graduation project, which kept the focus and made the project feasible within the given timeframe, while safeguarding that essential heritage elements were conveyed.

The created hybrid technology set-up is relevant for the field of musical instrument heritage preservation, specifically for the preservation of plucked string instruments; It provides a working application project of combined interactive technologies that captures the tangible playing sensation while also providing an immersive introduction to the instrument’s heritage. The how-to documentation (sensor specifications, full Arduino code, instructions on how to set up a Socket.IO server and Unreal Engine blueprints, see Appendices) can be consulted by others who want to build on this application, or learn how it works technically. This may inform

preservation projects of other (string) instruments too, stretching beyond the preservation of the rubab.

The list of design elements that convey the beauty of Afghan culture is relevant because it concretises what makes the design convey this beauty, showing the value of these elements in reaching the design goal. This is particularly interesting for possible further development of the designed experience, and may also inform other designers that would like to convey the beauty of Afghan culture in other contexts or applications.

Discussion

This section discusses the limitations of the graduation project.

Literature review limitations

The literature review in Part 1 was written in preparation of the graduation project, and formed the foundation of the project. If I were to redo the literature review, I would have revised the following exclusion criteria: “paper is not available” and “access to the paper is denied”. Although these exclusion criteria were adopted from a sample literature review provided during the *Graduation Launchpad* course and are practically convenient, they exclude potentially valuable literature because of accessibility issues. Moreover, one of the inclusion criteria was that the paper should be written in either Dutch, English, German or Swedish so I could read it, but this criterium also excludes potentially valuable research written in other languages. These criteria from a limitation to the review, since a broader, more inclusive selection may have led to different insights or conclusions.

Extended Reality

I initially assumed that mapping the VR controller to the virtual model of the rubab would be straightforward, but it turned out to be very time-consuming and not accurate enough for the desired playing interaction. This requires further research, including exploring alternatives such as an integrated accelerometer and gyroscope, to investigate how the alignment between the virtual rubab and the physical e-rubab can be improved. Better alignment would make it clearer which string needs to be struck in which position, and where to position the fingers on the frets in the Play level. Additionally, the elastic band currently used to keep the VR controller in place does not hold it securely enough in a fixed position. It also makes it impossible to replace the battery without removing the controller completely. Once the battery is replaced, the entire alignment process has to be redone—something that would not be feasible if this design were to be used in a public library or museum setting, where staff would be expected to handle it, which is an unrealistic expectation.

Different goals

Another challenge was balancing different expectations from both academic and commercial perspectives. A more specific focus might have led to different design decisions. As it stands, the project functioned both as a research exploration into the physical play experiences involving VR and sensors, and as a product concept to be further developed after graduation, as desired by Stichting Solh. One such compromise was the decision to use Mixed Reality (with passthrough) instead of full Virtual Reality. Based on input from the supervisory team — who noted that people in public spaces tend to feel more comfortable if they are able to see their surroundings — I chose passthrough. This created a Mixed Reality experience, with a Afghanistan-shaped portal showing an Afghan landscape that still conveys some partly virtual reality. However, this came at the cost of full VR immersion, which may have offered other advantages in integrating virtual and physical sensor feedback, as highlighted in my literature review. These opposing goals led to this difficult trade-off, but user comfort was prioritised (so Mixed Reality was chosen instead of Virtual Reality) with the eye on further development, although not fully in line with the design goal to incorporate VR.

Documentary

The production of a documentary during the project was an amazing opportunity, but it also required a significant time investment. In particular, during the session with members of the Afghan diaspora, the presence of the film crew and scheduled documentary interviews with the participant meant the planned research session had to be shortened. It should not be expected that the documentary storyline follows the exact structure and depth of the graduation project’s research, since it was a separate project, and it only captures the parts of the research that included RP1.

Target audience scope

In this project, I defined the target audience as non-Afghans, in order to honour the wishes of members of the Afghan diaspora I spoke with, who expressed a desire for non-Afghans to become familiar with the rubab. However, by doing so, I excluded the target group of Afghan youth. In hindsight, I see value in making the rubab playable in VR/MR for them as well, but this was not explored in my research. Future research could build on this, since I believe heritage preservation also lies with the new generations of Afghans—who, due to their roots, may be more inclined to view the rubab as an instrument they might actually want to learn to play. It would be worthwhile to study this target group as well and potentially adapt the experience so that it is meaningful and valuable for them too.

Afghan representation

I was able to interview two rubab players; however, they alone cannot represent the broader rubab-playing community. Similarly, speaking with only four Afghan

individuals—alongside documentary material and UNESCO letters—limits the representativeness of the analysis. A more robust approach would have involved engaging a larger and more diverse group of Afghan voices. In particular, I did not ensure representation across different Afghan ethnicities. If I were to redo this project, I would revise the recruitment criteria to include ethnic diversity within the Afghan diaspora, since I learned that Afghanistan is a country with many different ethnicities. As it stands, the current analysis may only reflect the perspectives of a small segment of the Afghan community.

E-Rubab

Another aspect that has not been addressed is making the e-rubab durable for use in public space (Dutch: “hufferproof”). The final prototype is still quite fragile — especially the exposed sensors and resistors, which are not ready for use in a public space. The e-rubab needs to be able to withstand rough handling, which it currently cannot.

The weight of the cardboard e-rubab (enacting prototype) does not match the weight of the wooden e-rubab, which is significantly heavier. This results in different findings regarding how easy it is to sit on the ground while holding the e-rubab. With the enacting prototype, this was very easy to do, whereas with the final prototype it was more difficult. Some test participants felt hesitant to hold the heavier version with one hand while sitting down, as they were concerned about potentially damaging it. The weight has not been taken into account while making the final prototype, but should have been.

Learning Unreal Engine

During the timespan of a graduation project, I had to learn how to use Unreal Engine, which was entirely new for me. I knew in advance that this would be time-consuming, thanks to the Graduation-in-One-Day exercise in which I had also included prototyping. Moreover, I found out too late that the VR Zone, which offers support to students in implementing extended reality technologies in their projects, would be closed in July and August—the final two months of my graduation project. This meant I received two months less guidance than I had anticipated, and I had to adjust my planning for the final phase and shorten the modelling process, without compromising on quality. If I had had more time for the modelling, I could have tested various design features earlier on (during modelling) and incorporate the findings directly into the design.

Some design features, like feedback on which string was selected, were not implemented in the Unreal Engine prototype due to time, knowledge and support limitations. Yet these could have generated important user insights or led to a more engaging experience during testing.

Diversity of evaluation participants

Although I was able to include a diverse range of non-IDE professions in the evaluation groups — such as a psychologist, crisis management officer, dentist, double bass player, and neurobiologist — greater age diversity would have strengthened the study. Most of the 21 target group participants were between 24 and 30 years old, with only three falling within the 50 to 65 age range. Additionally, the majority of participants were Dutch, meaning the design is largely tailored to a Dutch audience. Including a broader range of nationalities would have made the research more robust and its findings more widely applicable.

In-context implementation

Moreover, the prototype was not tested in its intended context (museums and libraries) but rather at the university, due to its reliance on a powerful gaming PC and a stable internet connection. Although the e-rubab is designed to be produced with laser-cutting (a scalable production method), and the used hardware is readily available and affordable, not other steps were taken yet to explore the scalability of the system — that is, how easily it could be installed across multiple institutions such museums or libraries, or festivals. The focus was primarily on content and technology rather than deployment.

If I were to do the project again, I would have involved museum and library employees as well, because I believe that they can offer very important additional insights into maintenance and implementation issues. I would also research the desirability from the museum’s and library’s perspective instead of only the perspective of the Afghan community and the target group.

Closing remarks

It can be concluded that both design goals of this graduation project have been achieved, and that the hi-fi prototype of the final design was well received by the target group. The final design incorporates Mixed Reality instead of Virtual Reality (the initial plan) because users feel more comfortable seeing their surroundings in public spaces, and user comfort was prioritised.

Should the design be developed further, the user group evaluation, recommendations and described limitations should offer an informed understanding of the design’s qualities and limitations.

Hopefully, further development will lead to a fully functional experience that can be practically implemented in the public space, so the rubab’s heritage may be promoted and thereby, kept alive.

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Appendices

Appendix A: Quotes from the UNESCO consent of community letters

Letter #	Heritage aspects mentioned + quote
1	<p>Nickname:</p> <ul style="list-style-type: none"> “Rubab, also known as “The King of the Mystical Music of the East”...” <p>Cultural significance:</p> <ul style="list-style-type: none"> “Rubab ... holds a special place of cultural significance in our country, and is our nation’s most famous musical instrument” <p>Relation to Afghanistan and other countries:</p> <ul style="list-style-type: none"> “Rubab finds its origins in today’s Afghanistan and the great Khorasan region of Iran...” <p>Literature & poetry:</p> <ul style="list-style-type: none"> “the inexhaustible reverent mention of the name in the literary texts of the writers and poets of Dari Persian...” <ul style="list-style-type: none"> Reason of significance: “The ... mention of its [the rubab’s] name in literary texts of the writers and poets of Dari Persian further proves this point” (the earlier mentioned point being that the rubab holds a special place of cultural significance in Afghanistan). <p>Sound:</p> <ul style="list-style-type: none"> “the exciting and uplifting sound of Rubab”; “Rubab’s life-affirming voice” <ul style="list-style-type: none"> Reason of significance: “The ... sound is ever present in our mystical evenings, and accompanies our aggrieved nation’s mirth and fun”
2	<p>Relation to Afghanistan and other countries:</p> <ul style="list-style-type: none"> “...Afghanistan, as a part of the region that Rubab has its ancient roots and origins in...” <p>Cultural significance:</p> <ul style="list-style-type: none"> “...Rubab acts as a solid foundation for the authentic music of my nation”;

	<ul style="list-style-type: none"> “The people of Afghanistan know this instrument as they know their own flesh and blood”
3	<p>Poetry:</p> <ul style="list-style-type: none"> “...which is played alongside a reading of Persian poems” <p>Relation with other countries:</p> <ul style="list-style-type: none"> “...and has its roots in the Khorasan region of Iran...”
4	<p>Relation with Afghanistan:</p> <ul style="list-style-type: none"> ““Rubab” is the most famous musical instrument in the historical-cultural area of the Great Khorasan with its geographical origin which today is Afghanistan.”; “This musical instrument ... in different cities such as Herat, Kabul, Balkh, and other cities is still crafted...] <p>Sound:</p> <ul style="list-style-type: none"> “...its exciting sound promotes happiness in happy and friendly gatherings of the people of this land.” <p>Music:</p> <ul style="list-style-type: none"> “As Rubab’s songs foster mystic passion and create turmoil with the chants of the Sufis, in the same way, have also sympathy for the sad hearts of the suffering people of our land.”
5	<p>Comment: Author is a rubab crafter and ‘oyster veneering artisan’.</p> <p>History:</p> <ul style="list-style-type: none"> “Rubab is an ancient instrument and have been around for more than 2000 years.”; “[Rubab] has been improved upon alongside changes in our culture and musical understanding.” <p>Relation to Afghanistan:</p> <ul style="list-style-type: none"> “This musical instrument has been made and played in what is today’s Afghanistan for centuries...”

	<p>Relation to other countries:</p> <ul style="list-style-type: none"> “Rubab also has many admirers and enjoyers in our neighboring co-cultural countries, who also make and play the instrument.”
6	<p>Comment: author is musician and head of Afghanistan’s music department.</p> <p>Relation to Afghanistan:</p> <ul style="list-style-type: none"> “Rubab is an ancient Afghani local musical instrument.”
7	<p>History:</p> <ul style="list-style-type: none"> “Historical research has shown that the Rubab instrument has been mentioned in the works of Persian-speaking thinkers, poets and mystics since the ancient past...”; Reason of significance: “...and this proves that this instrument has been historically used in the region that is today’s Afghanistan, and also those of Iran, Tajikistan and Uzbekistan.” “Rubab’s contemporary style ... was first introduced in the court of Akbar the Great (third Mughal emperor, 1556 to 1605).” <p>Poetry:</p> <ul style="list-style-type: none"> “Rubab has intermingled with Rumi’s poetry...” <p>Dance:</p> <ul style="list-style-type: none"> “...and [Rubab] has made available the theme to the formation of Sama. The notes of Rubab excite the Sufi dancing whirling dervishes...” <p>Music:</p> <ul style="list-style-type: none"> “The notes of Rubab excite the Sufi dancing whirling dervishes, and brings about the ethereal love that Rumi encouraged.” <p>Relation to Afghanistan & other countries:</p> <ul style="list-style-type: none"> “Rubab’s contemporary style has been commonplace in the Badakhshan region of Afghanistan...”

	<ul style="list-style-type: none"> “...the Rubab instrument is an ancient heritage made in Afghanistan, and jointly owned by Afghanistan, Iran, Tajikistan and Uzbekistan...”
8	<p>Comment: Author is a rubab player, poet and calligrapher.</p> <p>Relation to Afghanistan and other countries:</p> <ul style="list-style-type: none"> “[It is said that] The origin of Rubab is a region about Kandahar and Herat in today’s Afghanistan...” “...this heart-touching instrument of the Great Khorasan has been introduced and spread among countries by this region’s musicians.” “...shared cultural heritage of Afghanistan and its neighboring countries...” <p>Nickname:</p> <ul style="list-style-type: none"> “...this instrument of Afghanistan, which is also known as Rubab of Kabul...”
9	<p>Comment: Author is a rubab player and rubab crafter.</p> <p>History / Relation to Afghanistan:</p> <ul style="list-style-type: none"> “The rubab instrument is one of Afghanistan’s traditional musical instruments, the origin of which and its playing and crafting has been developed in Afghanistan.” <p>Parts:</p> <ul style="list-style-type: none"> “Rubab, speaking of current usage, has 21 strings, 3 main strings made of nylon, 3 king strings, and 15 sympathetic strings.” “Rubab is made of 3 pieces, which include the body, neck and head of Rubab.” <p>How a rubab is made:</p> <ul style="list-style-type: none"> ““Rubab is made of 3 pieces, which include the body, neck and head of Rubab. Then these three pieces are linked together and Rubab is covered with hide, using the goat hide. And then strings are passed through Rubab.” <p>Materials:</p> <ul style="list-style-type: none"> “3 main strings made of nylon...”

	<ul style="list-style-type: none"> “...the Rubab is made of seedless mulberry wood, which is also know as both Shir Tut wood and Bramkhani wood.” “...Rubab is covered with hide, using the goat hide.”
10	Illegible
11	<p>Poetry:</p> <ul style="list-style-type: none"> “The rubab musical instrument is one of the graceful instruments of oriental music, which Persian famous poets such as Daqiqi Balkhi, Nasir Khusraw Balkhi, Mevlana Jalal al-Din Muhammad Balkhi (Rumi), Hafez-e Shirazi, Abdul-Qadir Bedil and most of the speakers of this civilizational area talked about and described it in their works.” <p>Song / Literature:</p> <ul style="list-style-type: none"> “...this instrument has been used since the distant past in Sangardi and mountain songs, and speaking of local and folk songs, it has always accompanied the songs of villagers, and has been played in the ears of the nobles of Aryan descent, so that its songs shine in the sky of Eastern literature, and find its way in the rich romance works and mystical prayers.” <p>History / Relation to Afghanistan:</p> <ul style="list-style-type: none"> “Rubab is an instrument with age of several centuries...” [Rubab] “has followed a winding path of evolution, as at first this musical instrument was played differently with a variable-tension bow and it had a continuous sound, and based on a historical narrative in the 10th century of the solar Hijri, at the same time of Akbar the Great emperor of India, in the foothills of Badakhshan, Afghanistan, it [rubab] was invented again in a different form and in the form of String-Plectrum and at this stage it acquired a better geometric shape and sound.” <p>Stories/Legends about the rubab:</p> <ul style="list-style-type: none"> “...according to history, dear Rumi, this famous sheikh of the city, jumps out of the pulpit, he listens to the soulful sound of the Ney, and his heart listens to the heart touching sound of the Rubab.” <p>Famous rubab player:</p>

	<ul style="list-style-type: none"> “Master Mohammad Omar, who has the title of “King/Sultan of Rubab” in Afghanistan and then Indian subcontinent, brought the evolutionary process of this instrument to the level of perfection...” <ul style="list-style-type: none"> Reason of significance: <ul style="list-style-type: none"> “...he brought it out of the local state and according to the modern knowledge of music he provided Rubab with seven main and fives secondary music tonality and this is when Rubab becomes famous and popular musical instrument in Asia, the Indian subcontinent and the whole world.”
12	<p>Comment: the text of letter #12 has some overlap with the text of #9.</p> <p>History / Relation with Afghanistan:</p> <ul style="list-style-type: none"> The rubab instrument is one of Afghanistan’s traditional musical and authentic instruments of today’s Afghanistan and [it is said that] Rubab is originated from Ghazni in Afghanistan, and its playing and crafting have been developed throughout Afghanistan.” “Master ... says that Rubab has history of more than three thousand years in the Ghazni city of Afghanistan, and over time it has developed.” <p>Relation with other countries:</p> <ul style="list-style-type: none"> “...and during the past, it has been promoted in Afghanistan’s neighboring countries, also it has been known and promoted in Europe and America...” <p>Parts:</p> <ul style="list-style-type: none"> “Rubab, speaking of current usage, has 21 strings, 3 main strings made of nylon, 3 king strings, and 15 sympathetic strings...” “Rubab is made o 3 pieces. These 3 pieces include the body, neck, and head of Rubab.” <p>Famous rubab player:</p> <ul style="list-style-type: none"> “...this usage is the result of the annual hard works of Master Mohammad Omar also known for “King/Sultan of Rubab”. “Master Mohammad Omar is one of the most famous Rubab teachers in Afghanistan and in 1974 he was invited to the United States of America to teach the Rubab instrument of Afghanistan to the students of the Music University of that country and this

	<p>trip can be said to be an opportunity for the history of the Rubab instrument of Afghanistan.”</p> <p>Materials:</p> <ul style="list-style-type: none"> • “...3 main strings made of nylon”; • “Rubab is made of seedless mulberry wood, which is also known as both Shir Tut wood and Bramkhani wood in Herat.”; • “...covered with goat hide.”
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	<p>How a rubab is made:</p> <ul style="list-style-type: none"> • “Then these three pieces are linked together and Rubab is covered with goat hide. And then strings are passed through Rubab.” <p>Recordings:</p>
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	<ul style="list-style-type: none"> • “I invite you to [watch] the old video from the recordings of 40 or 50 years ago, in which my uncle and master talk briefly about the Rubab instrument of Afghanistan and continue to play an original Herati song with this instrument:” <p>Cultural meaning:</p> <ul style="list-style-type: none"> • “...the people of Afghanistan are proud of this heritage.”
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Appendix B: DG2 Prototypes and insights

Prototype 1: XR Zone consultation

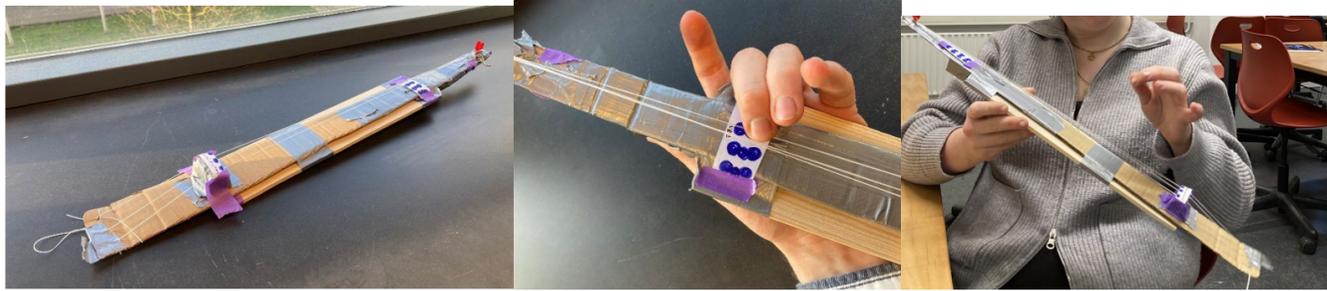


Figure X: Rapid prototype of the external hardware component. Down picture: small test

I used this prototype to convey my initial idea to and receive feedback from the XR Zone staff.

Goal: Communicate idea to XR Zone staff.

Insights:

- The staff from XR zone told me that some micro-processor units (MPUs) have a limited amount of sensor pins they support. I therefore need to know the required amount of sensors to select a suitable micro-processor unit (MPU).
- The staff from the XR Zone advised me to use a WebSocket for communication between physical sensors and Unreal Engine.

Next steps:

- Determine the amount of sensors needed through consulting a rubab player on finger positions and notes on the rubab.
- Create a simple prototype using touch sensors as fret input.
- Create a prototype that uses Arduino WebSocket communication between Arduino and Unreal Engine.

Prototype 2: simplified input code & setup

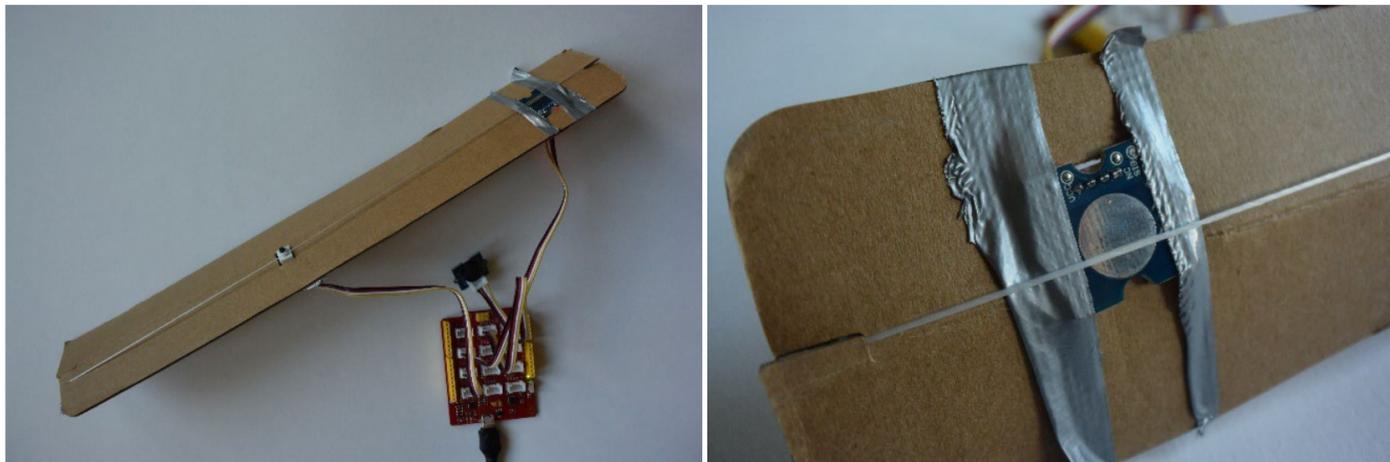


Figure X:

Goal: try initial set-up idea.

This prototype contains a Seeed TTP223-B touch sensor (right picture), positioned under a string, a Seeed button (as a simplified input for plucking the string), and a buzzer (sound output) on a Seeeduino Lotus 1.1 board.

Set-up:

- Uses one binary button as string sensor
- Uses one binary touch sensor as fret sensor

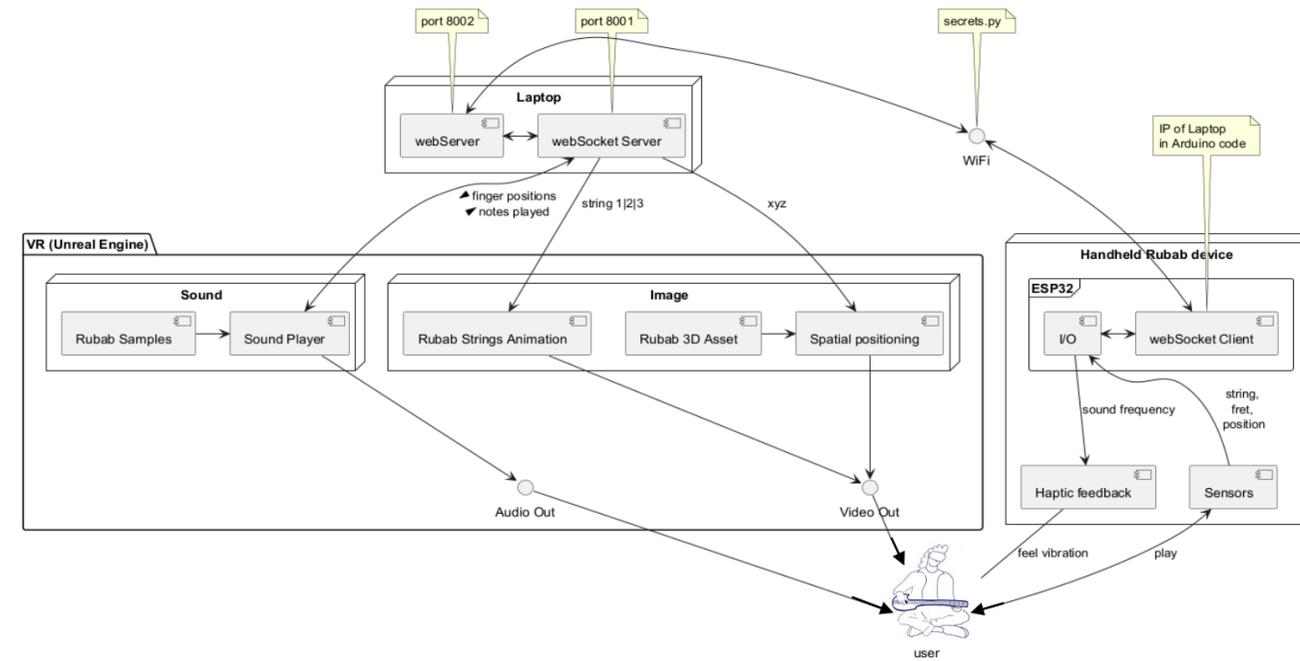
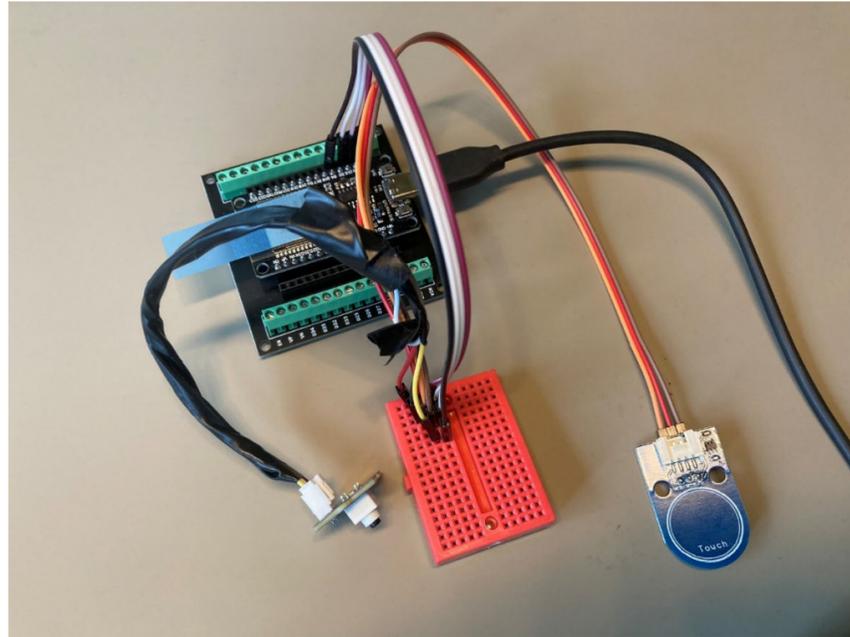
Insights:

- The fret sensor in combination with a string provides a physical interaction that is very similar to pressing the string onto the fret.
- The pressing of the button provides a physical interaction that is fully different than plucking a string, different sensor is needed.
- Although with this code a note can only be created by pressing the button (plucking the string) and touching the touch sensor (pressing string), there should also be a sound (a lower frequency sound) when only the button is pressed (string is plucked). This will be incorporated into the next prototypes.
- I do not know the frequencies of the notes of the rubab, and will ask rubab player 1 to help me with this.
- Seeeduino Lotus has too few grove inputs, not enough for 12 sensors = amount of notes rubab/fret positions → Using the ESP32 allows for connecting 12+ sensors
- Circle shaped sensors are not the same shape as fret's touch area → ESP32 allows for self made touch sensors (e.g. from alu foil), to create cheap flexible shapes (which are not circular like standard touch sensors, but any shape you cut them).
- The board used should have a Wi-Fi or Bluetooth module to communicate wirelessly, which the Seeeduino Lotus does not have.

Next steps

- Try out the ESP32 (has Wi-Fi module + more pins)
- Instead of buzzer, communicate the signal through a WebSocket to Unreal Engine, and get the output there.
- Try out capacitive touch functionality of the ESP32, to see if the self-made touch sensors work.
- Find different sensor than button that fits the physical interaction of plucking the strings.

Prototype 3: ESP32 with WebSocket Server



- Uses ESP32-Wroom as it allows for a lot of sensors, and has built-in Wi-Fi.
- Uses screw terminal breakout (green sides in picture) for pin connections.
- Uses mini-breakout board (red rectangle in picture) for GND and power.
- Uses one binary button as string sensor
- Uses one binary touch sensor as fret sensor

Based on different insights from different prototypes, the ESP32 was selected as most suitable circuit board. It was selected for the following reasons:

- It allows for enough sensors: There must be 12 fret sensors (4 frets per string), corresponding with the amount on the rubab, determined during the rubab theory lesson with RP1, and three string sensors for the three melodic strings.
- It supports capacitive touch, which means that the fret sensors can be custom-made in the right shape, corresponding with the shape of the rubab's frets instead of standard circular touch sensors.
- It has built-in WiFi, supporting connectivity (see section 4.3)

Insights:

- Avoid delays in the code, because they prevent the interaction from running smoothly.
- To make the WebSocket communication work with the available Unreal Engine plug-ins, instead of both a webserver and a webSocket Server (see diagram), I should use a Socket.IO Server (which is also WebSocket communication, but slightly different and compatible with the available Unreal Engine plug-ins).

Next steps:

- Set up Socket.IO Server and connect Arduino to Unreal Engine

Prototype 4: ESP-32 with socket.io server connection to Unreal Engine

Set-up:

- The hardware is the same as in prototype 3.
- Uses socket.io server instead of websocket server.

Insights:

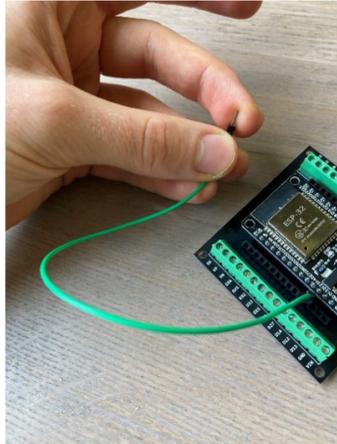
- The connection between the sensors and Unreal Engine works well using the socket.io server.
- The prototype still uses buttons for the string input, which is unlike the physical interaction of playing a string.
- The prototype still uses only 3 sensors

Next steps:

- Try out a different type of sensors for the string input
- Embed the sensors into a physical rubab device.

Prototype 5: Custom fret sensor integration

I tested the ESP32 touch functionality ('capacitive touch sensor'). By connecting a cable to the touch input and touching the metal at the end of the cable, the touch input senses HIGH.



Set-up:

- Uses one capacitive touch sensor as fret sensor

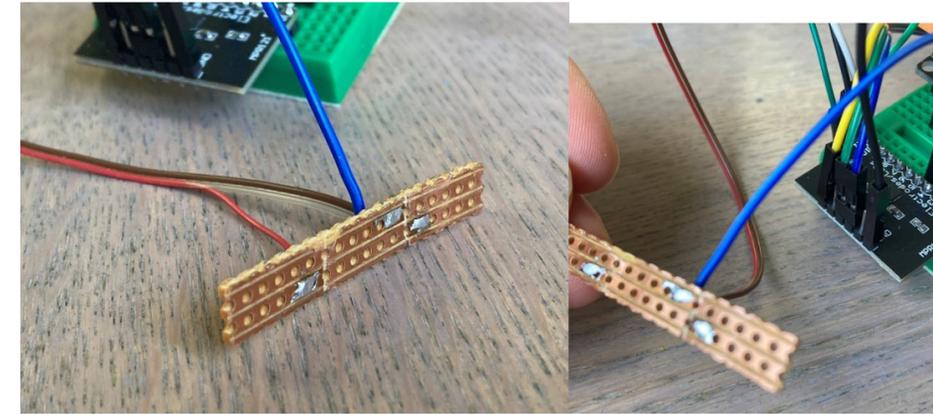
Insights:

- The capacitive touch sensors basically works, which makes it possible to create any custom shaped touch sensor by connecting any (self-made) metal sheet to the pin.
- The ESP32 does not have a default value that determines HIGH or LOW for the touch pins. The capacitive touch sensor gives different readings based on how it's touched:
 - When the sensor is not touched at all, the value is above 60.
 - When a person touches the sensor and is also in contact with GND or the laptop, the sensor value is ~9, due to the body conducting a small current.
 - When only the sensor is touched (without also touching GND/laptop), the value is typically between 20–30.
 - To ensure that a touched sensor is read as HIGH, the value of HIGH must include both the value 9 and 20-30, and be below 60 (because 60 has not been touched), and thus a threshold value must be used above 30 and below 60, e.g. 35.
- The ESP32 has too few pins that support touch (max 9, 12 required for frets).
 - Solution: MPR121 is a touch sensor break-out that uses I2C communication protocol (allows multiple devices to communicate using just two wires), which fixes the pin shortage of the ESP32 board.

Next steps:

- Connect MPR121 to ESP32.
- Integrate all 12 fret touch sensors (based on rubab player lesson on finger positions and notes).

Prototype 6: Custom fret sensors integration



Set-up:

- Custom made capacitive touch fret sensor connected to MPR121 breakout.
- Sensor with three pads attached.
- Uses Adarfruit_MPR121 Arduino library. The original repository is here: https://github.com/adafruit/Adafruit_MPR121

Insights:

- The MPR121 converts the sensor input into a binary value (HIGH/LOW) To do this, the MPR121 uses a default threshold value, for both touch and release, unlike the ESP32. These default values are sufficient, and therefore a manually set threshold_value is not needed in this case.
- MPR121 breakout works well as an extension of the ESP32, and now it supports the required amount of fret capacitive touch sensors (12).
- The implemented fret touch_treshold value of 35 works well to determine the correct fret played.
- On the rubab, the string frequency is determined by the finger position on the fret. If there are multiple frets pressed on the rubab, only the fret that is closest to the bottom of the rubab should be considered to determine the note. So when two fret touch sensors are pressed on the same snare at the same time, the code should only pick up the value of the fret closest to the bottom of the rubab. This is already integrated in the code of this prototype.
- The fret sensor output should only be communicated in combination with a string sensor output, since there is no sound on the rubab when you only press a fret. You need to play a string to create sound.

Next steps:

- Integrate fret sensors and string sensors in ESP32 code
- Create an actual custom fret sensor area in the shape of the rubab's fret area
- Attach it to the MPR121.

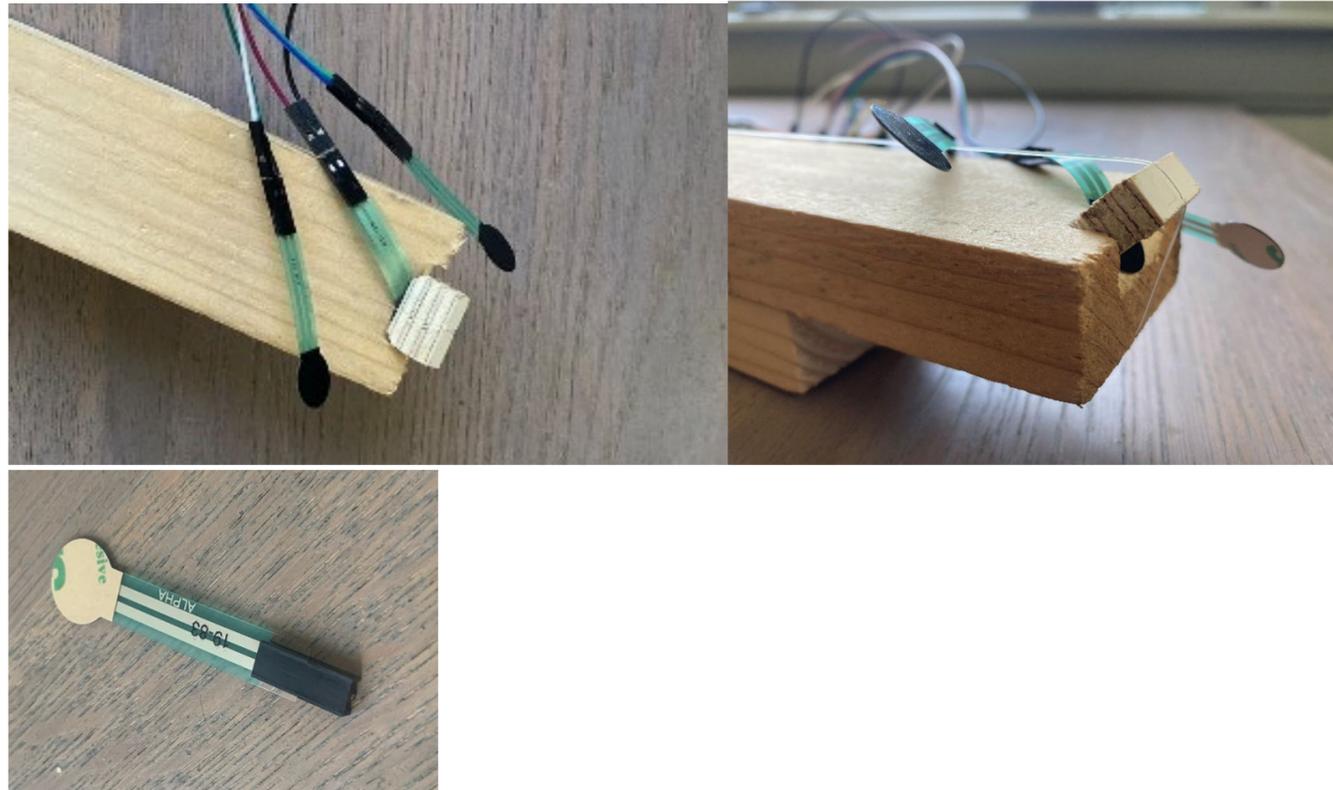
Prototype 7: Force Sensitive Resistor Sensors

I searched for "Arduino sensor" on different Dutch micro-electronics web shops (Tinytronics, Elektronikavoorjou, Otronic, Adafruit), to find a sensor that is carriable, low-cost, and signals the user has plucked a string. The following options were identified:

- An on/off button (like previous prototype): cheap, but unlike a Rubab playing feel. Mount on side of string?
- A microphone: must tune Rubab, labour-intensive and not scalable, how to prevent noise being captured by microphone?
- Hall effect sensor/magnetic sensor: requires magnetic strings. For simple proximity sensing, cheap, but not fit for this application because snare is not magnetic.
- An acoustic proximity sensor: range often in 0.3-5m range
- A tension sensor: very expensive, heavy, not suitable for such a small object.
- Force Sensitive Resistor (FSR): convert string tension to pressure force. Cheap, simple two pin connection. Is plucking enough to trigger it?

I decided to start with the cheap and simple FSRs and find out if plucking is enough to trigger it. I used the following tutorial:

<https://www.instructables.com/How-to-use-a-Force-Sensitive-Resistor-Arduino-Tuto/>



Set-up:

- 20x40mm wood, cut corner
- nylon fishing wire, attached to screw head underneath with simple knot
- 10mm 2-wire FSR sensor
- 10x10x10mm wooden block between string and sensor sensing area, which presses on the sensor when the snare is plucked.
- 10 k Ohm resistor to pull FSR output to GND
- 2 jumper wires
- Mini-Breadboard
- MPR121

Insights:

- The 0.5 mm fishing line used as a snare is thinner than the nylon guitar snares used on the rubab → use nylon guitar strings.
- When plucking the fishing line used, the tension goes down and remains low for a while. It therefore takes appr. 3 seconds to regain the original sensor pressure.
- This works for plucking the strings quite firmly, but does it also work for plucking the strings with a plectrum, as is the way of playing the rubab?
- When the string is plucked, the Arduino code using a simple threshold value, senses multiple snare inputs above the threshold. This is caused by the string vibrating in an amplitude that is above the threshold value.
 - Solution 1: increase the threshold
 - Solution 2: when the sensor goes from HIGH to LOW, ignore follow-up signals for this snare for a certain amount of time (~0.1 seconds) using a timer.
- The piece of wood between the snare and the sensor slightly changes position over time, requiring recalibration of the input sensor threshold in the ESP32 code.
- The environment (e.g. temperature, humidity, touching the prototype) also changes the tension in the string, requiring recalibration of the input sensor threshold in the ESP32 code.
 - Solution 1: notification in the Serial Monitor for manual recalibration (very inconvenient)
 - Solution 2: automatic calibration of treshold initial value, setting the calibration somewhat above the highest of the three snare sensor values.

Next step:

- Integrate the required amount of fret sensors (12) and snare sensors (3) into a set-up with 3 snares that can be attached to the physical rubab device.
- Use nylon guitar strings (the rubab players interviewed indicated they use regular nylon guitar strings on the rubab).
- Check if one common threshold_value suffices for the three different snares, since they have different thickness, or use three identical (same thickness) nylon strings.
- Test for playing with a regular guitar plectrum.
- Check if the firmly pressing error also occurs when the strings are plucked with a plectrum.

Prototype 8: Integration of string sensors

This prototype combined 12 custom made fret sensors (made from printplaat/PCB) and the FSR sensors on a flat rubab device with nylon guitar strings. The goal of this prototype was to implement the different parts into one playable e-rubab.



Insights:

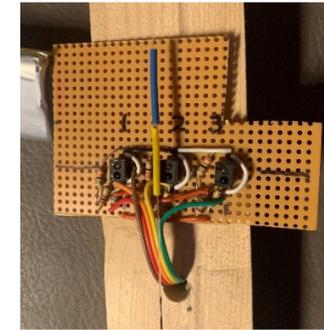
- When holding the neck of the rubab in the left hand, your fingers touch the frets on the right side, which activates these frets unintendedly. Solution: piece of transparent tape on the edges.
- The fret sensors work really well
- If you press one of the three FSRs too firmly by hand, the value goes up very high and the other two sensor are also sensed as HIGH somehow. → The FSR are too unstable for scalable use and require too much tweaking based on their environments, not reliable for this purpose, where the string you play is very important (for both notes you play and choice you make in the XR application). Therefore, the sensors were discarded, and in this prototype, replaced by three touch sensors on the back of the e-rubab so testing in Unreal Engine could continue.
- In combination with Unreal Engine (which worked well), for the pop-up menus where the user needs to pick a string, there was a bug since when you were still holding a note from a previous note you played or other option with your finger, it was registered as new input. Solution: I changed the Arduino code so that when you leave your finger on the touch sensor, it was not registered as a new input, only once, so that for the menus there was no longer an issue; you just had to 'press' the string again. This was an issue for the temporary solution of the three fret sensors, but for the next prototype, when the string sensors did work, this was still a good addition.

Next steps:

- Try out infrared sensors instead of FSRs, which might be more stable in their output.

Prototype 9: Infra-red sensors

Since the FSRs did not turn out to be very reliable, in the sense that they often did not correctly register the played string, I selected infrared sensors as a potentially more reliable solution. I tried three strings at the same time now, to make sure it would work for three strings, unlike with the FSRs before.



Insights:

- The infrared sensors, combined with a coloured cable insulation piece, proved effective in detecting string movement. The colour yellow (for the insulation piece) performed particularly well, as lighter colours reflect more infrared light compared to the darker colours tested.
- Deciding which resistors to use took some time and trying out.

Next steps:

- Integrate infra red sensors into full e-rubab prototype.

Prototype 10: alignment with cardboard e-rubab



To make the 3D rubab visible through the VR headset align with the physical rubab device (e-rubab), I created a simplified cardboard rubab based on real rubab measurements, and attached a Meta Quest 3 VR controller to the cardboard rubab using tape, and aligned the 3D rubab model with onto the controller, .

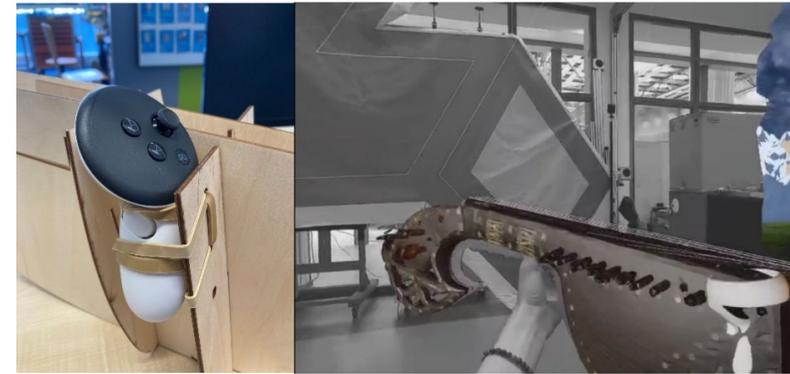


Insights:

- The sensation feels very aligned with the 3D model in VR
- With pass-through enabled in the headset, however, the shape of the physical rubab must be more similar to the 3D model. The cardboard prototype was too simplified in area slopes, so there are parts sticking out of the 3D mapping.
- The duct tape used does not hold the controller in place well enough, causing a shaking movement of the virtual model; sturdier mounting is needed.

Prototype 11: alignment with wooden e-rubab

This prototype uses a wooden e-rubab, lasercut, and a mounted VR controller, mounted using a rubber band.



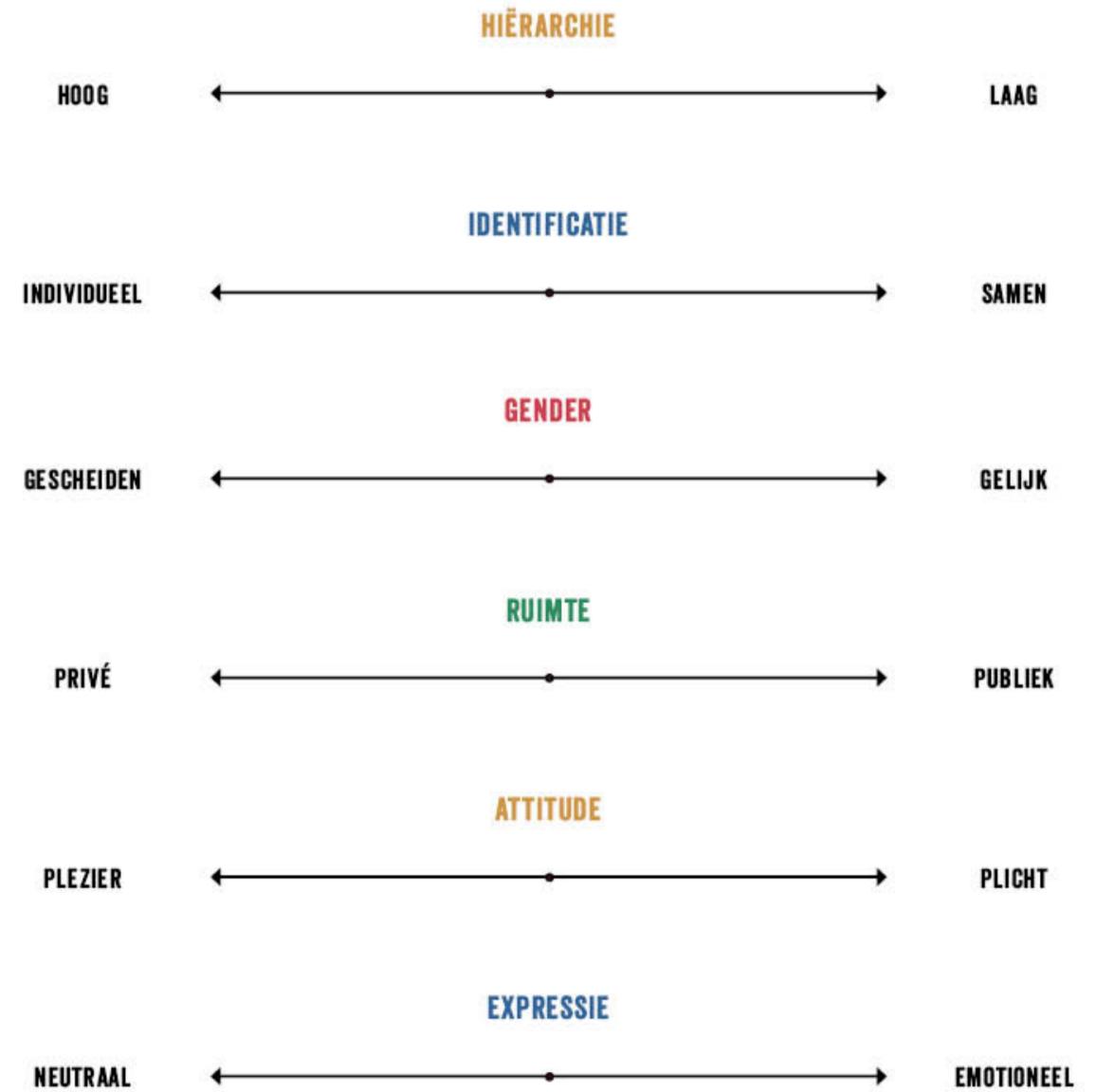
- The positioning is quite a lengthy process because of the limited orientation movement features in Unreal Engine, but can be done through trial and error.
- There is a minor lag in the alignment, making the e-rubab visible sometimes.

Appendix C: Rubab heritage aspect cards

<p>MUSIC e.g., common music pieces</p>	<p>COMPOSERS</p>	<p>MATERIALS e.g., goat skin, wood</p>	<p>APPEARANCE OF THE RUBAB</p>	<p>DANCE</p>	<p>SONG & POETRY</p>
<p>PLAYING TECHNIQUE e.g., how you pluck a string</p>	<p>NAMES OF PARTS e.g., Ghwagi / غوري</p>	<p>DECORATIONS e.g., mother-of-pearl / صدف</p>	<p>STORIES/LEGENDS ABOUT THE RUBAB</p>	<p>THE ROLE OF IMPROVISATION</p>	<p>WHEN THE RUBAB IS PLAYED e.g., at weddings or at home</p>
<p>FAMOUS RUBAB PLAYERS bv. Homayoun Sakhi</p>	<p>FINGER SETTINGS</p>	<p>HOW A RUBAB IS MADE</p>	<p>HOW IT FEELS TO PLAY THE RUBAB e.g., the physical sensation of your hand plucking a string</p>	<p>STORAGE & TRANSPORT e.g., what a rubab bag looks like</p>	<p>MAINTENANCE</p>
<p>MUSIC NOTATION</p>	<p>SOUND OF THE RUBAB</p>	<p>THE HISTORY OF THE RUBAB</p>	<p>REGIONAL DIFFERENCES e.g., differences in playing technique or appearance</p>	<p>CULTURAL MEANING OF THE RUBAB (what the instrument means to Afghan people)</p>	<p>HOW YOU LEARN PLAYING THE RUBAB e.g., from a teacher</p>
<p>THE RELATION WITH AFGHANISTAN e.g., in which regions is the rubab played a lot?</p>	<p>HOW TO HOLD THE RUBAB</p>	<p>TUNING THE RUBAB e.g., how to use the tuning pegs</p>	<p>CONTEXT OF PERFORMANCE e.g., other instruments (tabla)</p>	<p>PLAYING THE RUBAB YOURSELF (letting someone play the instrument)</p>	<p>FUNCTIONS OF PARTS e.g., غوري: tuning the strings</p>

...	...
...	...
...	...
...	...
...	...

SOCIO-CULTURELE DIMENSIES



Appendix D: Rubab D Major finger positions

This information is based on a music theory and finger position lesson I got from RP1. It helped me in modelling the XR experience.

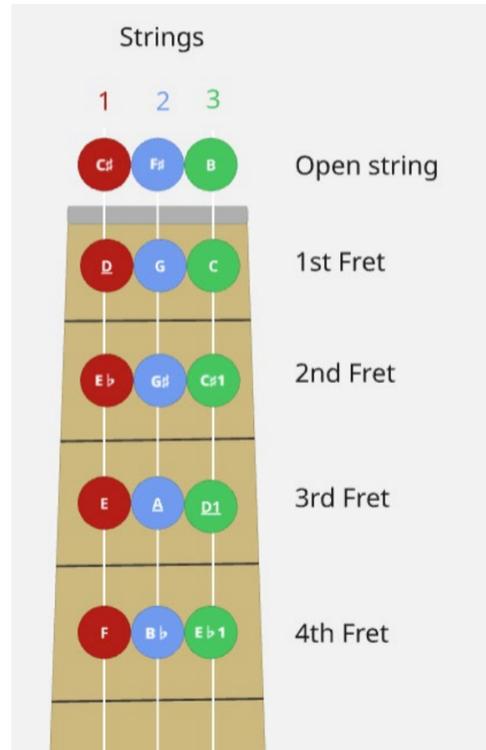


Figure 9: Fingerboard of rubab viewed from above, filled in together with rubab player Mo Mohammadi. The amount of circles is the amount of notes on the rubab: 15.

There are three melody strings and four frets (fig. X). This gives 12 notes that are played using the frets, and 3 additional notes played using the open string (without pressing the string onto a fret). The fifth fret does not exist, although higher octaves can be found by pressing the string beyond the fourth fret, but this is very unstable and therefore almost never done, only for decorations in the music.

For traditional pieces, it is common that the tonic (Sa in the sargam system, Do in the doremi system) sounds like a D. This is why I added the D major scale. Since I am more familiar with working with the western music notation, I created a table that shows the corresponding notes, when the strings are tuned. The note Sa usually sounds like the western C, although the sargam system is relative (just like do re mi fa so la ti do), so it depends on the tuning what note the Sa sounds like.

In D Major tonality, the main strings are tuned as C# (S1), F# (S2) and B (S3) so the interval between the strings is a fifth. The notes Sa (tonic) and Pa (dominant) are stable, whereas the other notes can be flat (b/Komal) or sharp (#/Teevra) as well.

Tuned in D	Sargam	Doremi	Position (Snare/Fret)	
			S1 (Snare 1)	No Fret / F10
D	Sa (tonic)	Do (tonic)	S1 (Snare 1)	F11 (Fret 1 on snare 1)
E♭	Komal Re	Di (Flat Re)	S1	F12
E	Re	Re	S1	F13
F	Komal Ga	Ma (Flat Mi)	S1	F14
F#	Ga	Mi	S2	No Fret / F20
G	Ma	Fa	S2	F21
G#	Teevra Ma	Fi (Sharp Fa)	S2	F22
A	Pa	Sol	S2	F23
B♭	Komal Dha	Si (Sharp Sol)	S2	F24
B	Dha	La	S3	No Fret / F30
C	Komal Ni	Ta (Flat Ti)	S3	F31
C#	Ni	T	S3	F32
D1	Sa 1	Do 1	S3	F33 (first octave)
E♭1	Komal Re 1	Di (Flat Re) 1	S3	F34 (first octave)

Appendix E: Generative Session Plan

Before the session (at home)

1. Sensitizing

Participants will be asked to:

- Bring a photograph/drawing/object representing a meaningful memory in which they:
 - Encountered a new culture
- Watch a short video showcasing aspects of the rubab's heritage. This video serves as a cultural reference and shows different aspects of the rubab's heritage (based on the heritage elements identified in Q3). The video consists of a collection of video snippets.

During the session

1. Welcome & Introduction (5 minutes)

- Welcome!
- Present goal of the session
- Let participants sign the informed consent forms
- Present the agenda, including the end time and breaks. The agenda will remain visible throughout the session.

Part 1: Looking at a past experience

2. Brainwriting on post-its [*diverging*]: (5 minutes)

- Look at the picture/drawing/object you brought. What made this cultural encounter into a meaningful experience for you?
- These post-its are collected and put aside. They will later be added to the pile of ideas in step 7

3. Sharing memories: names & pictures (15 minutes) **RECORD**

- Standing in a circle, each participant introduces themselves by:
 - Saying their name.
 - Showing the photo/drawing/object they brought and sharing what it represents and why it was meaningful to them.

The next person asks a question about the previous participant's photo before introducing themselves and sharing their own.

- Purpose: To learn each other's names, reduce the threshold for speaking in front of the group, facilitate a conversation about what makes a cultural encounter meaningful, and share memories.

Part 1: Towards a future experience

4. Watch the rubab heritage aspects video together (5 minutes)

- Purpose: The video is watched again as a group to refresh participants' memory (or in case they have not watched it beforehand) and prepare them for the next activity focused on the future.

5. Brainwriting on post-its [*diverging*]: (10 minutes)

- Problem statement (written and visible to all participants):

"How to create a personal connection between **you** and the rubab's cultural heritage?"

- The participants are asked to create more options, and more, and more.

6. Spontaneous Clustering [*reverting*] (20 minutes) **RECORD**

- Clustering all the post-its (step 2 & 6) and giving each cluster a catchy title.

7. **BREAK** (15 minutes) DOCUMENT THE CLUSTERS (pictures)

8. Create your miniature encounter with the rubab's heritage [*converging*] (50 minutes)

- Each participant duo receives a dollhouse toolkit, consisting of:
 - A basic structure (floor and two walls made of cardboard),
 - Figurines
 - A variety of ambiguous creative materials (e.g. corks, wool, paper, LEGO blocks, cardboard) to build their envisioned encounter with the rubab's heritage.

- Assignment prompt (available in English and Dutch):

"Please close your eyes. Take a deep breath. Imagine yourself in a space where you are about to be introduced to the rubab. Everything is possible. Look around you. What do you see? What can you do in this space? What do you hear? What do you feel? ... Now open your eyes again, and create a 3D space in which you can have a meaningful introduction to the rubab's heritage."

/

"Sluit je ogen. Haal diep adem. Stel je voor dat je in een ruimte bent waar je kennis gaat maken met de rubab. Alles is mogelijk. Kijk om je heen. Wat zie je? Wat kun je doen in deze ruimte? Wat hoor je? Wat voel je? ... Open nu je ogen weer, en creëer een 3D ruimte waarin je op een betekenisvolle manier kennis kunt maken met het erfgoed van de rubab."

- Building (30 minutes) **TAKE PICTURES W/ CAMERA**
- Presenting (20 minutes) **RECORD W/ CAMERA**

9. Wrap-up & Closure (10 min.)

- Thanking the participants for their valuable input
- Recording all output (collages & doll houses) with a camera (during the explanations)
- Treat all outcomes with respect

Appendix F: Heritage aspects insights from the Afghan community consultation

A part of Afghan identity

For Afghan people, all over the world, the rubab evokes pride and emotional connection to their roots. It therefore holds great cultural significance for the Afghan community and is an important part of the Afghan identity.

Letter #12: "...the people of Afghanistan are proud of this heritage."

RP1: "Look, I am a proud Dutchman, born and raised here, but whether I like it or not, it [the rubab] is also a part of who I am or who my parents are and therefore me too. So I like the fact that it's something I chose myself, and besides that it's also something that represents my roots in a very positive way."

ADM2: "If you ask that to a real Afghan, you already have that answer. You don't need to make a connection with me. I already have that connection. It is already in my veins. It flows through my veins, the rubab."

Letter #1: "Rubab ... holds a special place of cultural significance in our country, and is our nation's most famous musical instrument"

Letter #2: "...Rubab acts as a solid foundation for the authentic music of my nation ... The people of Afghanistan know this instrument as they know their own flesh and blood"

RP1: "It's something that connects everyone ... Imagine you have an Afghan here and an Afghan in Australia. They have nothing in common, but the sounds from the past, and especially the rubab, build a bridge between them."

RP2: "I think this is a part of the identity of Afghanistan. For me, this is important and also an emotional part of my country ... And this is a part of identity, this is a part of long history, and I think why it should not be forgotten."

RP2: Cultural meaning is very important, because the cultural meaning of the rubab is not only for rubab players, but for all Afghan people.

A symbol of Afghanistan's beauty

For Afghan people, the rubab is a symbol for the beauty of Afghan culture. Preserving the rubab's heritage is important because through the beauty of the rubab, non-Afghans can learn that Afghanistan is more than a war-torn country, and has a

beautiful side too. Showing this beauty is important to the Afghan community, because it can counter the prejudices and stereotypes about Afghanistan and Afghan people they encounter.

ADM2: 'And through rubab also gets acquainted actually eventually with Afghanistan. To associate Afghanistan not only with war and terrorism and misery, but also with beautiful things, with music.'

ADM2: When you think of Afghanistan, when you think of Afghans, an average Western person thinks of terrorism, of Taliban. Of misery, of dark sides. But the beauty of Afghanistan, the decent people, the hardworking people, the beautiful culture, the warmth, that is just not well highlighted. We are only actually being compared to all the misery I just listed. While Afghans are very hardworking people, try to achieve a lot and have achieved a lot, but that is not seen. And also Afghanistan itself, the beautiful landscape, the beauty, the warmth, the beautiful mountains. All the beauty we have in Afghanistan, you don't see that anywhere. When you think of Afghanistan people only think of poverty, of drought. While that is not the case. We have beautiful water, we have beautiful mountains, we have very beautiful nature. Very nice food. Four beautiful seasons. But you don't hear people say that. Because just the media in all these years, in the last 20, 30 years, has only shown the miserable side of Afghanistan. The misery that has come over the people there, that is only shown put on display. While it is not. All that misery, true, it's certainly part of the truth, but that doesn't describe Afghanistan. That's not the whole of Afghanistan.

Kamal Nasrati (Stichting Solh): 'The rubab is Afghanistan. How wonderful would it be if even non-Afghans would think that when they hear it?'

RP1: "To demonstrate that what Afghanistan is known for—being a war-torn country and all that—it also has this culture..."

ADM4: "Where a connection did come to me while watching the video was particularly the Afghan landscape. Which is pretty unfamiliar to people. Most people have [with Afghanistan] the image of the bombed-out cities, Kabul in particular. But it is so immensely rich in landscape and environment ... Yes, and that combination with [rubab] sound and that landscape, that did give me some peace just now."

The rubab's relation to Afghanistan

Highlighting the rubab's relation to Afghanistan is considered very important for Afghan people, because they are proud that the Rubab is Afghan heritage. The rubab's relation to Afghanistan is considered important because the Afghan people have experienced much loss and they want to cherish and protect their remaining cultural heritage against cultural appropriation by others. Among Afghan people, some see the rubab as solely Afghan heritage, while others see it as part of a shared cultural heritage with countries that were once part of the Greater Khorasan region.

Letter #3: "...and has its roots in the Khorasan region of Iran..."

RP1: "But it's like hey, it's really Afghan. The techniques come from rubab players from Afghanistan. The best rubab are made in Afghanistan. So that one is very important yes."

RP2: "Securing the Afghan rubab as a purely Afghan folk music instrument from exploitation by neighboring countries."

Letter #1: "Rubab finds its origins in today's Afghanistan and the great Khorasan region of Iran..."

Letter #8: "...shared cultural heritage of Afghanistan and its neighboring countries..."

RP1: "He wants to convince UNESCO to recognise the rubab as an exclusively Afghan instrument." [about RP2].

RP2: The rubab's relation to Afghanistan is important because we want to keep our culture and present it, and we are proud of our country and culture, just like other countries are proud of their culture.

RP1: "Because by those more famous rubab players, and they are often Afghans, you know, it's linked to Afghanistan. It will be really clear a link to Afghanistan and we always want to keep that ... That's also what we're trying to do I think. Also the aim to highlight of: that's an Afghan instrument and it's played worldwide. ... But Afghanistan is the core. That's what it's all about."

ADM3: "A lot has been taken away from us... A lot of Afghan cultural heritage has been taken from us, except the dirty geopolitics, yes, we are in the middle of that."

History (other than the relation to Afghanistan)

Although knowing the rubab's history is a must for rubab players, there is not much information available about the rubab's origins.

RP1: "The history of the rubab isn't very well documented, as in, they can't say, 'It originated at this time, this person created it,' and so on."

RP2: "If you want to learn something, whatever you want to learn, you must know the history."

Finger positions

You can only play music on the rubab when you know how to play the notes, and for that you need to know where to put your fingers on the frets.

RP1: "There are three strings that are played. The most important thing is that you become familiar with those first. So with that plectrum you can try going from the first, then the second, then the third string. So you get a feeling of how much space there is between them."

Observation: RP1 explains the finger positions to Casijn.

RP1: "So the first [note] is the first [string] from above and then first fret. So all the way to the left ... yes, a bit more to the left ... And then the third [string] ... And then you need to practice these patterns so your fingers get used to them."

RP1: "I only use my index finger, ring finger and middle finger."

Literature & poetry as historical proof

Historical stories, literature and poems about the rubab and rubab players are valued because they underscore the historical relationship between the rubab and Afghanistan.

Letter #7: "Historical research has shown that the Rubab instrument has been mentioned in the works of Persian-speaking thinkers, poets and mystics since the ancient past and this proves that this instrument has been historically used in the region that is today's Afghanistan, and also those of Iran, Tajikistan and Uzbekistan."

Letter #11: "The rubab musical instrument is one of the graceful instruments of oriental music, which Persian famous poets such as Daqiqi Balkhi, Nasir Khusraw Balkhi, Mevlana Jalal al-Din Muhammad Balkhi (Rumi), Hafez-e Shirazi, Abdul-Qadir Bedil and most of the speakers of this civilizational area talked about and described it in their works."

RP1: "Stories and legends about the rubab? I'll include those under cultural significance as well. Because through stories, through legends, and through people who have been important, cultural significance emerges, and it also strengthens the association with Afghanistan."

Letter #1: "The inexhaustible reverent mention of the name [rubab] in the literary texts of the writers and poets of Dari Persian further proves this point" [the earlier mentioned point being that the rubab holds a special place of cultural significance in Afghanistan].

Letter #11: "...according to history, dear Rumi, this famous sheikh of the city, jumps out of the pulpit, he listens to the soulful sound of the Ney, and his heart listens to the heart touching sound of the Rubab."

Non-Player 0: "For me, it's mainly the combination between the instruments and the music itself and the singer or singer in question. And especially if some profound poetry is incorporated.... As you know, besides our cult historical instruments, we also have famous poets. You have that, I think, just with Rumi.... ...all of which have their origins from the region, from that area. If you put that combination of that music, and that poetry, the poet, together...in my opinion.... From Rumi at one point, Nasrami, which is a combination of dance, music and poetry. And that gives you a certain trance it seems. They then start dancing in circles. That gives you such a different experience of life. It's just a certain tranquillity. I think nothing on this globe can almost compete with that. To find your inner peace that way. And for me that's really always the combination, so not just the rubab, but the accompanying music, song and poem what goes with it. To really fathom it, really feel it in your body."

You've got to know the functions

Understanding the functions of the different parts of the rubab is important for understanding and playing the instrument. The importance of naming its parts varies between players.

RP2: I think that the naming of the of these parts are not important. Well, because what is the naming? You can call it or you can give it another name. I think the naming is not the part that is important. Yeah ... The part self is important, but the naming, I think this is not important. Okay. For me, it's the naming. Or if we can use a English name or you can use a fancy name."

RP1: In order to best play/understand your own instrument, you also need to know it. And that includes what everything is called and how everything works

Observation of RP1: The very first thing he tells about the rubab during a first lesson is the strings and the resonating: "So this is the rubab. It has three strings that are played. 17 other strings also need to be tuned for the full sound. They resonate."

Afghan mulberry wood = quality

The wood is an important indication of the rubab's quality. Afghan mulberry wood is considered the best wood, and can be recognised by its straight stripes. This is important to know when buying a rubab. This is mainly important for advanced players, as beginners do not necessarily need a quality instrument.

RP2: "For me, if I buy the rubab, I check the wood. Yeah. If the wood is good and the physical of rubab is good, then I buy this rubab ... I can make self a good bridge, and then I change it. Yeah. But the wood of the instrument and the physical part of the instrument, I cannot change."

RP1: "The real rubab is made in Afghanistan from Afghan wood."

RP1: "So ultimately what produces the sound is the cohesion of materials ... so if you don't use the right wood ..."

RP1: "I have a few rubabs. They all come from Afghanistan and you see it by the wood. It is mulberry wood, which has straight stripes. That's a rule: a good rubab has straight stripes [on the murberry wood]."

RP2: "It is better in the beginning to have a bad instrument ... And and for for the beginners, I told them always buy what you can buy."

Dance

For non-players more than players, dance is a significant part of the rubab's heritage. They value the combination of rubab music and dance, specifically the Sufi whirling dance, which is related to 13th century Afghan poet Rumi. One of the interviewees mentions that the combination of rubab music, dance and poetry provides a sense of inner peace.

UNESCO Letter #7: "The notes of Rubab excite the Sufi dancing whirling dervishes..."

RP1: "When you get invited [to play], and you know there will come around 20 elderly people, then you know they won't get up and dance ... You need to activate their memories ... It's really important when you go somewhere, to know your audience, why the gathering is organised, and then way you choose what you will play.

ADM0 (non-player): “For me, it's mainly the combination between the instruments and the music itself and the singer or singer in question. And especially if some profound poetry is incorporated.... As you know, besides our cult historical instruments, we also have famous poets. You have that, I think, just with Rumi.... ...all of which have their origins from the region, from that area. If you put that combination of that music, and that poetry, the poet, together...in my opinion.... From Rumi at one point, ..., which is a combination of dance, music and poetry. And that gives you a certain trance it seems. They then start dancing in circles. That gives you such a different experience of life. It's just a certain tranquillity. I think nothing on this globe can almost compete with that. To find your inner peace that way. And for me that's really always the combination, so not just the rubab, but the accompanying music, song and poem what goes with it. To really fathom it, really feel it in your body.”

Both rubab players identified dance as a non-essential aspect of rubab heritage.

Decorations are a nice extra

While the rubab's decorative elements (e.g. mother-of-pearl inlays) are not essential for its sound, they are valued as a nice extra and may hold personal and cultural significance; beads can add a personal touch to the instrument, and from the wood carvings you can tell who crafted the rubab.

RP1: [about beads decorations on his rubab] "I saw it, someone else had it, I liked it ... It does feel a bit more of myself or something, instead of a rubab, now it's really my ruab.”

RP1: "How beautiful it is and the decorations are all just nice, just extra.”

RP1: “Appearance of the rubab is not necessarily important, but it is valued.”

RP1: “Decorations are, depending on who you ask, not very important for the rubab’s sound, so it goes all the way to the back ... There are enough people who want it as a decoration piece, maybe then it’s all the way there [points to ‘most important’]”

RP2: "My ustad, he told always, as my meaning is, that sound is more important than materials or decorations."

RP1: “You can tell by the head who made it [the rubab], and also, for example, by these kinds of details [shows carvings on the back of the neck].”

The ustad on a pedestal

Having a good ustad (master) to learn from is highly valued among rubab players, because rubab players have a lot of respect for (their) ustads; they are their idols and examples. Still, rubab players also learn their skills from YouTube these days, without an ustad.

RP1: “To become a student of a Ustad ... And then I can truly say, you know, that I am learning from him and that I am his student ... Then it takes on even more color, scent, and shape, so to speak.”

RP1: “...Your Ustad is like your father. In the past, students also did groceries or cleaned the ustad's house, in return for lessons. They were really put on a pedestal, it was really your idol, the big person that you were looking upto”.

RP2: "I think many people dream of finding a good ustad. I think this is important."

RP1: "In Afghanistan and Iran, I got to know people—rubab players up close, some of the greatest rubab players... For a little girl in the Netherlands, someone like Ariana Grande might be an idol, someone completely out of reach. But over there, it's different. To me, he has the same status, but he is very accessible... And then suddenly, you find yourself sitting with your biggest idol."

RP2: "I think dat if you want to hold it the right way, and with the right way I mean the way we learn it from big ustads, like Ustad Mohammad Omar ... we think that is is a good way to hold it ... And if you don't use it, maybe you'll find another way, which is also good ... But the chance to learn, the chance will be better, when you learn the way from the ustad."

RP1 learned his rubab skills from YouTube, and RP2 has a YouTube channel to teach rubab skills.

The Sultan of Rubab: Ustad Mohammad Omar

Ustad Mohammad Omar, nicknamed the King/Sultan of Rubab, is considered an important figure in the history of the rubab, because of his contribution to the development and promotion of the instrument. He still serves as an example for rubab players.

RP2: "I think dat if you want to hold it the right way, and with the right way I mean the way we learn it from big ustads, like Ustad Mohammad Omar ... we think that is is a good way to hold it ... And if you don't use it, maybe you'll find another way, which is also good ... But the chance to learn, the chance will be better, when you learn the way from the ustad."

Letter #11: “Master Mohammad Omar, who has the title of “King/Sultan of Rubab” in Afghanistan and the Indian subcontinent, brought the evolutionary process of this

instrument to the level of perfection ... he brought it out of the local state and according to the modern knowledge of music he provided Rubab with seven main and fives secondary music tonality and this is when Rubab becomes famous and popular musical instrument in Asia, the Indian subcontinent and the whole world.”

Letter #12: “Master Mohammad Omar is one of the most famous Rubab teachers in Afghanistan and in 1974 he was invited to the United States of America to teach the Rubab instrument of Afghanistan to the students of the Music University of that country and this trip can be said to be an opportunity for the history of the Rubab instrument of Afghanistan.”

RP2: "I learned from my uncle and my uncle learned from Ustad Mohammad Omar. This is why we have this Ārshif, this repertoire of Ustad Mohammad Omar. And this was also a big important point for me to keep this tradition and to keep these compositions,

Letter #12: “...this usage is the result of the annual hard works of Master Mohammad Omar also known for “King/Sultan of Rubab”.

Learning face to face

The personal interaction between student and ustad, where they sit in front of each other during the rubab lessons, was central to the learning process, but this is disappearing.

RP1: “You no longer have the way of playing the rubab as it used to be in Afghanistan, where you would actually go to, as we call it, a Ustad or a teacher, and sit one-on-one, facing each other.”

RP2: "He [his ustad] sits in front of me, he writes for me, and he tells me what I have to write in my book, in my notebook, yeah ... And in Afghanistan, a lot of people learn in front of each other ... meet his teacher personally."

You need time to learn this difficult instrument

The rubab is a difficult instrument, and some skills, such as playing scales and tuning, take years of practice, and are too difficult to learn in a short time. Both players and non-players I spoke to, acknowledge that the rubab is a difficult instrument.

RP1: The rubab is a difficult instrument to play.

RP1: "Tuning alone takes someone two years to learn ... For every piece, you need to tune again."

RP1: "Rubab playing is based on scales. Depending on the note you press, you choose your scale. Dat is tricky, it really takes years to understand and do this, so to explain it now can be a bit much and confusing."

ADM3: "It is quite a complicated instrument to learn, though."

Tuning is key

Knowing how to tune the rubab is very important for a rubab player, because without tuning your instrument sounds bad and you cannot play.

RP1: "Tuning the rubab is, I think, one of the most important things. Because if an instrument isn't tuned, it's useless."

RP2: "You have to know how to tune it. And one of the first beginning parts in my lessons is about the tuning."

RP2: "Tuning the rubab, yes, this is... I think this is for playing, for players and for listeners, that the rubab is tuned."

Holding the instrument correctly

If you want to learn how to play, you need to know how to correctly hold the rubab and the plectrum, because only then you can start learning to play.

RP1: "After you know how to hold it, you can start that process [of learning to play the rubab]."

RP2: [about what he talks about on his YouTube channel]: "...and also the correct way how you hold your plectrum ... because the big masters, they hold this with two fingers."

Observation RP1 during lesson: corrects how the student (Casijn) is holding the rubab, before explaining how to play notes.

Improvising keeps the music fresh

Improvisation is an important part of playing the rubab, because it gives new colour to the music, adds a personal flavour, and it keeps the music interesting.

RP2: "I think that the history and composition, they are set facts ... that you can't change. But improvisation is a part, where you can give new colour to this idea, this music from your side ... For compositions you can't do anything, for the rubab's

history you can't do anything ... You should learn it, but nothing else. But the role of improvisation depends on yourself ... It is more important."

RP1: "Because, you know, the thing is, if you play a song that has already been played twenty times by twenty other rubab players, at some point, people might think, 'Huh? I've heard this so many times before.' So they always say, if you play something by someone else, try to add your own flavour to it, so that others will think, 'Oh, this is the ... version' or whoever's version."

Give it a try

To preserve the heritage of the rubab, it is essential that people continue to learn and play the instrument—especially in light of the ban on music in Afghanistan.

Encouraging people to simply try playing the rubab is key; mastering it is not the priority. By learning the basics and experiencing the instrument firsthand, individuals are introduced to the rubab, and a foundation for further learning is established.

RP2: "I think if the people learn the basics of rubab playing and they play yourself, play self this instrument, I think they can take more identities. They can feel better as the artist, how did they learn it? How is the process to learn this? How is the living process? How hard is it? ... They don't must be the best player in the world. Yeah. Also if they play in simple way, they will keep his tradition."

RP2: "This I tell everybody: If you don't want to be a best musician, but you can keep one instrument from Afghanistan in your home. And you can touch it. You can feel it. You can also play it in an easy way, like something like hobby ... Have an instrument and try yourself. Try and learn this yourself. If you don't want time, if you don't want to grow to be as a good musician, but you can try it ... you can keep your tradition."

RP2: "I would like to offer an open opportunity to anyone interested from anywhere in the world to learn or experience it [the rubab]."

RP1: "...not as important as the intention, I think. The intention to preserve it [the rubab playing] and to draw attention to it is more important than being able to play it yourself."

Physical playing sensation

The physical sensation of playing the rubab, touching the strings and feeling the vibrations, is 'wonderful' and 'truly satisfying'.

RP1: "Yes, so if your rubab is properly tuned, and you're holding it, and you touch the string, you just feel it—you hear it and you feel it. Yes, it vibrates along, even through

the wood. Yeah, okay, it's perfectly in tune, and that's wonderful. It sounds really strange, but it's truly satisfying."

Rubab crafting is where it starts

For rubab players, the art of rubab crafting is very important, because without rubab crafters, there would be no rubabs to play on.

RP1: "How a rubab is made is where it starts. As I said, a good Rubab is made by an Afghan, well not necessarily by an Afghan, but made of Afghan wood."

RP2: [about his YouTube channel] "I also introduce to the history of Rubab makers ... This is also an important part, how this tradition is kept in Afghanistan, in which places, which families [of makers] we had, for example."

RP2: "if you want to keep the instruments, music instrument rubab in your music genres, you need the rubab makers."

Playing from memory

Afghan rubab players mostly learn and play music from memory, as many musicians in Afghanistan, especially older generations, cannot read or write. Hindustani or Western music notation is used for teaching, but there is no single, official system. Since compositions are rarely written down, Afghan music is mainly passed down through personal teaching rather than documents. This explains why music notation is not considered an important heritage aspect.

RP1: Unfortunately, especially for the older generations in Afghanistan, many are illiterate and cannot read or write well. We have many great musicians who sing and play everything from memory, so they carry a vast amount of knowledge. There is so much theory within them that you won't be able to find anywhere else.

RP1: There is no official notation system. Afghan music is primarily based on Hindustani music, which uses seven notes: Sa, Re, Ga, Ma, Pa, Da, Ni. Some teach using that system, while others teach using the Western notation with notes like C, D, E, F.

RP2: "The first thing I learned was the musical notation used in Afghanistan. A 12-note system. This is a good starting point for understanding the defined notes and their subdivisions."

RP2: "But this repertoire of composition, we don't have any book for that."

RP2: "If we have in Afghanistan in the future, another music notation ... It's okay. We can keep the same we use now ... But any people come and say no, we don't do, we have to use this [new notation system], and this is okay for me."

RP2: "I learned from my uncle and my uncle learned from Ustad ... This is why we have this Ārshif, this repertoire, of Ustad ... And this was also a big important point for me to keep this tradition and to keep these compositions, and give it further to other new joiners, new learners, new Afghan people, who do not have the possibility to learn it from anyone else from Afghanistan because they don't have the content ... Lots of composition what my uncle said you will find it in YouTube ... But you don't find the notes ...

Choosing the right music to play

Rubab players carefully choose the music they play based on the audience, setting, and purpose of a gathering. Music is deeply emotional for many Afghans, and certain songs require a fitting atmosphere, such as playing nostalgic pieces by candlelight in the evening. Understanding the context, whether a prayer, classical setting, or festive gathering, is essential in selecting the right music

RP1: "When you get invited [to play], and you know there will come around 20 elderly people, then you know they won't get up and dance ... You need to activate their memories ... It's really important when you go somewhere, to know your audience, why the gathering is organised, and then way you choose what you will play.

RP1: "Some songs bring tears ... I play it in the evening when I turn on a candle and for the rest, the room is fully dark. Then I want deeper songs, then there are different emotions that come to the surface."

RP2: You need to be aware where you play (e.g. prayer, classical context) to know what music you should play.

RP1: "For Afghan people, music is a bit of a getaway ... because they have lived in such misery ... The value of music is very high ... Its expression is very emotional ... and emotion doesn't mean crying, or only sad emotions. Good memories too. Also when you play, or when you listen."

Melody & Rhythm

The rubab's melody and a percussion instrument's (Zerbaghali/Daira/Tabla) rhythm belong together.

RP2: If the people play the rubab, they also want to find a percussion instrument ... It's two parts. One musical instrument is you play the melody and one instrument is your percussion instrument. And both together, it comes always together."

The richness of regional diversity

One of the interview rubab players emphasised the importance of preserving Afghanistan's regional diversity in rubab playing, as it reflects the richness of Afghan culture, despite the unfortunate divisions between ethnic groups.

RP1: ""To demonstrate that what Afghanistan is known for—being a war-torn country and all that—it also has this culture. And within that culture, it's beautiful because, as in, there are many ethnic groups, different ethnic groups. Some look down on others, some speak ill of others, some see others as inferior. Unfortunately. And to show that in that Afghanistan we have, and in that music we have, everyone, every taste, every population group, and ethnic group is represented, each in their own way. Yes. So, I would want to include that as well."

RP2: Every province has its own clothes and food, and style of music.

Maintenance just needs to be done

As a rubab player, it is important to know how to maintain the instrument, because it just "needs to be done". In order to maintain it, you need to know its parts and materials, and use a proper bag for storing and carrying the instrument around.

RP1: "And once in a while, a new sheet on a new string needs to be put on. Yes, that needs to be done too."

RP1: "Some people play an instrument, some know the instrument, and you have to know the instrument... You need to understand its parts—like, what is this made of? How does it wear down? And so on, in order to maintain it."

The 'heart-touching' sound

The rubab's sound is an important aspect of the rubab's heritage, because it is 'heart-touching', brings happiness, and brings nostalgic memories from the past, to Afghan people all over the world who recognise the rubab's sound. The characteristic rubab sound is more important than the music played, since there is no specific music only played on rubab.

Letter #4: "...its exciting sound promotes happiness in happy and friendly gatherings of the people of this land."

Letter #1: "The ... sound is ever present in our mystical evenings, and accompanies our aggrieved nation's mirth and fun."

Letter #8: "...this heart-touching instrument..."

Letter #7: "The notes of Rubab excite the Sufi dancing whirling dervishes, and brings about the ethereal love that Rumi encouraged."

RP1: "It's something that connects everyone ... Imagine you have an Afghan here and an Afghan in Australia. They have nothing in common, but the sounds from the past, and especially the rubab, build a bridge between them."

ADM2: " I thought about it for a while of how can you describe Afghanistan in sound. And if you describe Afghanistan in sound, there are three things that really authentically describe Afghanistan. One is Ahmadzor, which has been the Elvis Presley of Afghanistan. Two is Richak and Three is Rubab."

RP2: "My ustad, he told always, as my meaning is, that sound is more important than materials or decorations."

Letter #11: "...according to history, dear Rumi, this famous sheikh of the city, jumps out of the pulpit, he listens to the soulful sound of the Ney, and his heart listens to the heart touching sound of the Rubab."

RP2: There are no songs specifically for rubab, "Afghans songs, it's not really related to an instrument...they play it on rubab. They play it on guitar."

A sense of peace

The rubab can provide a sense of peace to the player and the listener.

RP1: "Playing the rubab gives me a sense of calm and a feeling that I can reconnect with myself for a moment."

ADM4: "Yes, and that combination with [rubab] sound and that landscape, that did give me some peace just now."

Appendix G: Reflections on meaningful cultural encounters

Taking part in the water pistol fight during Songkran (Thai New Year):

- Feeling accepted among strangers
- Actively taking part in a cultural phenomenon: water pistol fight

Taking part in a Djembe (percussion instrument) workshop in primary school:

- Expanding your world view: a non-Western musical instrument
- Comparing with what you already know (the piano), experiencing the differences and similarities
- Actively taking part in a cultural phenomenon: djembe playing
- Expressive and physical immersion: warm, hurting hands
- Having a shared experience: playing both in a group and alone
- Reason to buy their own mini djembe, and still having that djembe

Doing a Chinese cooking course using Szechuan peppers:

- New sensory experiences: a new taste experience
- New experiences: cooking with new ingredients and tastes

Buying and viewing a book with Hokusai prints in the 1980s

- New experiences: their first artbook they ever bought, at age 20
- Encountering something before it became famous
- A relation to personal roots: bought in their home country Singapore
- Recognising yourself in the other cultural phenomenon, and comparing yourself with the other
- Being impressed by beauty
- Finding inspiration for your own work: using the Fuji mountain in their own art work
- Initiating a long-held dream: to visit Japan once

Listening to LangLang's piano CD you received as a gift:

- Defining experiences in the past that relate to the present: the event lead to him playing a new music genre and start liking classical music; He still goes to classical music concerts now.
- New experiences: discovering a new music genre through listening to the CD, a genre with which no one in his surroundings was familiar with
- A relation to other personal memories: Having had a piano master class from LangLang later on
- Finding an example, an inspiration
- Unique experiences: the LangLang masterclass

Attending a folk music concert during Sziget festival:

- Feeling a shared respect towards each other
- Celebrating different cultures
- Having musicians openly sharing their culture with outsiders (you)
- Having a shared experience of enthusiasm
- Actively taking part in a cultural phenomenon: folk dancing
- Feeling part of a group of strangers
- New experiences: talking to people from Australia and China

Common themes:

1. **New experiences**
2. **Active participation in a cultural phenomenon**
3. **Inspiration**
4. **A shared experience (with strangers)**
5. **Relate it to your own life**

Appendix H: Generative Session Idea Clusters

General 'Learning'

- Learn about the history of the rubab: **LEVEN OUDER GESCHIEDENIS**
- Learn about Afghani music theory: **LEARN TO KNOW MORE ABOUT THE POSITIVE IMPACT OF THE RUBAB ON OTHERS/DEVELOPMENT**

Observing expert demonstrations

- Live: **Kijken hoe een rubab gemaakt wordt**, **een demonstratie door een expert.**
- Video: **HOE MAAKT JE EEN RUBAB? UITGEBOORTE DOOR**

Use the rubab in your artwork

- draw a rubab musician in my artwork
- rubab-patterns use patterns on the rubab instruments in my artwork

Building-sized rubab

- Make rubab building toy like a maze
- Like Corpus Museum!

Dancing along

- Dancing like the people do on rubab music
- Samen dansen op rubab muziek
- Dansen op de muziek met Afghaanse lady
- dancing classes with rubab music

Listen to your rubab music playlist in your own time

- rubab music on playlist
- listen to rubab music during sport (workout)
- Luist een naar bekende opnames van de rubab
- Schijf Playlist

Parallels with your own culture

- Like Rhye with the Royal Albert Hall clock together with Paris and central to Rome
- Making your personal song into a rubab version
- RUBAB: **Naar de klassieke instrumenten**
- HITSTER RUBAB
- Een stukje van jezelf hebben herkennen in het instrument 2022

Rubab Concert

- Concert with classic music rubab
- een concert met rubabs bijeen
- Luisteren naar een Rubab Concert
- 1x naar ruwbare... RUBAB CONCEPT
- Festival all about the rubab

Composing

- een eigen rubab nummer schrijven
- Making your own songs with rubab
- rubab tones in digital music app so that I can make songs
- Geluiden (patrons) als input so verhalen andere culturele sensatie als output

Give me food

- make African snacks
- RUBAB & ETEN

Educational programmes

- Educational themes together with concert talk about the rubab in the school day
- Pipowagen over rubab die door het land rijst

Multi-sensory experiences

- Geuren: smaken, kalveren en ritme
- Wind: warme wind, koude wind, berglandschap

Learning about Afghan culture

- Learn to know more about Afghani culture
- Andere licht op het onbekende van omroepingen naar samen & muziek

Create an atmospheric setting/ambience

- KAMPVUE: RUBAB
- Valei: Bezinning? verbinding met poëzie!
- RUBAB = MIMO AVOND

Play the rubab

- RUBAB WAKENS
- rubab how to play rubab lesson (learn to play rubab)
- Lessons: een les krijgen in rubab, Les krijgen van een Rubab speler
- Hold it: een rubab vasthouden, De aanwezigheid van het instrument (aantbaar) (aantbaar) (aantbaar)
- Try it: Het instrument bespelen, probeer een Afghani nummer na te spelen op de rubab, mee gammen met je eigen instrument, Experimentering with rubab like just drama / guitar hero
- Experimentering with rubab like just drama / guitar hero

Speechless communication and connection

- Verbinding vinden zonder te horen: Maken en zonder elkaar te horen kennen
- Like 'Love is Blind' but only communicate w. each other w. Rubab

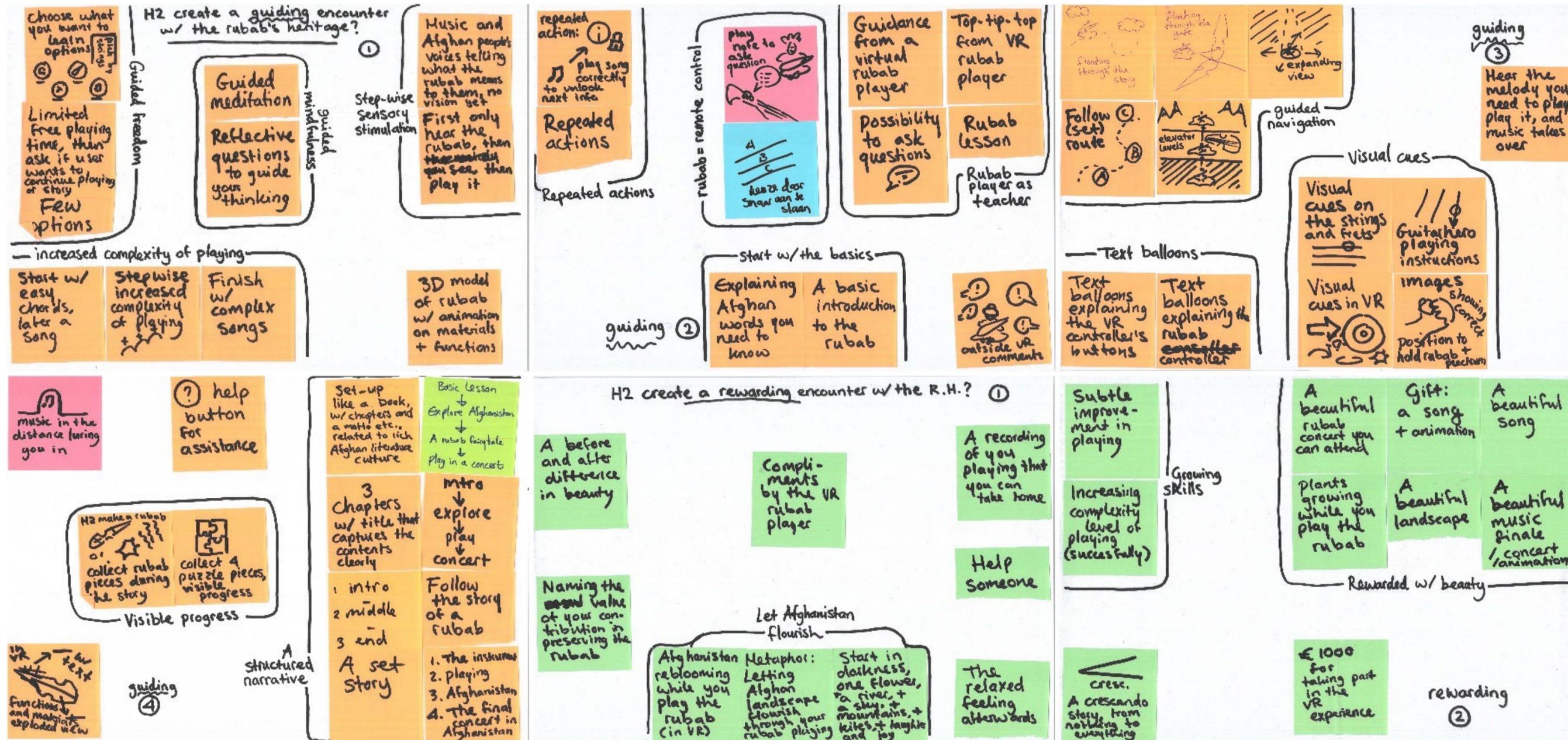
A rubab fairytale

- Alfred J. Docus Krent Luister CD Verhaal & muziek
- een vet (fictief) verhaal horen over de Rubab. of een sprookje.

Other

- Mijn vertalen dat de Rubab-cultuur draagt de verhalen
- creatie a Soprano rubab instrument.
- Het orgel + spanned? + verspreid van het instrument over
- een boek lezen over de rubab

Appendix I: Clustered ideas from the ideation phase



Points for playing correctly +1
Competition: win! +1

rewarding ③

competition

- Achieve a goal

A solved puzzle (rubab pieces collected)

Successfully smuggling the rubab

Build a rubab for the rubab player by completing songs = collecting parts (learn ab. musicals)

A goal to achieve

Guess the song

Small tasks to complete

Finish a song

musical passwords informative / immersive / animations

Unlocking chapters or new music

Give the rubab player a rubab to play on → concert

After crafting a rubab, playing on it

Unlock the next scene

Together in the real world

group chaos

Rubab Co Day!

Rubab festival

Follow on screen

Make the VR experience part of a rubab exhibition

Taking turns in playing

Both play

Both do the experience

H2 create a shared encounter w/ the R.H.? ①

buttons to communicate to other users (as with Storm Ziguandri ngen)

chat w/ other users

Meet strangers on the internet

A guest book where you can read other users' experiences

connect w/ other (past) users

Virtual rubab player as teacher/helper

Learn the basics from your استاد

Virtual people

The simulation of being w/ others

Social VR

Other people in the VR world

2x social VR (2 rooms w/ cameras) see each other in VR

Shared ②

A rubab duet

playing a duet (w/ rubab in a concert)

Play along concert

Converse with rubab player. Pick your question by playing

@ how does...?

@ when does...?

@ ...?

H2 convey rubab Relation to Afghanistan?

— Afghanistan's shape/map

Both in VR and in reality

Sit on an Afghanistan shaped rug/map

glowing borders when Afghanistan is mentioned

Afghanistan shaped pedestal

Near Afghanistan

3D aarabol

Afghan props (Afghan props Persian carpets)

Afghan flag

Mention: 'the rubab is the national instr. of Afghanistan'

Visit Afghanistan

Afghan landscapes

A gate to Afghanistan (metaphor)

entering Afghanistan

Rubab!

Afgh. dar/ pas/toe text w/ Dutch/English text, connection to Afgh.

H2 facilitate comparison of the Rubab's heritage w/ the user's own life?

Play your favourite music on the rubab

Explain the differences between rubab and guitar

Reflective questions

Reflective questions about your own life.

R.Q: "What music has an emotional meaning for you?"

Ret.Q: "What would the national instrument of your country be?"

'Maybe you know how to hold a guitar' - by rubab player

recognise yourself in the RP

Recognising yourself in the rubab player

The rubab player speaking your language

— kleding w/ de user's cultuur = hacking

The rubab player wearing western clothes

H2 make the encounter inspire?

Encourage user to start playing the rubab

personalised information: artists, musicians, ...

Letting the user play the rubab

Reflective questions

waerde van user's bijsprake bevroemen: doodat ij' dit leest hou je het erbij in leven

Souvenir

Record your concert and send it to your email

Keeping a souvenir of the encounter

H2 facilitate personal creation?

Compose rubab music

play your own songs on rubab

Compose / freestyle

Decorate your rubab so it becomes distinctively yours

play

Play the rubab

to play music:

— kleding w/ de user's cultuur = hacking

H2 convey appearance?

- 3D model of rubab
- Show 2 different rubabs
- Mirrored view of your rubab
- huge rubab to see details
- view RP's rubab
- photo-graphs
- Video's

H2 convey finger positions?

Now play S2F3 Say the position

Visual cues

String you need to pull glows

Visual cues

2D scheme

H2 convey how to hold the rubab + plectrum correctly?

VR rubab player in mirror position

Mirror image of correct way of holding

mirrored example

Give adjustment instructions w/ animation

Sense when it's held correctly, then say correct

H2 convey materials? part functions?

Intro by RP on important functions

Huge rubab 3D model animation like prezi

Quiz of part functions

H2 convey rubab as part of Afghan identity?

Audio quotes of what rubab means to Afghan people

Identity related quotes

Book w/ quotes

Stories by Afghan people

Voices in the dark

Next rubab players

H2 create a calming encounter w/ the rubab's heritage?

Being in Afghan nature

Nature sounds

Comfortable temperature

No impulses from outside the VR experience

Sitting in one spot, no need to move

VR privacy

External (outside VR) environment

A grounding activity

Meditate w/ rubab music

Getting a massage during the encounter

Breathing exercises at the start

Mindfulness

Turn inwards

An individual experience inwards

Time to reflect afterwards

H2 convey materials?

Materials Quiz

Rotatable 3D model w/ material annotations

Materials are alive

Goats, Mulberry tree, sheep

The material sources are around you

When a part is collected, describe material & fabrication

Virtual RP tells you

H2 convey how a rubab is made?

Drag the parts together

collection of pictures

say it

Long text

now rubab is made

DIY Assembly

Step-wise DIY

Show the loose parts + assembly

Visit workshop in Afgh.

Visit a workshop in Afghanistan

Exploded view animation

Exploded view assembly animation

Exploded view assembly + voice-over

Observe

Demo by VR rubab crafter

video of rubab crafting

Appendix J: Concepts 1–3 Feedback

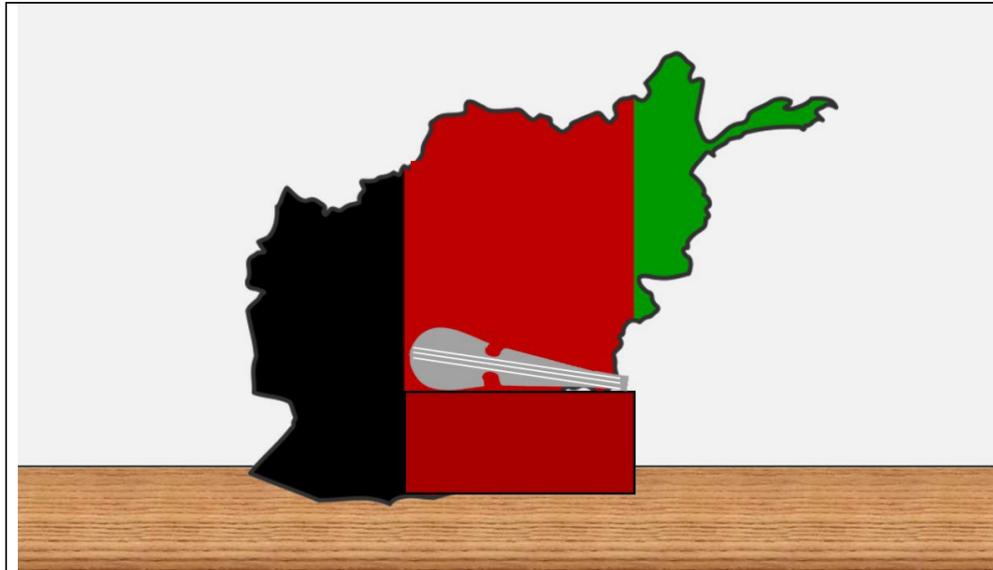
Concept 1: The Rubab – Afghanistan – The Duet	
+	<ul style="list-style-type: none"> Humour works well (goat, tree, magic): makes it light and appealing. The atmosphere is pleasant, calming (mountains, goat, mulberry tree). Clear structure in steps/parts, nice pace. Introduction with rubab sound works well (you know what to play). Strong connection to Afghan culture through chapters with Afghan characters, and map of Afghanistan. Technical learning - chapters provide structure and progression. Interaction with virtual teacher is appreciated. Elements like carpet, rubab-shaped gate to outside, light/darkness are appreciated as ambience creators. Physical object outside the VR (rug) is valued as a link to the VR world.
-	<ul style="list-style-type: none"> The mention of the word 'Chapter' can feel like lengthy and slow, due to its association with long books ('how long will this take?'). Lacks context or motivation as to why you are learning to play the rubab in the first place. Begins with no clear reason or storyline (for some, 'why am I playing this?'). Limited choice of sequence - linear and less free. The rubab player is only a man - gender inclusivity is missing, so women do not recognise themselves in the player. Less emotionally charged than the other concepts. Walking on a national flag (the rug) is considered not done
Opportunities	
<ul style="list-style-type: none"> One participant suggested it would be nice if you could see your hands when playing - increases sense of control and realism. Add choice Include a female rubab player or character Remove the word 'chapter' but keep the part structure Add emotional engagement Include a clear reason and storyline Remove the flag from the rug, keep the Afghanistan shape 	

Concept 2: The rubab is in danger, put out the fire with music	
+	<ul style="list-style-type: none"> symbolic gesture of saving rubab by playing is praised as very meaningful. Intro with rubab prohibition and fire makes motivation clear: you have to do something, you feel a sense of responsibility. Emotional urgency: fire/threat makes it involving. Good for attention and focus: feels shorter and more powerful. Rewarding: 'putting out fire' is tangible progress. Suitable for non-musicians: less technical, more emotional
-	<ul style="list-style-type: none"> No other characters present, lacks social connection. No possibility to return - seems to be a one-off experience. Could benefit from a hopeful or positive message The many coloured dots (frets) are confusing, especially for colour-blind people. The coloured dots as 'sheet music' are confusing. Lacks traditional context - more experience than education. Technical part (after fire) feels abrupt - transition to 'learning' could be smoother.
Opportunities	
<ul style="list-style-type: none"> One participant suggests that instead of 'killing the fire', the user should 'bring back to life' the rubab, which would be a more positive framing. One participant suggests: standing during the fire introduction, and sitting when starting the playing gives dynamics and provides a more natural transition to the learning and playing. One participant suggests adding a symbolic and hopeful transition scene post-fire, such as two generations playing rubab, or an older person handing the rubab over to the new generation. Add a human element. Provide a possibility to return to sections, especially the playing part. Add more Afghan context. Simplify the fret feedback system. Provide smoother transition to learning. 	

Concept 3: Tiles

+	<ul style="list-style-type: none"> Conversations with Afghans make it more personal, more human, giving a face to Afghanistan. Interactivity is praised: choosing tiles, exploring at one's pace. Tile interface is playful, interactive and clear. Fun interactions: choosing songs via strings is simple and convenient. Representation important: diversity of characters is possible (male/female, young/old). The collection of songs to choose from (Für Elise, the Afghan Sarzamin-e Man, and Make You Feel My Love) is diverse, and therefore appealing to different people, making the amount sufficient. You can come back to learn more Idea of zooming back to central space with the tiles and rubab music gives continuity. May feel as most 'rewarding' due to freedom and human interaction.
-	<ul style="list-style-type: none"> Lacks clear opening: why are you playing this? No sense of urgency. No main storyline such as 'banishment of the rubab'. Less guidance - may feel too open for some. Possibly confusing if not well structured. Miss clear progression or motivation to continue? Rubab sounds (e.g. tktktk, grrrt) in the beginning feel pointless, since they are not integrated in the story
Opportunities	
<ul style="list-style-type: none"> One participant suggest that the rubab sounds (e.g. tktktk, grrrt) could be integrated with the fire in C2, which would make more sense since you would hear the instrument struggling. Representation of Afghan people should be accurate Add a storyline and motivation. Provide more guidance 	

Appendix K: Concept 4 Storyboard



In the physical space, outside of VR, a map of Afghanistan in flag colors and a pedestal with the e-rubab device are visible. The user begins standing, wearing the VR headset. The remainder of this storyboard depicts the virtual experience.



Afghan mountain landscape, a starry night.
 Voice-over (female voice): Have you ever heard of the rubab? It is the national musical instrument of Afghanistan.
 Sounds: rubab music, happy



Huge rubab appears.
 Sound: rubab music



Rubab floats up, continues playing.
 Sounds: rubab music



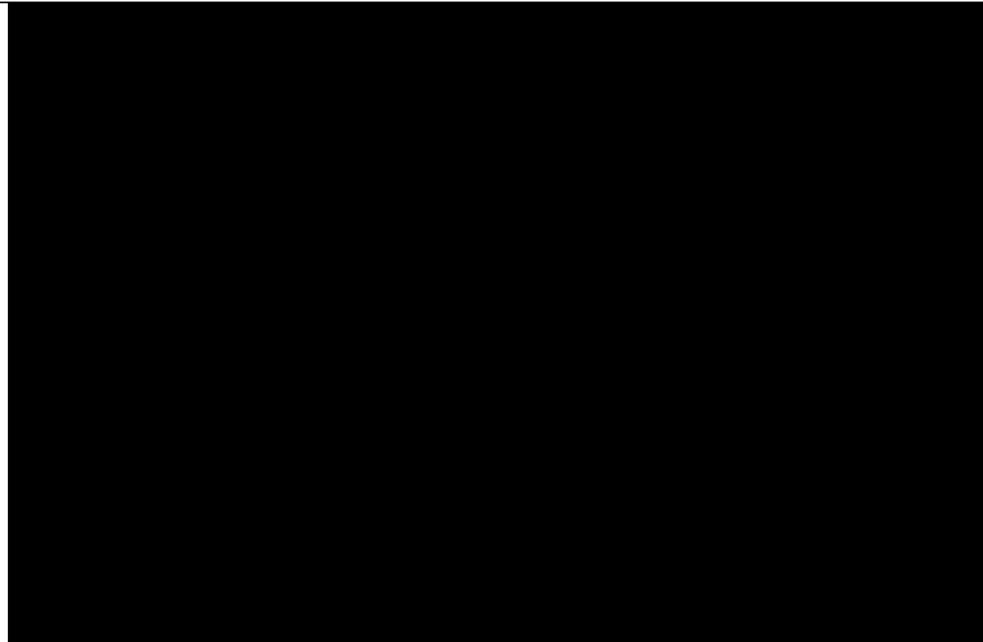
Thunder clouds.
 Voice-over: But the rubab is now forbidden in Afghanistan, and the heritage, that means so much to the Afghan people, is in danger.
 Sounds: rubab music, thunder rumbling



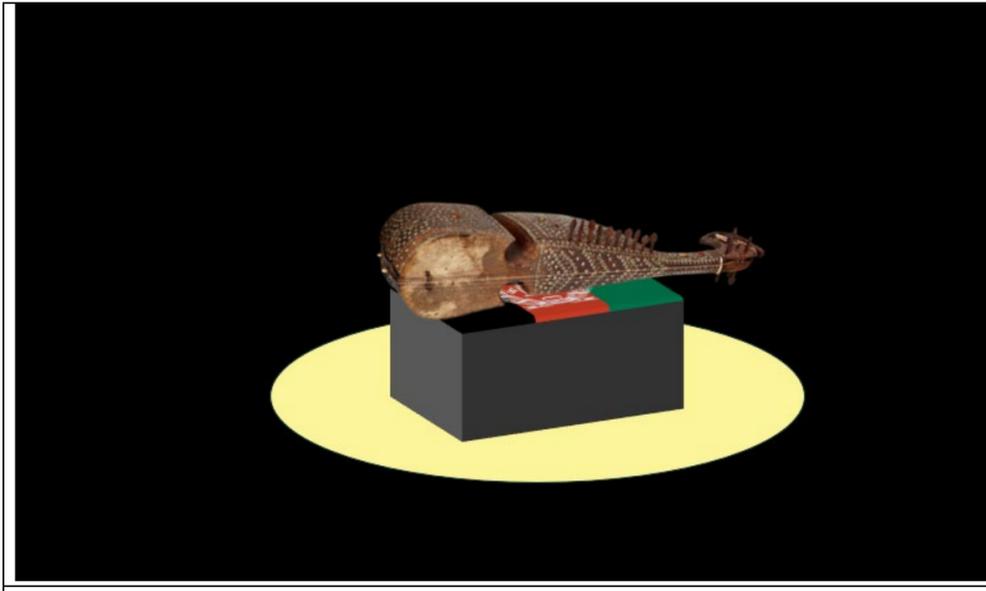
Lightning bolt hits the rubab. Music stops abruptly.
 Sounds: loud lightning bolt sound, thunder rumbling



Rubab falls on the ground, on fire.
 Voice-over: But I can teach you how to play the rubab, and keep its heritage alive.
 Sounds: fire sounds, no music, thunder rumbling.



Fade to black



Spotlight on the rubab (same position as external device).
 Voice-over: This will be your very own rubab. Pick up the instrument to continue.
 Sounds: fire sounds stop, light switch sound, calm rubab music starts

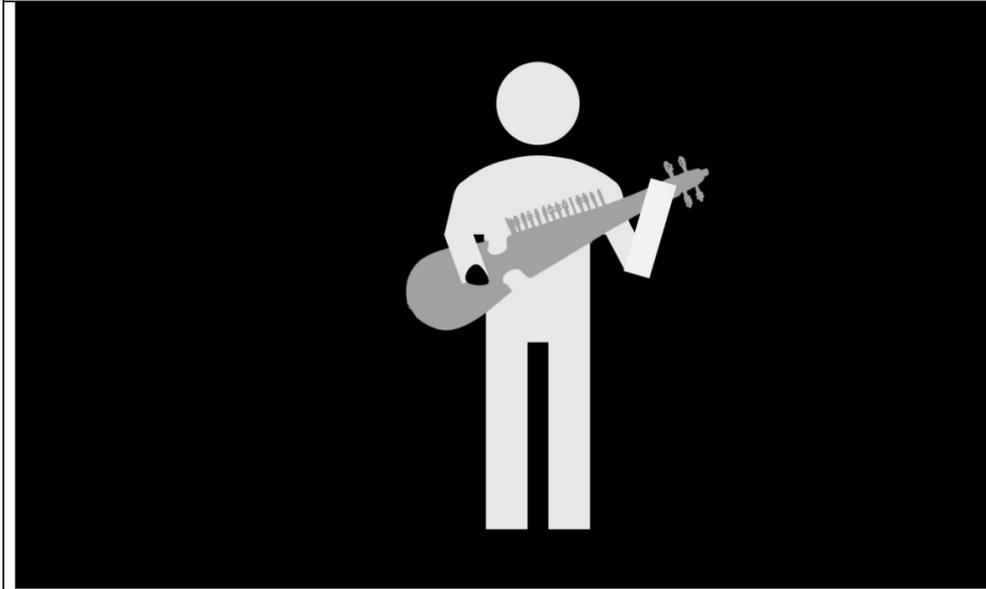
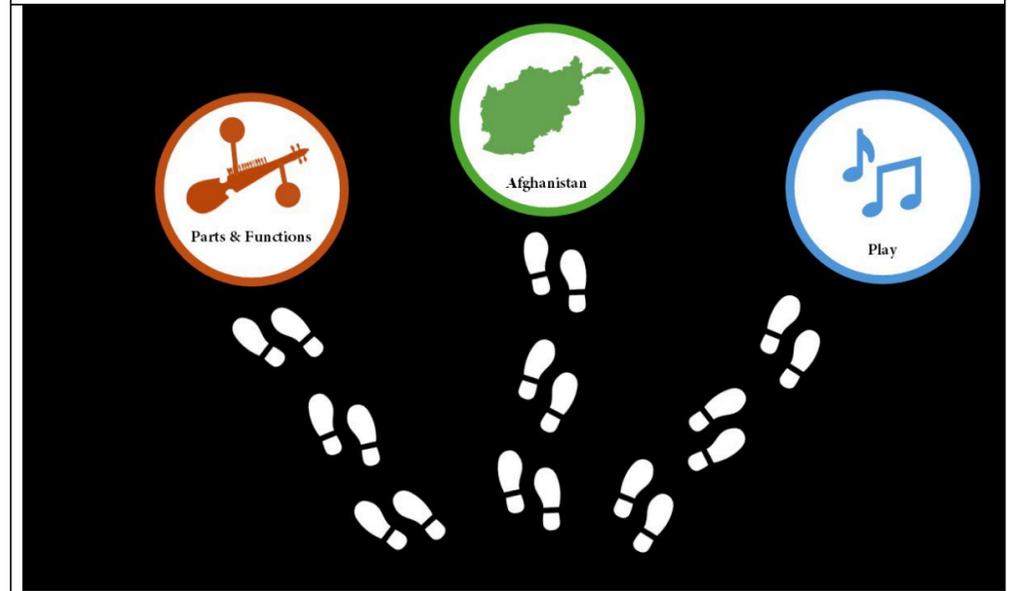


Image showing how to hold the rubab (standing).
 Voice-over: Maybe you know how to hold a guitar. This is almost the same. You hold the rubab's neck in your left hand, and press the strings onto the frets with your fingers. In your right hand, you hold the plectrum, and you can play the three melodic strings.



Sounds: calm rubab music (https://www.youtube.com/watch?v=weSaQKy_SBo)
 Voice-over: Very good! Now, it's up to you. What would you like to learn about the rubab's heritage?



Three tiles appear on the floor, with guiding footsteps.
 User walks on the tile of choice (in this prototype, first choice is 'Afghanistan').
 Sound: calm rubab music (https://www.youtube.com/watch?v=weSaQKy_SBo)

Afghanistan

افغانستان

Section title shown with Dari translation.



Map of Afghanistan is shown.
 Voice-over: Afghanistan, my home country.
 Sound: rubab music: sarzamin-e man (Afghan traditional song, meaning 'home country')



Map turns into a table with four Afghan people behind it.
 Voice-over:
 Sound: music continues.



Voice-over: Ask your questions to the people of Afghanistan by playing the coloured strings on your rubab.
 In this prototype, only question 1 is functioning.
 Sound: music continues



When selected, a voice balloon appears for the person speaking

Voice Afghan man: The people of Afghanistan know this instrument as they know their own flesh and blood. It's something that connects everyone. Imagine you have an Afghan here and an Afghan in Australia. They have nothing in common, but the sounds from the past, and especially the rubab, builds a bridge between them. It is also an emotional part of my country, it is part of a long history, and it should never be forgotten.

Sound: sarzamine-man rubab

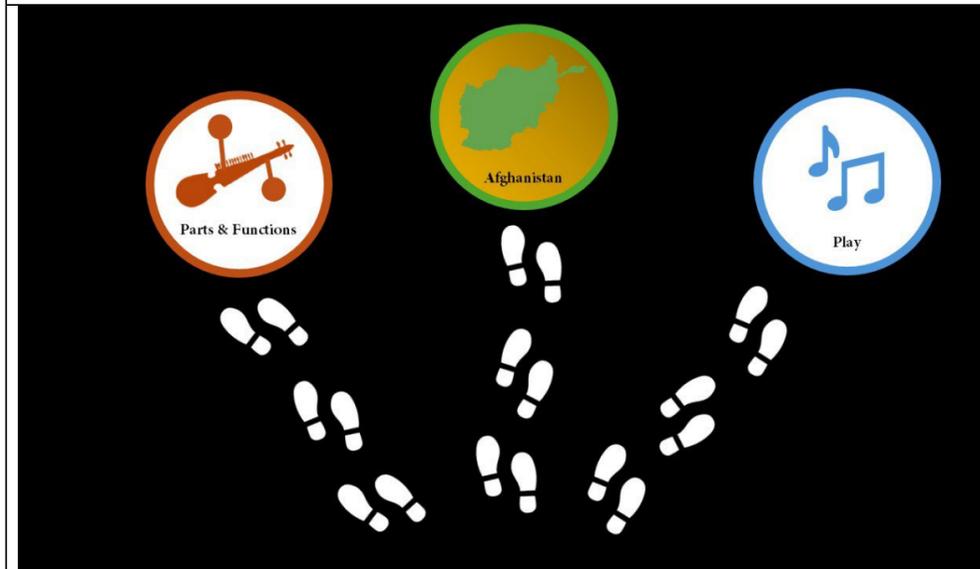


Voice Afghan woman:
 I think about the situation of the girls and women of Afghanistan everyday. A feeling of powerlessness overwhelms me then, and I like to listen to the rubab

during those moments. It's a remedy. It represents all the beautiful things, warmth and love that Afghanistan has to offer.



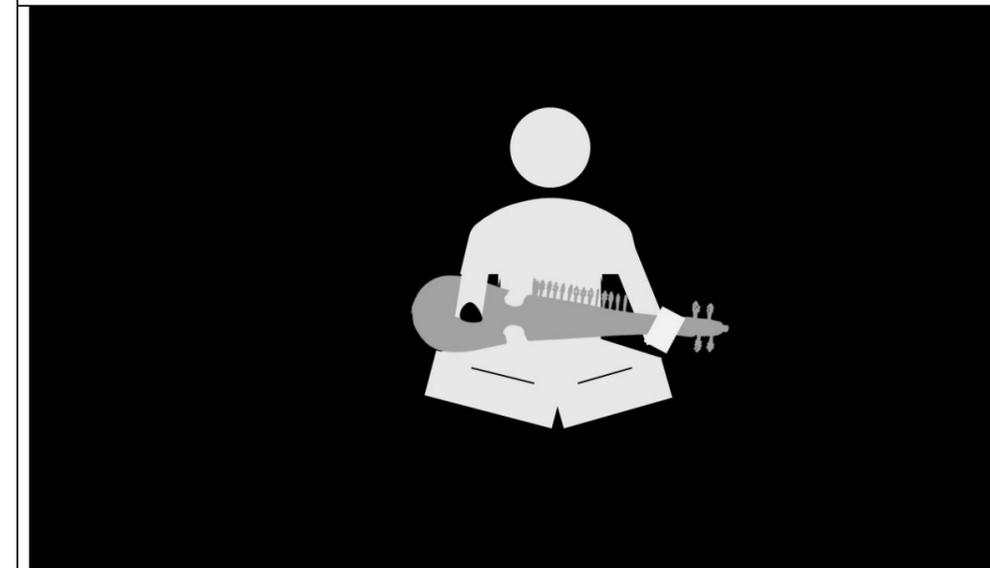
Pop-up menu, asking if they want to ask another question. Yes: back to question menu. No: back to tiles.



Tiles appear again. The Afghanistan tile is now coloured gold.
Sounds: calm rubab music (https://www.youtube.com/watch?v=weSaQKy_SBo)
In this prototype, the next step is play, although that would be a choice of the user.



Section title shown with Dari translation.



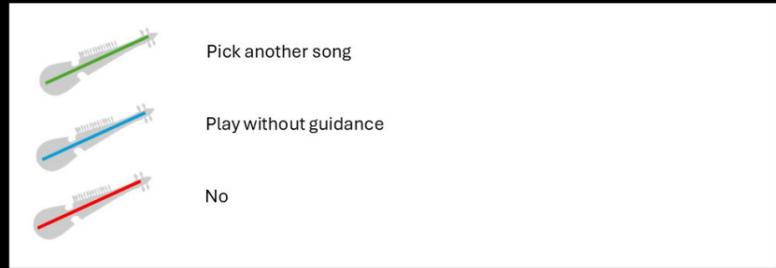
Voice-over: Please sit down on the floor in cross-legged position. This is the traditional way of playing the rubab.



Voice-over: Pick a song you'd like to play.



On the 3D model of the rubab that the user is holding, coloured dots are shown on the fret positions that relate to the notes of the song. After the song is completed, an applause is heard. The string that should be played lights up.
Sounds: sounds of the played notes. Applause in the end.



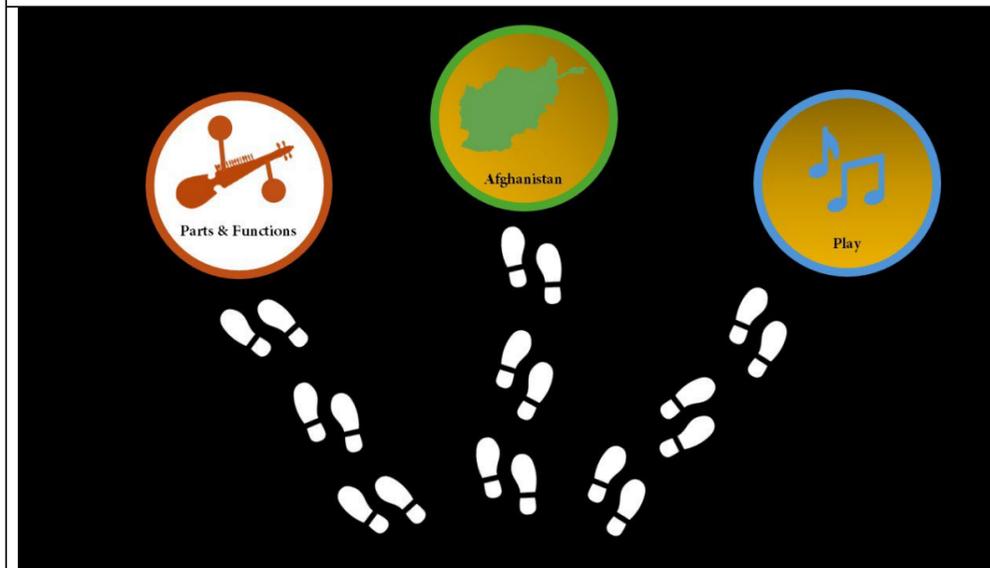
After the applause, a menu pops up.

Voice-over: Would you like to play another song? Or perhaps play freely, without guidance?

Pick another song: back to menu 1

Play without guidance: 1 minute timer without coloured dots, after which this menu appears again.

No: back to tiles



The two visited tiles are now coloured gold.

Sounds: calm rubab music (https://www.youtube.com/watch?v=weSaQKy_SBo)

Parts & Functions

اجزا و کاربردها

Section title shown with Dari translation.



Animation of a goat walking closeby, and a tree in the distance.

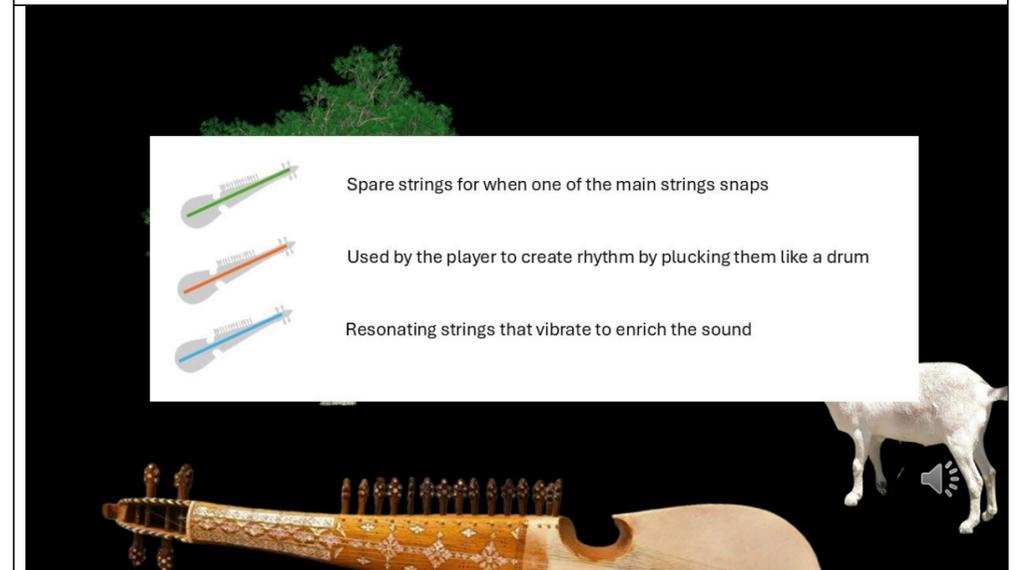
Sounds: goat sounds (chewing, walking)



Voice-over: Let's take a good look at your rubab. If you were to make one yourself, you would need two main materials: the wood from the mulberry tree, and the skin of a goat. The body is carved from the wood, and the goat skin is stretched over the lower part. When you pluck the strings, the skin vibrates, giving the rubab its warm, earthy sound.

The rubab has many parts. See the little flower-shaped pegs? They're for tuning the strings. There are three main strings we play, usually made of nylon. But there are also lots of other strings. Can you guess what those are for?

Sounds: no background music.

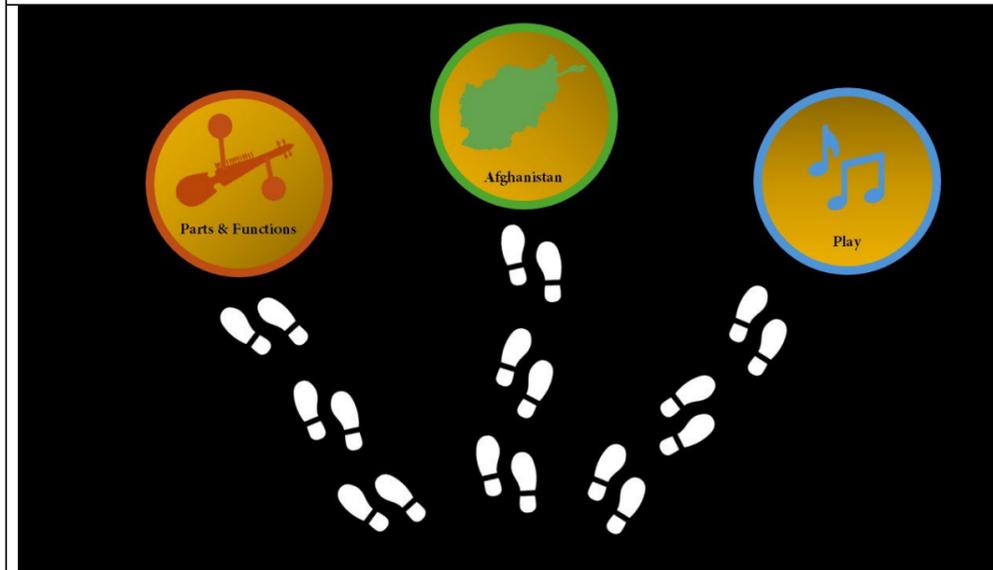


Quiz menu pops up with multiple choice answers. When played correctly, the voice-over says:

Indeed! These metal strings resonate in harmony with the main strings. They create that characteristic sound of the rubab. If you listen to the instrument without the resonating strings, the music feels bare, almost hollow [sound 1, without] But the moment they're added back in, the sound blooms; warm, vibrant and unmistakably rubab.

Sounds: recordings of rubab without [sound 1] and with [sound 2] resonating strings.

After that, back to the tiles



Sounds: no music, thunder and fire crackling



The rubab on fire appears again, and the fire slowly goes out.

Sound: thunder, fire crackling, no music.



Voice-over: Thank you, for keeping the rubab's heritage alive.

Sound: chirping crickets.



Rubab floats up, music starts playing. Slow sunrise, fade from night to day.

Sound: joyful rubab music with percussion.



Sunrise animation, goat walks in.

Sound: joyful rubab music with percussion.

Credits

Black; end credits.

Appendix L: Concept 4 Feedback

Feedback from target group

<p>What works well</p> <ul style="list-style-type: none"> • Interactivity: Almost all participants felt actively engaged: by plucking strings themselves, making choices using the instrument, and having the freedom to choose from the three tiles. • Fret dots as cues are well understood by all participants • The combination of cultural background education and play (learning <i>and</i> doing) was highly appreciated. • Background music: the music was considered beautiful, adding atmosphere and emotional involvement. • The goat was unanimously seen as a highlight – humorous and surprising. • String-based choice system: This was intuitively picked up by all participants and the interaction was considered fun. • The voice was perceived as pleasant and clear. • The experience was seen as suitable for young and old people. • Many valued the freestyle playing option. • Sitting was experienced as appropriate and supportive, and there were no problems with standing up again after playing. • The applause after finishing the song brings joy • The strings 'lighting up' is valued, bringing 'even more' clarity • The combination of familiar music and Afghan music was valued, because you can choose what you like. <ul style="list-style-type: none"> • The experiences was mostly scored for 'calming' between 4 and 5 out of 5 (calm, but not boring). The lightning strike limited the "zen" feeling, but felt appropriate. Reasons mentioned for high calm scores: calm voice, music, no hurry, able to decide your own tempo. • Guiding: scored very good (mostly 4–5), except for 1 participant who gave a 2/5 score, explaining they experienced freedom instead of (forced) guidance, which they liked. The combination of freedom of choice and guidance was valued. Reasons mentioned for high guidance scores: footsteps, coloured strings, projections on the strings, clarity of what should be done, not too many options, structured set-up. • Rewarding: average of 4. Reasons mentioned for high rewarding scores: 'thank you' at the end, applause, sunrise, being able to play, tiles turning gold.
<p>To be improved:</p>

<ul style="list-style-type: none"> • Plectrum: Almost everyone picked up the plectrum late – or forgot it altogether. In most cases, it was picked up after the voice-over mentions the plectrum for the first time. • It remained unclear why the rubab is forbidden in Afghanistan. Repeated comment: it's mentioned, but not explained <i>why</i>. Users were genuinely curious about the why. • Ending: several participants felt that the ending was too abrupt and wanted to keep on playing a little longer, or have the options to choose when to stop. • Sound balance: some audio fragments (music and chewing goat sound) were considered too loud, making them distracting. • Some participants forgot plucking the string when they put their finger on the frets, to play a note. • One participant indicated they would like to see/hear which string they selected in the choice menus, as feedback. • The goat walking in the Parts & Functions section took too long, making one of the participants think they had to do something, not knowing what to do.
<p>Suggestions:</p> <ul style="list-style-type: none"> • One participant suggested a menu pop-up before the final animation, asking the user if they are done exploring or want to keep exploring.

Feedback from Stichting Solh & Rubab Player:

<p>What works well</p> <ul style="list-style-type: none"> • The option to play freely, without guidance, was appreciated, and seen as fun by the rubab player. • The goat representing the material was considered well done • The word 'earthy' to describe the rubab's sound was considered 'well found' by the rubab player • The concept is appreciated. • The minimalist design of the e-rubab is valued by Stichting Solh. • The minimalist aesthetic is valued by Stichting Solh.
<p>To be improved</p> <ul style="list-style-type: none"> • Do not stand on the shape/map of Afghanistan, insensitive. Stepping into a floating map of Afghanistan, rotating 3D shape, is perfectly okay, as long as you don't step <i>on</i> it.

<ul style="list-style-type: none"> • The music notes icon on the tile for 'play' would better be replaced by a rubab, since music notes might be understood as leading to a music playlist instead of playing. For the parts & functions icon, you could show loose parts. • One of the background music pieces used in the prototype was recognised as played by a Pakistani rubab player, while the experience should be completely Afghan. • The Dari translation of 'Parts & Functions' was not fully correct, the translations of 'Play' and 'Afghanistan' were correct. • Stichting Solh would like to see both Pashto and Dari language translation in the three titles, instead of only Dari. • More Afghan songs to pick and play would be appreciated • More options in song selections would be nice. • While discussing the parts, the parts should be highlighted on the instrument you're holding, to clarify what are the strings, the pegs etc. • The introduction is too short. • "The rubab being hit by lightning does not fit the message we want to convey, because it is too definitive." Keeping the fire low would be better. Kamal Nasrati explained that the Taliban regime could fall tomorrow, and something as definitive and destroying as fire would not fit that. • Too tied to current events: Saying "it is forbidden now" risks becoming outdated. The experience may lose actuality when the Taliban regime would fall, and it still mentions that the rubab is forbidden <i>now</i>. Preferably the focus would not be on the rubab being forbidden now, but on the rubab having faced many difficulties because of the Sharia, and can overcome all these through our shared contribution to keep the heritage alive. • Suggestion to tell more about Afghanistan in the beginning: known as a country of war; a country with so many tribes, languages, ethnicities ("tell it euphorically, poetically"), but they have one thing they all share: de rubab and the memories to the rubab. • The Afghan flag may be politically sensitive, so leaving the flag out might be better. The shape of Afghanistan is not considered sensitive, and in combination with a landscape, perfect. •
<p>Suggestions</p> <ul style="list-style-type: none"> • Suggestion to add footage of the Taliban and people playing the rubab in the introduction.

- Suggestion to show recognisably Afghan contexts, such as the two buddhas now destroyed by the Taliban.
- Suggestion to show Afghan traditional clothing as well as western clothing from the 80s or 90s Afghanistan.
- Responding on the question how the aesthetic could be more Afghan: Stichting Solh explained that a simplistic approach should be kept, keeping the design minimalist and as simple as possible, as it is now. "Simplicity is key". And maybe add an Afghan tapestry.
- Suggestion to show different generations of Afghans in the Afghanistan part

Feedback from supervisory team

What works well

- The walking-interaction is good, it doesn't need explanation
- Playing the strings as the choice interaction is good and interesting.
- The experience is well-paced

To be improved

- The voices are too generic and synthetic. The tone of voice is too formal and could be more spontaneous, so it sounds like talking instead of reading
- Develop wrong answers for the quiz question that are slightly more believable
- Make it Mixed Reality (with pass-through) instead of full Virtual Reality, so users see what's happening around them, especially important for use in public places for a secure feeling.
- Make it possible for people around to see how it works from the distance, so they are more likely to do it
- Make the aesthetic more Afghan, so it has resonance with the Afghan people.
- The objects/tiles could be 3D floating objects instead of 2D.
- The flag at the beginning might not be recognised as the Afghan flag by non-Afghans
- The flag might be politically sensitive, it might be better to use the country shape with landscape imagery, which would be less generic, more interesting for Afghans (own comment: this also relates better to the goal of conveying Afghanistan's beauty).

Opportunities

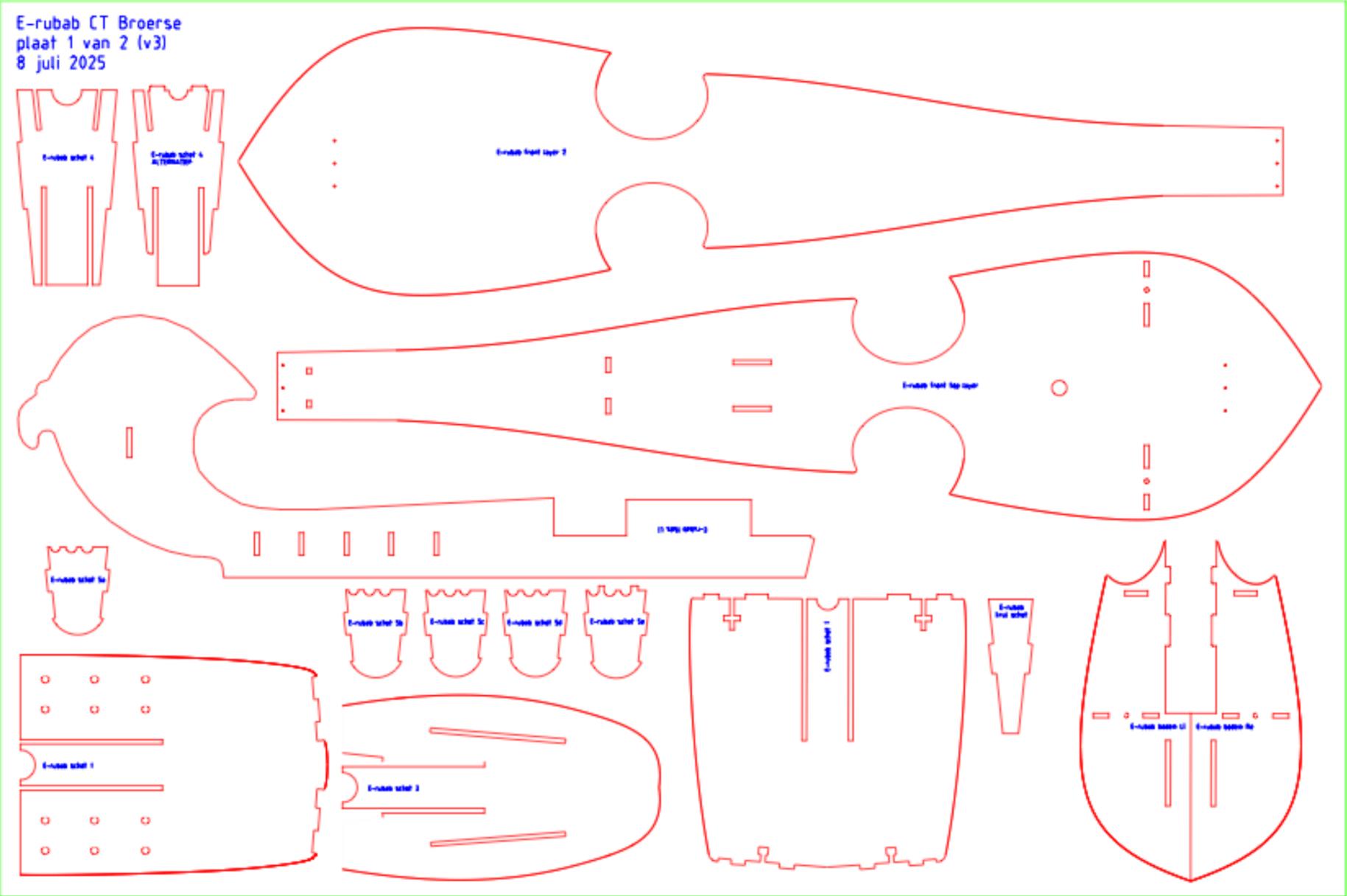
- How to integrate timing and speed in playing?
- Make the music sound spatial, fitting a performance setting

Appendix M: 3D Scanning the rubab

The 3D model of the rubab was created using Artec 3D software in combination with Artec Eva and Artec Spider scanners, with Artec Spider used for detailed parts, such as the tuning pegs. The final model was constructed from approximately six scans, merged using Artec 3D software through both automated point recognition and manual alignment of corresponding points. Additionally, the scanners captured the rubab's material appearance. The 3D model was exported as an .stl file, while the appearance data was saved as a .jpeg file.

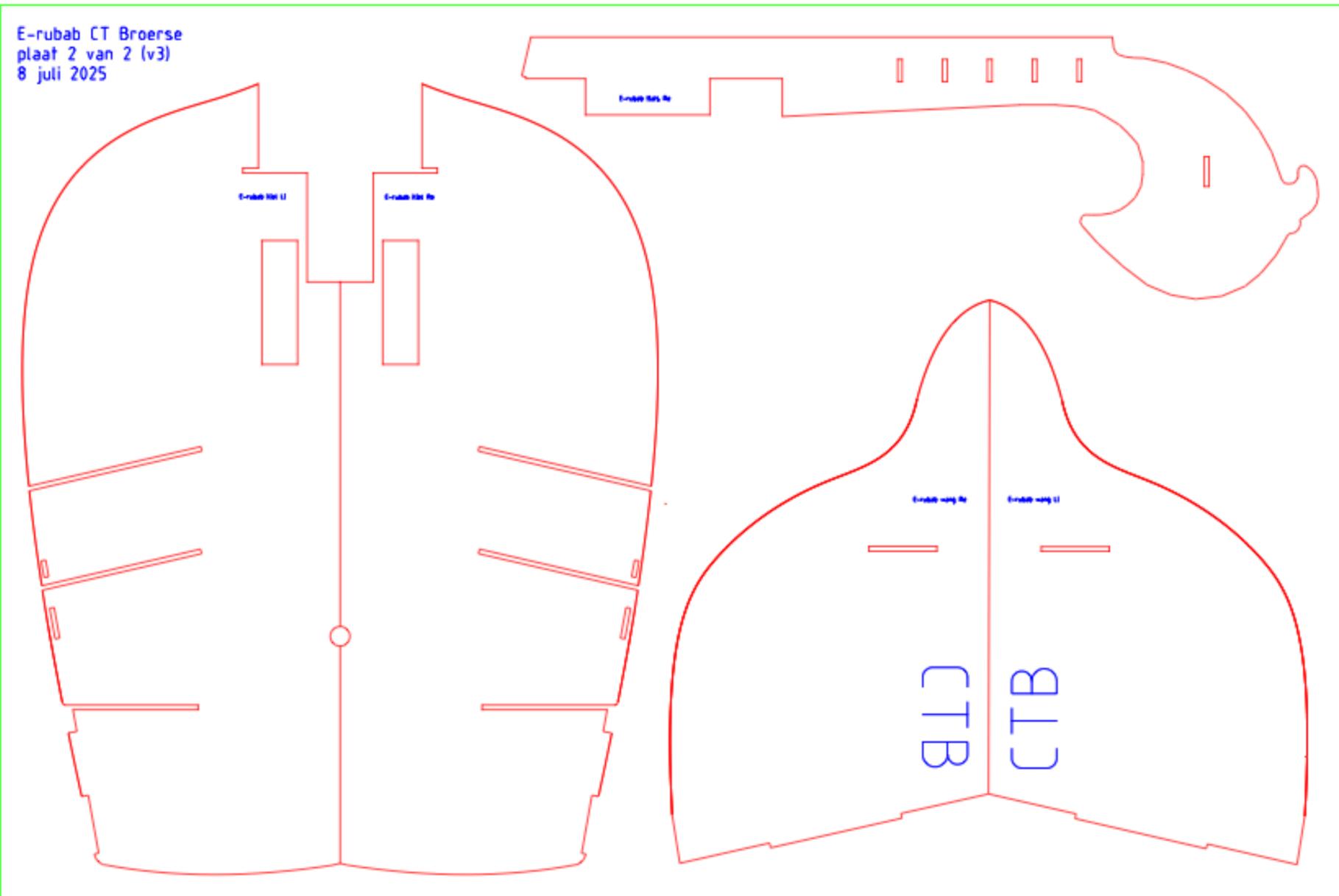


Appendix N: E-rubab lasercut outlines



Scale 1:7.5

E-rubab CT Broerse
plaat 2 van 2 (v3)
8 juli 2025



Appendix O: The Socket.IO Server

The Socket.IO server file can be downloaded from: <https://github.com/CB-rubab/rubab-legacy>

The E-rubab relies on a local node.js socketIO server in order to use the socket.io plugin.

Installation

The following Windows instruction is based on the official Getting started tutorial. For Linux and Mac, specific instructions to install node.js are available online.

Step 1

Start by installing node.js on your local PC, see <https://nodejs.org/en/download>.

To download and install Chocolatey, a installation manager, open the Terminal/Windows Powershell application and enter:
`powershell -c "irm https://community.chocolatey.org/install.ps1|iex"`
and hit Enter

Let choco download and install Node.js:
`choco install nodejs --version="22.17.1"`

Verify the Node.js version:
`node -v # Should print "v22.17.1".`

Verify the npm version:
`npm -v # Should print "10.9.2".`

Step 2

Continuing in the Terminal, enter:
`npm install express@4`

This will set up as basic server, see <https://socket.io/docs/v4/tutorial/step-1>

Install socketIO by entering:
`npm install socket.io`
hit Enter, and then:
`npm install socket.io-parser`

Step 3

In Network settings of the PC running the socketIO server, find the IP Address (IPv4 address), and enter it in your ESP32 Arduino code and the Unreal Engine settings to tell them which server to connect to.
VERY IMPORTANT: All IP addresses entered should be the same (so only one IP address is used).

Set up Unreal Engine plugin, see separate Appendix Q.

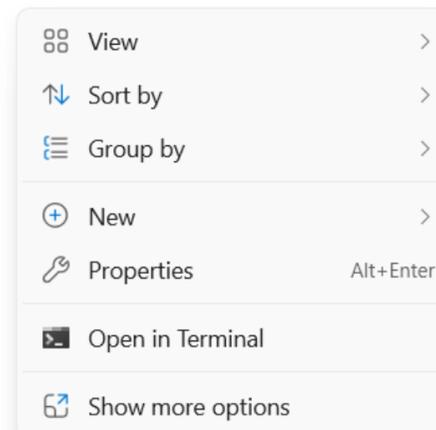
This completes the communication between the e-rubab's ESP32 and Unreal Engine (using the socket.io plugin).

Step 4

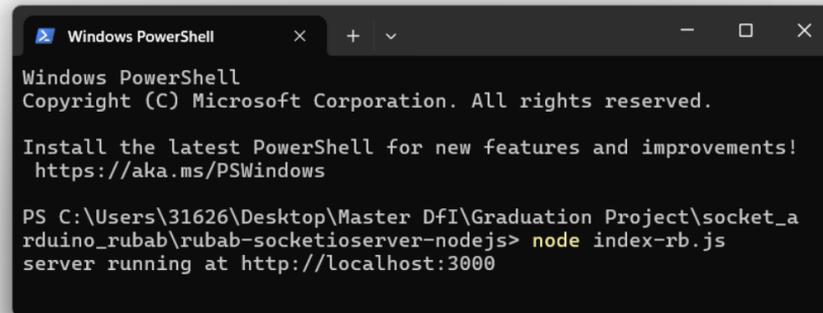
To start socketIO server:

1. Unzip the folder 'socket_arduino_rubab'. This folder contains two folders:
 1. Folder: rubab-socketioserver-nodejs (Socket.io server files)
 2. Folder: sioClientEsp32.ino (Arduino files)
2. Make sure that the PC that runs the server, the ESP-32, and the device that runs Unreal Engine are on the same Wi-Fi network and have the IP address of the PC running the server in their settings.
3. Make sure the Arduino file is uploaded to the ESP32.
4. Open the folder 'rubab-socketioserver-nodejs'
5. Right-click on the empty space in the folder and click 'Open in Terminal':

node_modules	13/05/2025 11:33	File folder	
chat	27/05/2025 16:16	Data Base File	16 KB
index	13/05/2025 11:32	Brave HTML Docu...	12 KB
index-rb	19/06/2025 09:58	JavaScript Source ...	3 KB
package	13/05/2025 11:32	JSON Source File	1 KB
package-lock	13/05/2025 11:33	JSON Source File	91 KB



- In the opened terminal, write this prompt:
`node index-rb_v3.js`
and press Enter. It should now say 'server running at http://local-host:3000', 3000 being the port defined in the socket.io server.



```
Windows PowerShell
Copyright (C) Microsoft Corporation. All rights reserved.

Install the latest PowerShell for new features and improvements!
https://aka.ms/PSWindows

PS C:\Users\31626\Desktop\Master DfI\Graduation Project\socket_a
rduino_rubab\rubab-socketio-server-nodejs> node index-rb.js
server running at http://localhost:3000
```

Figure 10: A terminal window with the address of the rubab-socketio-server-nodejs file, the prompt, and the message 'server running'. Windows PowerShell is an example of a terminal, this can be any terminal application.

- Make sure that in Unreal Engine, the two event names (message categories) 'note' and 'menu' are correctly entered in the BP_rubab blueprint. Also make sure that the messages (e.g. 'S1F11') are correctly entered. If the event names or messages are not correctly written in Unreal Engine With the server, Unreal Engine won't be able to access the data on the server.

- Turn on the e-rubab's ESP32. It will log in automatically to the set Wi-Fi network and connect to the socketIO server. The server will report:

```
a user connected

...

rb_note event message: str 2 frt 1
```

With the server, ESP32 and Unreal Engine running, the sensor input will now be communicated to the Unreal Engine output (i.e., corresponding sounds and visuals).

To stop the server, hit Ctrl + C

Extra tutorials:

<https://techtutorialsx.com/2018/05/17/esp32-arduino-sending-data-with-socket-client/>

<https://socket.io/docs/v4/socket-io-protocol/#sending-and-receiving-data>

How to unpack the contents of a received socketIO Object:

<https://github.com/socketio/socket.io-json-parser>

Appendix P: ESP32 Arduino Code

The Arduino file can be downloaded from: <https://github.com/CB-rubab/rubab-legacy>

Setting up the Arduino code

To install and run a Socket.IO client on an ESP32 using the Arduino IDE and send text (string) messages to a Socket.IO server, follow these instructions:

Prerequisites

1. **Arduino IDE:** Ensure you have the Arduino IDE installed on your computer.
2. **ESP32 Board Package:** Install the ESP32 board package in the Arduino IDE.
3. **Socket.IO Client Library:** You'll need a Socket.IO client library compatible with the ESP32. One such library is SocketIoClient for Arduino.

Step-by-Step Instructions

Step 1: Install the ESP32 Board in Arduino IDE

1. Open the Arduino IDE.
2. Go to File > Preferences.
3. In the "Additional Boards Manager URLs" field, enter: https://dl.espressif.com/dl/package_esp32_index.json
4. Click OK.
5. Go to Tools > Board > Boards Manager.
6. Search for esp32 in the Boards Manager and install the "esp32 by Espressif Systems".

Step 2: Install Required Libraries

1. Go to Sketch > Include Library > Manage Libraries.
2. Search for ArduinoWebSockets and install it.
Note: You directly use the WebSockets library, since it supports a SocketIoClient class. See the example here: <https://github.com/Links2004/arduinoWebSockets/blob/master/examples/esp32/WebSocketClientSocketIoack/WebSocketClientSocketIoack.ino>

Step 3: Write the Code

A basic example of how to set up a Socket.IO client on an ESP32 to send text messages to a server:

```
#include <WiFi.h>
#include <SocketIoClient.h>

// no longer required/supported, see Note

const char* ssid = "YOUR_WIFI_SSID"
const char* password = "YOUR_WIFI_PASSWORD"

// Socket.IO Server details
const char* host = "YOUR_SOCKET_IO_SERVER_IP"
const int port = 3000; //Selected port is 3000 in this project

SocketIoClient socket;

void setup() {
  Serial.begin(115200);

  // Connect to Wi-Fi
  WiFi.begin(ssid, password);
  while (WiFi.status() != WL_CONNECTED) {
    delay(500);
    Serial.print(".");
  }
  Serial.println("");
  Serial.println("WiFi connected");

  // Connect to Socket.IO server
  socket.begin(host, port);
```

```

// Set up event handlers
socket.on("connect", [(const char * payload, size_t length) {
Serial.println("Connected to Socket.IO server");
}]);

socket.on("disconnect", [(const char * payload, size_t length) {
Serial.println("Disconnected from Socket.IO server");
}]);

}

void loop() {
socket.loop();

// Example: Send a text message to the server
socket.emit("message", "{\"text\": \"Hello from ESP32\"}");
delay(5000); // Send a message every 5 seconds
}

```

Step 4: Upload the Code to ESP32

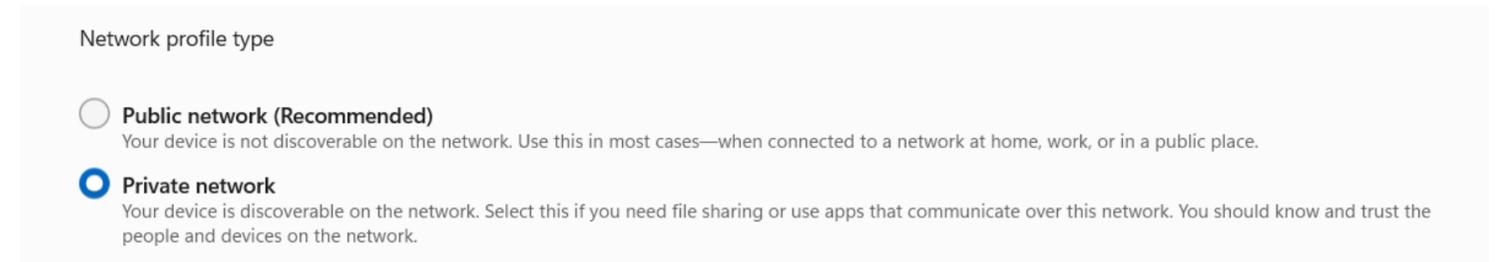
1. Connect your ESP32 board to your computer.
2. In the Arduino IDE, go to Tools > Board > ESP32 Arduino > ESP32 Dev Module
3. Select the correct port under Tools > Port.
4. Click the upload button to upload the code to your ESP32.

Step 5: Monitor the Output

1. Open the Serial Monitor in the Arduino IDE by going to Tools > Serial Monitor.
2. Set the baud rate to 115200.
3. You should see messages indicating the connection status and messages being sent to the Socket.IO server. Reboot (press the small 'EN' button on the ESP32 board to reboot it) if the monitor does not show messages.

Notes

- Replace the following credentials and Socket.IO server details in the secret.py file:
 - YOUR_WIFI_SSID
 - YOUR_WIFI_PASSWORD
 - YOUR_SOCKET_IO_SERVER_IP (IPv4-address of the PC running the server, which you can find under Wi-Fi settings)
 - YOUR_SOCKET_IO_SERVER_PORT (3000)
- Ensure your Socket.IO server is running and accessible from your ESP32's network. For Windows PCs: Make sure that in the Wi-Fi settings of the PC running the server, the network profile type is set to 'Private network', so the device is discoverable on the network. If it is set on 'Public network', the server will not connect.



This setup will allow your ESP32 to connect to a Socket.IO server and send simple text messages periodically.

For the e-rubab application, the Final Arduino code is as follows:

```
/* SPDX-FileCopyrightText: 2025 */ /* SPDX-License-Identifier: GPL-3.0-
or-later */

/*
 * E-rubab sockketIO client v0.8.6
 * By Casijn Broerse, 13 July 2025
 * Adapted from WebSocketClientSocketIOack.ino, AdaFruit and randomnerdtutorials.com examples
 *
 * Works on laptop + node.js socketio server + ESP32
 * Sends notes as string (chat) message for Unreal Engine
 * Senses Touch pad via MPR121 breakout, connected over I2C
 * Snares are IR Proximity (line following) sensors RPR220 with threshold and min. interval
  set
 * Also tested with Sparkfun QRE1113 "QA" IR breakouts
 * Additional (debug) note inputs: 3 digital touch buttons to keep testing in Unreal Engine
 * Refactored functions to fix code duplication, stores data in arrays
 * Calibrated for 3x RPR220 on custom PCB
 * Added SPDX header, see https://reuse.software/faq/
 */

#include <Arduino.h>
#include <WiFi.h>
#include <Wire.h>
#include <Adafruit_MPR121.h> // lib for touch sensor breakout
#include "driver/rtc_io.h"
#include <ArduinoJson.h>
#include <SocketIOclient.h>
#include "arduino_secrets.h"

WiFiClient client;

const char credits[] = "ESP32 E-rubab by Casijn Broerse, 2025";
const char sio_host[] = "172.20.10.3"; // set for the laptop/PC running socket.io server

// sensitive data in the Secret tab/arduino_secrets.h
const char ssid[] = SECRET_SSID; // network SSID (name)
const char password[] = SECRET_PASS; // network wifi wachtwoord (use for WPA, or use as key
for WEP)

// Global variable definitions
int status = WL_IDLE_STATUS;

// SocketIO server details
bool connected; // socketIO server status

// IP address set at top of code
const uint16_t sio_port = 3000;
SocketIOclient socketIO;

unsigned long messageTimestamp = 0;
int msgId = 0; // to filter out duplicates already sent

bool sendData(char eventName[], int data1, int data2=0, int data3=0); // in header set
default values for optional parameters
char PLAYSTR[] = "rb_notestring";
// char MENUSTR[] = "rb_menustring";
char CHAT[] = "chat message";
int maxLength = 1;

#define USE_SERIAL Serial
#define onboard_LED 2

// for comparing MPR121 touch states
// from https://github.com/adafruit/Adafruit_MPR121/
#ifndef _BV
#define _BV(bit) (1 << (bit))
#endif

//==== I/O definitions

// FRETTS:
// capacitive touch threshold value on capacitive touch areas
// single value, applied to all fret touch sensors
// settable in lib, but MPR121 defaults work fine

// MPR121 breakout board I2C setup, use default SCL=22 & SDA=21 pins
Adafruit_MPR121 cap = Adafruit_MPR121(); // requires cap.autoconfig() in setup()

// Keep track of the last pads touched, returned as 12 bit integer
// every bit is a pad state: 0000 0000 0010 0000 Pad #5 touched, 0000 0000 0000 0001 Pad #0
touched.
// so defined as uint16_t, not default int = uint8_t
uint16_t currTouched = 0;
uint16_t lastTouched = 0; // check to enter sleep mode
const int bitPositions[3][4] = { { 0, 1, 2, 3 },
{ 4, 5, 6, 7 },
{ 8, 9, 10, 11 } };

// Used to fetch corresponding bit from MPR121 byte

// Equivalent to the lowest bit position for the index

// SNARES aka "musical strings":
// Add 30mm piece of yellow plastic cable insulation over sensor around transparent snares
#define NUM_SNARES 3 // the number of snares, starting count at 1

const int snare1IrPin = 34; // IR sensor1 ADC on D34 - top left (with USB @ bottom)
const int snare2IrPin = 35; // IR sensor2 ADC on D35 - same row left, a bit down
const int snare3IrPin = 32; // IR sensor3 ADC on D32 - same row left, a bit down

// IR sensor on 3.3V with:
// 10k Ohm extra pulldown resistor for Sparkfun QA pin "S"
// 68k Ohm pullup resistor for RPR220 pin 4, and 330 Ohm resister for LED pin 1-2

const int IR_THRESHOLD = 1800; // for RPR220, adjust if distance to IR sensor > 2mm
// Base value for Sparkfun QA breakout: 1323. For RPR220: 300-511
const int START_COUNTDOWN = 100; // Minimum wait cycles between playing the same snare

// Arrays to hold the pin numbers, states etc.
int snarePins[NUM_SNARES] = {snare1IrPin, snare2IrPin, snare3IrPin};

int prevSnareIrStates[NUM_SNARES] = {HIGH, HIGH, HIGH}; // Initial states for IR snare
sensors
int snareValues[NUM_SNARES] = {0, 0, 0};
int snareCounters[NUM_SNARES] = {0, 0, 0};
bool snareHighs[NUM_SNARES] = {false, false, false}; // these are defined above

// end of variable definitions

void setup() {
  USE_SERIAL.begin(115200); // 921600); // lower as advised
  USE_SERIAL.setDebugOutput(true);

  // initialize ESP32 built in LED as an output.
  pinMode(onboard_LED, OUTPUT); // ESP32 WROOM v1
  // temporary snare buttons

  for (uint8_t t = 4; t > 0; t--) {
    USE_SERIAL.printf("[SETUP] BOOT WAIT %d...\n", t);
    USE_SERIAL.flush();
    delay(1000); // required for WiFi connect succes
  }
}
```

```

USE_SERIAL.println(credits); USE_SERIAL.println();

// INPUTS

// Frets, 4 per snare ("string")
// pads 0-3 under Snare 1, pads 4-7 under Snare 2, pads 8-11 under Snare 3

// Fret inputs use touch/analog input via MPR121 breakout over I2C, no config
USE_SERIAL.print("MPR121 Capacitive Touch Sensor breakout board ");
// use default MPR121 address: 0x5A
Wire.begin(); // already running?
if (!cap.begin(0x5A, &Wire)) {
  USE_SERIAL.println("not found. Check the frets wiring");
  while (1);
}
USE_SERIAL.println("found"); USE_SERIAL.println();
cap.setAutoconfig(true); // adjust threshold per touch area

// Snares, 1 = top snare (low), 3 = bottom snare (high)
// uses analog input on GPIO32/35/34
USE_SERIAL.println("IR snare sensors active.");
for (int i = 0; i < NUM_SNARES; i++) {
  snareValues[i] = analogRead(snarePins[i]);
}
USE_SERIAL.print("Snare 1-3 IR base values: 1="); // print initial PSR value
USE_SERIAL.print(snareValues[0]);
USE_SERIAL.print(" 2=");
USE_SERIAL.print(snareValues[1]);
USE_SERIAL.print(" 3=");
USE_SERIAL.println(snareValues[2]);
if (max(max(snareValues[0], snareValues[1]), snareValues[2]) < IR_THRESHOLD) {
  USE_SERIAL.print("Ready to play, all IRs are below IR_THRESHOLD, now set to: ");
} else {
  USE_SERIAL.print("WARNING: Can't play, one or more are over IR_THRESHOLD ");
}
USE_SERIAL.println(IR_THRESHOLD);

// CONNECT to wifi
digitalWrite(onboard_LED, HIGH);
USE_SERIAL.println();
USE_SERIAL.println("*****");
USE_SERIAL.print("Connecting to ");
USE_SERIAL.println(ssid);

// Set WiFi to station mode
WiFi.mode(WIFI_STA);
// WiFi.disconnect(); // disconnect from an AP if it was previously connected.
WiFi.begin(ssid, password);

int j = 0;
while (WiFi.status() != WL_CONNECTED && j < 40) {
  j++;
  delay(500);
  USE_SERIAL.print(".");
}
if (WiFi.status() == WL_CONNECTED) {
  USE_SERIAL.println("\n Connected to WiFi");
  USE_SERIAL.print("ESP32 IP address: ");
  USE_SERIAL.println(WiFi.localIP());
} else {
  USE_SERIAL.print("\n Sorry, could not connect to WiFi "); USE_SERIAL.println(ssid);
}
digitalWrite(onboard_LED, LOW);

// Connect to socket.io server
digitalWrite(onboard_LED, HIGH);
// server address, port and URL
socketIO.begin(sio_host, sio_port, "/socket.io/?EIO=4");
// this format tells the Arduino lib it wants socketIO, so must include =4

// use HTTP Basic Authorization (optional - for extra security as suggested)
// websocket.setAuthorization("username", "password");

digitalWrite(onboard_LED, LOW);

// event handler
socketIO.onEvent(socketIOEvent);
}

void loop() {
  socketIO.loop(); // reads incoming, keeps SocketIO active

  // repeat static message - testing
  if (msgId >= 18000){
    msgId = 0;
    // sendString(CHAT, "Hello from esp32"); // causes callback() crash on socketio
server
  }
}

// CHECK THE INPUTS

// FRETS
currTouched = cap.touched();
// will CRASH here if no MPR121, so must DEFINE to activate FRETS, see #else next

// Get the currently touched fret pads from MPR121 cap
// as a 2 byte int value containing 12 bits 0-11 for 'touched' state of each pad
// fret state is parsed only when a snare is actually played, see checkSnareIr()

// Debug MPR121 touch pads to Serial Console
// prints out the bits from the MPR121 return value nicely formatted
// for (uint8_t i=0; i<12; i++) {
//   // if it *is* touched and *wasnt* touched before, mark:
//   if ((currTouched & _BV(i)) && !(lastTouched & _BV(i)) ) {
//     // Debug: print out as as bits
//     USE_SERIAL.print("Pads byte from MPR121: ");
//     // //printBits(currTouched); USE_SERIAL.print(" Pad #");
//     USE_SERIAL.print(i); Serial.println(" touched.");
//   }
//   // if it *was* touched and now *isnt*, mark too:
//   if (!(currTouched & _BV(i)) && (lastTouched & _BV(i)) ) {
//     // Debug: print out as as bits
//     USE_SERIAL.print("Pads byte from MPR121: ");
//     // //printBits(currTouched); USE_SERIAL.print(" Pad #");
//     USE_SERIAL.print(i); Serial.println(" released.");
//   }
// }
// store touched state for comparison in next loop (debugging only)
if (currTouched != lastTouched) { // activity/change
  lastTouched = currTouched; // store for next loop
}

// SNARES
// Check state of snares 1-3
for (int i = 0; i < NUM_SNARES; i++) {
  checkSnareIr(i);
}

delay(50); // add delay for stability. DEBUG, reset to 10 normal?
}

// SUPPORTING FUNCTIONS

```

```

void checkSnareIr(int index) {
    // Determine which pin and variables to use, based on index. Index 0 = snare 1 etc.
    int snareCounter = max(snareCounters[index] - 10, 0); // decrease countdown timer for snare i
    bool snareIsHigh = snareHighs[index];
    // read IR value
    int currentValue = analogRead(snarePins[index]);
    //USE_SERIAL.print(index + 1); USE_SERIAL.print(" "); USE_SERIAL.println(currentValue);
    // DEBUG ONLY, full Monitor!

    // Perform IR snare played logic
    if (currentValue >= IR_THRESHOLD) { // no reflection, snare pulled aside
        snareHighs[index] = true;
    } else if ((currentValue < IR_THRESHOLD) && (snareCounter == 0)) {
        if (snareHighs[index]) {
            // snare goes from HIGH/OFF to LOW/rest: reset and send note to socketIO 1x
            if (currentValue > 10 && currentValue < 4095) { // don't send from an E-rubab without sensors
                sendNote(index + 1, getFretState(index)); // frets under snare[index] get parsed, send Note
                snareCounter = START_COUNTDOWN;
            }
            snareHighs[index] = false;
        }
    }
    // Update global variable
    snareCounters[index] = snareCounter;
}

int getFretState(int index) {
    // Parse global currTouched for index (= index=0 for frets under snare 1 etc.)
    // Compressed logic, aided by Mistral lechat AI
    // Same logic for index == 1 in a more readable form:
    //   fret1State = 10; // bitRead() checks a fret state by its index
    //   if (bitRead(currTouched, 3)) { // only highest fret is picked up
    //       fret1State = 14;
    //   } else if (bitRead(currTouched, 2)) {
    //       fret1State = 13;
    //   } else if (bitRead(currTouched, 1)) {
    //       fret1State = 12;
    //   } else if (bitRead(currTouched, 0)) {
    //       fret1State = 11;
    //   }

    int baseState = (index + 1) * 10; // e.g. 20 for snare 2 (note: snare2 index = 1 !)

    int fretState = baseState; // default state with no frets touched

    // Calculate the bit positions for the current index: defined in global array

    // Check each bit position to determine the fret state
    if (bitRead(currTouched, bitPositions[index][3])) {
        fretState = baseState + 4;
    } else if (bitRead(currTouched, bitPositions[index][2])) {
        fretState = baseState + 3;
    } else if (bitRead(currTouched, bitPositions[index][1])) {
        fretState = baseState + 2;
    } else if (bitRead(currTouched, bitPositions[index][0])) {
        fretState = baseState + 1;
    }

    // Return the calculated state
    return fretState;
}

/* SocketIO functions to send an receive */

/* Send note depending on snare and fret pressed */
void sendNote(int snareNum, int fretPressed) {
    USE_SERIAL.println(" sendNote(S" + String(snareNum) + ",F" + String(fretPressed) + ")");
    // To send note to socketIO as JSON, uncomment next line
    // sendData(PLAYED, snareNum, fretPressed);

    // Send note to socketIO as TXT
    char payload[] = "S";
    char snr[2];
    itoa(snareNum, snr, 10);
    strcat(payload, snr);
    strcat(payload, "F");
    char frt[2];
    itoa(fretPressed, frt, 10);
    strcat(payload, frt);
    sendString(PLAYSTR, payload);
    // sendString(MENUSTR, payload); // send same payload, but sent as a user menu selection
    // not required on client as a copy is emitted by the socketIO server
}

/* Send a note as String to the socketIO Server + callback (counter) */
bool sendString(char eventName[], char textString[]) {
    // Parameter defaults are set in header

    // Build object tree in memory to store the data you want to send in the request

    digitalWrite(onboard_LED, HIGH); // turn on onboard LED

    // create JSON message for Socket.IO
    JsonDocument docOut;
    JsonArray array = docOut.to<JsonArray>();

    // add event name
    // Hint: socket.on(eventName, ....
    array.add(eventName); // element[0] = event_name

    // add payload
    array.add(textString);
    int clientOffset = msgId;
    array.add(clientOffset);

    // JSON to String (serialization)
    String outputString;
    serializeJson(docOut, outputString);

    // Send event
    socketIO.sendEVENT(outputString);

    digitalWrite(onboard_LED, LOW); // turn off the LED
    msgId++;
    return true;
}

/* Send a note as data elements to the socketIO Server.
Not used in Unreal plugin. Leave in code for TODO info */
bool sendData(char eventName[], int data1, int data2, int data3) {
    // Parameter defaults are set in header

    // Build object tree in memory to store the data you want to send in the request

    digitalWrite(onboard_LED, HIGH); // turn on onboard LED

    // create JSON message for Socket.IO
    JsonDocument docOut;
    JsonArray array = docOut.to<JsonArray>();

    // add event name
}

```

```

// Hint: socket.on(eventName, ...
array.add(eventName); // element[0] = event_name

// add payload
JsonObject param1 = array.createNestedObject();
param1["now"] = millis();
param1["data"][0] = data1;
param1["data"][1] = data2;
param1["data"][2] = data3;

// JSON to String (serialization)
String outputString;
outputString += msgId;
serializeJson(docOut, outputString);

// Send event
socketIO.sendEVENT(outputString);

// Print JSON for debugging
// USE_SERIAL.println(outputString);

digitalWrite(onboard_LED, LOW); // turn off the LED
msgId++;
return true;
}

/* Print all received event messages to Monitor */
void event(const char * payload, size_t length) {
    USE_SERIAL.printf("got message: %s\n", payload);
}

void socketIOEvent(socketIOMessageType_t type, uint8_t * payload, size_t length) {
    switch(type) {
        case sIOType_DISCONNECT:
            if (connected) {
                USE_SERIAL.printf("[IOc] Not connected!\n");
                connected = false;
            }
            break;
        case sIOType_CONNECT:
            USE_SERIAL.printf("[IOc] Connected to url: %s\n", payload);
            connected = true;
            // join default namespace "/"
            socketIO.send(sIOType_CONNECT, "/"); // TODO use namespace /rubab
    }
}

```

```

break;
case sIOType_EVENT: {
    char * sptr = NULL;
    int id = strtol((char *)payload, &sptr, 10);
    USE_SERIAL.printf("[IOc] got event: %s id: %d\n", payload, id);
    if (id) {
        payload = (uint8_t *)sptr;
    }
    JsonDocument doc;
    DeserializationError error = deserializeJson(doc, payload, length);
    if (error) {
        USE_SERIAL.print(F("deserializeJson() failed: "));
        USE_SERIAL.println(error.c_str());
        return;
    }

    String eventName = doc[0];
    // USE_SERIAL.printf("[IOc] event name: %s\n", eventName.c_str());

    // Message Includes an ID for an ACK (callback)
    if (id) {
        // create JSON message for Socket.IO (ack)
        JsonDocument docOut;
        JsonArray array = docOut.to<JsonArray>();

        // add payload (parameters) for the ack (callback function)
        JsonObject param1 = array.createNestedObject();
        param1["now"] = millis();

        // JSON to String (serialization)
        String output;
        output += id;
        serializeJson(docOut, output);

        // Send event
        socketIO.send(sIOType_ACK, output);
    }
}
break;
case sIOType_ACK:
    USE_SERIAL.printf("[IOc] got ack: %u\n", length);
    break;
case sIOType_ERROR:
    USE_SERIAL.printf("[IOc] got error: %u\n", length);
}

```

```

break;
case sIOType_BINARY_EVENT:
    USE_SERIAL.printf("[IOc] got binary: %u\n", length);
    break;
case sIOType_BINARY_ACK:
    USE_SERIAL.printf("[IOc] got binary ack: %u\n", length);
    break;
default:
    USE_SERIAL.printf("[IOc] got unknown: %u\n", length);
}
}

/* UTIL */
void printBits(long int n) {
    // Util method to print an N-bit integer in the form: 0000 0000 0000 0000
    // works for 4 - 32 bits. accepts signed numbers
    // only used for debugging MPRL21 frets in loop()
    byte numBits = 16; // 2^numBits must be big enough to include the number n
    char b;
    char c = ' '; // delimiter character
    for (byte i = 0; i < numBits; i++) {
        // shift 1 and mask to identify each bit value
        b = (n & (1 << (numBits - 1 - i))) > 0 ? '1' : '0'; // slightly faster to print chars
        than ints (saves conversion)
        USE_SERIAL.print(b);
        if (i < (numBits - 1) && ((numBits-i - 1) % 4 == 0 )) USE_SERIAL.print(c); // print a
        separator at every 4 bits
    }
}

```

Appendix Q: Meta Quest 3 & Unreal Engine Settings

The Unreal Engine file of the Rubab Legacy can be downloaded from:

<https://github.com/CB-rubab/rubab-legacy>

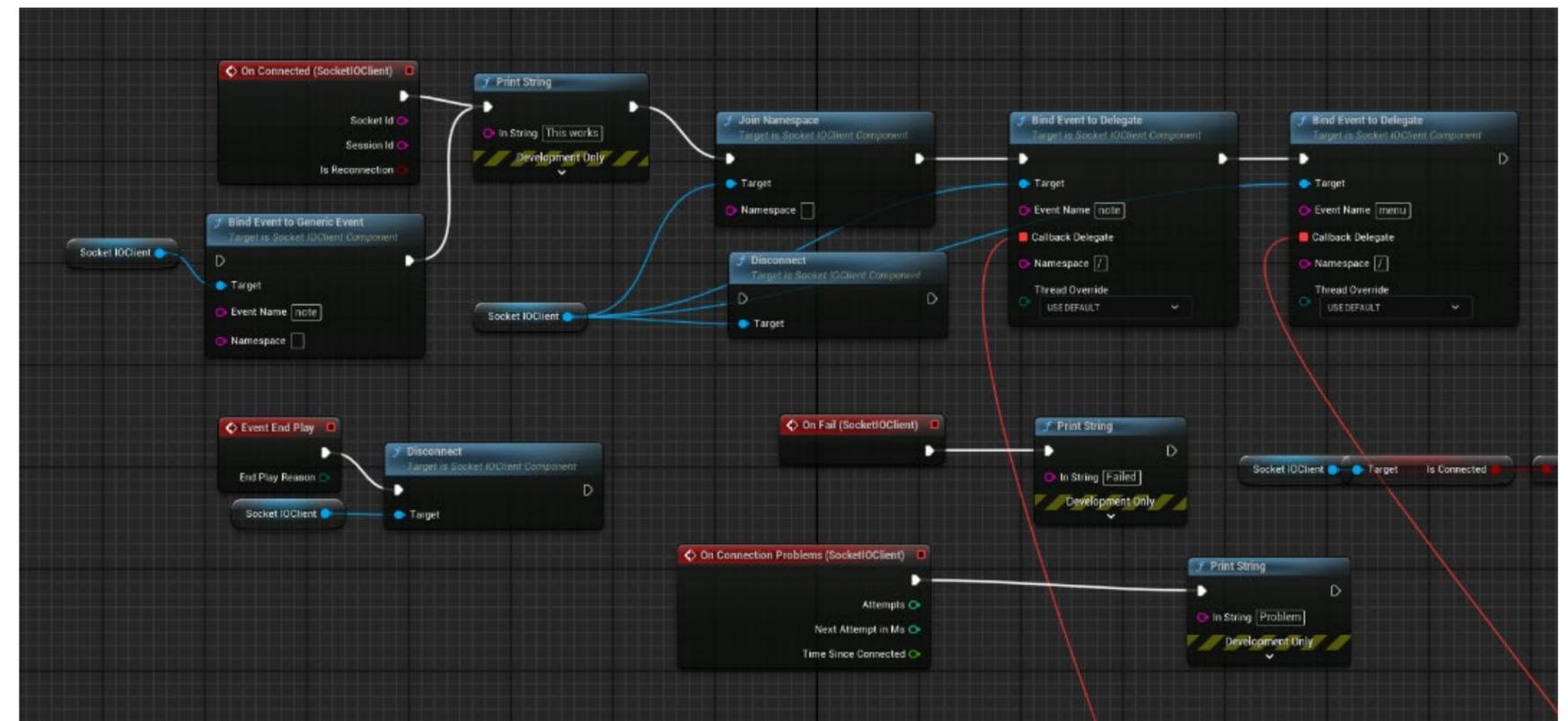
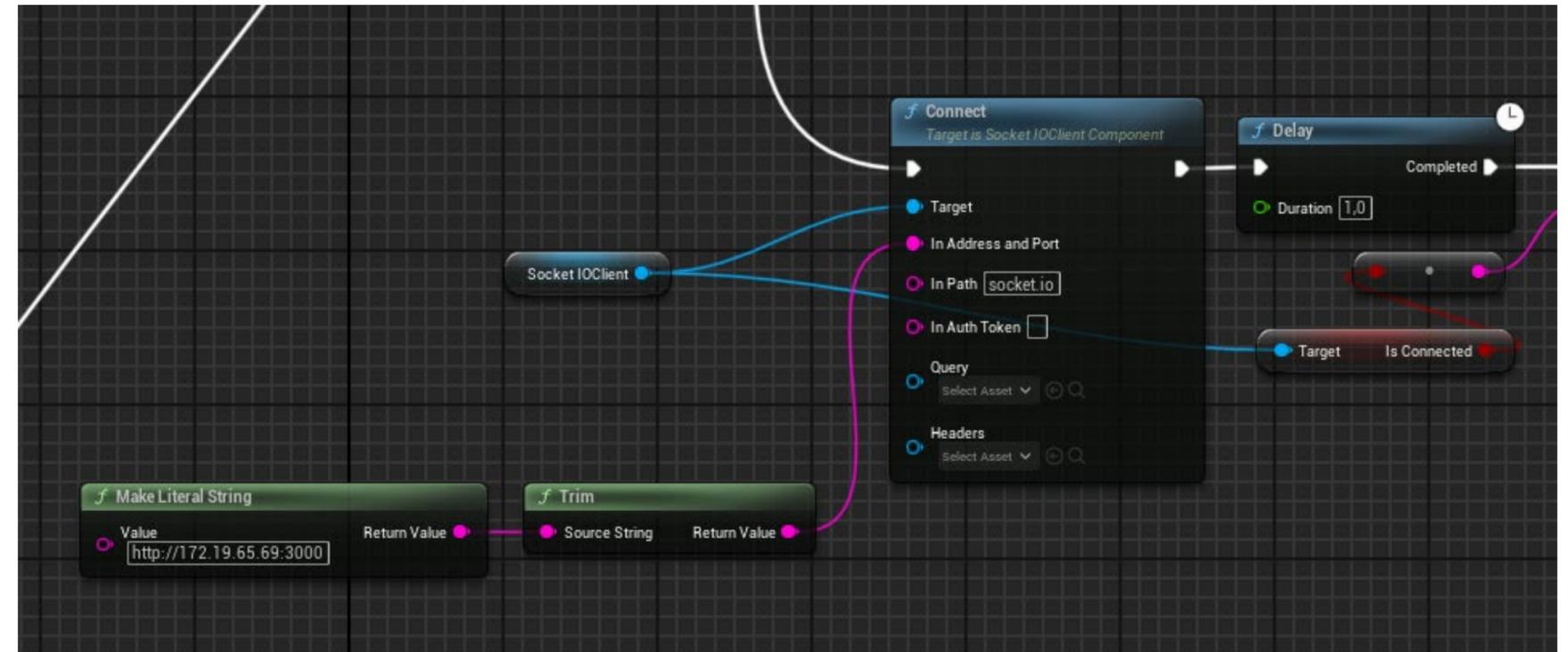
Setting the right virtual environment boundary for the walking interaction

To make it possible to walk around in a larger area (including the tiles), do the following:

1. Put on the Meta Quest 3 headset.
2. Navigate to the main settings > environment setup > select boundary Here, set 'stationary boundary size' to 'large', so your boundary is big enough to reach the tiles.
3. Set 'room scale boundary sensitivity' to the lowest.

Let Unreal Engine listen to the Socket IO server

1. Find the Socket.IO plugin for Unreal Engine here: <https://github.com/getnamo/SocketIOClient-Unreal>
Download it and add it to your (Rubab) blueprint in Unreal Engine.
2. Configure the Blueprint as shown in the two screenshots on the right. The top image demonstrates how to connect to the Socket.IO client, while the bottom image illustrates how to use the 'Bind Event to Delegate' node to handle server messages and trigger Unreal Engine outputs (e.g., sounds). For a more detailed Blueprint example, visit this detailed documentation: <https://github.com/getnamo/SocketIOClient-Unreal>



Appendix R: Unreal Engine Prototype Script v1 and v2

This is the script of the Unreal Engine prototype. Script elements that occur in Version 1 of the application (i.e., the application for during the Taliban regime, speaking in the present tense about the Taliban), are coloured orange. Those that occur in Version 2 (post-Taliban application) are coloured blue. The black text is the same in both versions.

INTRO

Voice-over (female voice):

Have you ever heard of the rubab?

It is the national musical instrument of Afghanistan – a land of breathtaking contrasts: towering mountains, vast deserts, and a rich tapestry of languages and cultures.

Yet among all this diversity, one sound has always connected the Afghan people: the rubab.

V1: But this instrument has endured many threats – war, displacement, and religious bans on music under Taliban regimes. In Afghanistan, the rubab can no longer be played freely; its voice is being silenced.

V2: But this instrument has endured many threats – war, displacement, and religious bans on music under Taliban regimes. At times, its voice was nearly silenced.

But I can teach you how to play the rubab – so its story can continue in your hands, and its beauty can be shared with the world.

Do you see the instrument next to you? This will be your very own rubab. Pick up the instrument and the plectrum to continue.

Maybe you know how to hold a guitar – playing the rubab is quite similar. Hold the rubab's neck with your left hand and press the strings down onto the frets with your fingers. In your right hand, hold the plectrum and use it to play the three melodic strings to create sound.

Very good! Now, it's up to you. Which part of the rubab's heritage would you like to explore first?

LEVEL AFGHANISTAN

V-O:

Afghanistan, my home country.

Ask your questions to the people of Afghanistan by playing the coloured strings on your rubab.

Question 1: What does the rubab mean to you?

Voice Afghan man: Rubab acts as a solid foundation for the authentic music of my nation. The people of Afghanistan know this instrument as they know their own flesh and blood. It's something that connects everyone. Imagine you have an Afghan here and an Afghan in Australia. They have nothing in common, but the sounds from the past, and especially the rubab, builds a bridge between them. It is also an emotional part of my country, it is part of a long history, and it should never be forgotten.

Voice Afghan woman: **V1: Living in Europe, I think about the situation of the girls and women of Afghanistan everyday. A feeling of powerlessness overwhelms me then, and I like to listen to the rubab during those moments. It's a remedy. It represents all the beautiful things, warmth and love that Afghanistan has to offer.**

V2: During difficult moments, I like to listen to the rubab. It's a remedy. It represents all the beautiful things, warmth and love that Afghanistan has to offer.

Question 2: What is the relation between rubab and Afghanistan?

Voice Afghan woman: The rubab and Afghanistan share a deep, inseparable bond. It is Afghanistan's national instrument and a cornerstone of its musical heritage. It originated in the region and has been played there for centuries, woven into the country's cultural identity. The instrument's rich, warm sound embodies the beauty of Afghanistan. Each city and region adds its own flavour—whether in playing style or instrument design—making the rubab a truly diverse symbol of Afghan culture.

Question 3: Which political challenges has the rubab faced over the years?

Afghan man: **V1: The rubab has faced many political challenges, especially under the Taliban regimes. Under the current regime, music is banned because it is seen as contrary to the Taliban's strict interpretation of religious law. They view music as morally inappropriate and a distraction from religious duties. Despite this ongoing oppression, the rubab is played in secret, making it a symbol of resistance and resilience.**

V2: The rubab has faced many political challenges, especially during the Taliban regimes. Under their rule, music was banned because it was seen as contrary to the Taliban's strict interpretation of religious law. They view music as morally inappropriate and a distraction from religious duties. Despite this oppression, the rubab was played in secret, making it a symbol of resistance and resilience.

LEVEL PLAY

V-O: Please sit down on the floor in cross-legged position. That's the traditional way of playing the rubab. But if that's not comfortable or possible for you, feel free to sit on the bench instead.

Now pick a song you'd like to play. Choose by playing the coloured strings on your rubab.

Do you want to play another song? Or maybe play without guidance?

LEVEL PARTS & FUNCTIONS

V-O: Let's take a good look at your rubab. If you were to make one yourself, you would need two main materials: the wood from the mulberry tree, and the skin of a goat. The body is carved from the wood, and the goat skin is stretched over the lower part. When you pluck the strings, this skin vibrates, giving the rubab its warm, earthy sound.

The rubab has many parts. See the little flower-shaped pegs? They're for tuning the strings. There are three main strings we play, usually made of nylon. But there are also lots of

other strings. Can you guess what those are for? Pick an answer by playing the coloured strings on your rubab.

When answered correctly, the voice-over says:

Indeed! These metal strings resonate in harmony with the main strings. They create that characteristic sound of the rubab. If you listen to the instrument without the resonating strings, the music feels bare, almost hollow [sound 1, without] But the moment they're added back in, the sound is warm, vibrant and unmistakably rubab.

Wrong answer 1:

Almost! Have another go!

Wrong answer 2:

Not quite! Have another try!

FINALE

V-O: Thank you, for keeping the rubab's heritage alive.

Project Brief



Personal Project Brief – IDE Master Graduation Project

Name student Casijn Broerse

Student number 4,775,937

PROJECT TITLE, INTRODUCTION, PROBLEM DEFINITION and ASSIGNMENT

Complete all fields, keep information clear, specific and concise

Project title Preserving Afghanistan's rubab heritage through interactive technologies

Please state the title of your graduation project (above). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

Introduction

Describe the context of your project here; What is the domain in which your project takes place? Who are the main stakeholders and what interests are at stake? Describe the opportunities (and limitations) in this domain to better serve the stakeholder interests. (max 250 words)

Many musical instruments are at risk of 'disappearing' due to a range of challenges, including globalisation, restrictive laws that hinder musical expression, the complexity of playing techniques, and physical inaccessibility (sources in launchpad review). Human-computer interaction (HCI) offers new possibilities for the preservation of these endangered instruments by providing innovative ways to capture and interact with their heritage. Comprehensive preservation is crucial, as the loss of such instruments would mean the disappearance of unique and culturally rich musical traditions.

An example of such a 'disappearing' musical instrument is the Afghan rubab (De Groene Amsterdammer, 2022, <https://www.groene.nl/artikel/via-muziek-laten-we-zien-dat-we-bestaan>). "As music is banned in Afghanistan, the craftsmen and musicians struggle to preserve the heritage of this ancient instrument, vital to the nation's cultural identity" (Mathrubhumi newspaper, 29 December 2024, <https://english.mathrubhumi.com/news/world/unesco-listed-musical-instrument-rubab-stifled-in-afghanistan-1.10205504>).

My project takes place in the domain of cultural heritage preservation and human-computer interactions (HCI). The interest at stake is the preservation of the Afghan rubab. The project will be in collaboration with Stichting SOLH. In preparation of my graduation project, I wrote a literature review on the employment of different interactive technologies in preserving tangible and intangible aspects of musical instrument heritage. The review concludes that through integration of the immersive capabilities of VR with sensor-based embedded technology (for more accurate physical/tangible playing sensations), a more comprehensive and accurate preservation could be achieved. This, I want to do in my graduation project for the rubab.

introduction (continued): space for images



image / figure 1 The rubab (Naveed.yzi, 2014, commons.wikimedia.org/wiki/File:Centries_old_heritage_Rubab.JPG)



image / figure 2 VR glasses (Marco Verch, ccnull.de/foto/vr-brille-in-schwarz-weiss-auf-weissem-hintergrund/1103102)

→ space available for images / figures on next page

Personal Project Brief – IDE Master Graduation Project

Problem Definition

What problem do you want to solve in the context described in the introduction, and within the available time frame of 100 working days? (= Master Graduation Project of 30 EC). What opportunities do you see to create added value for the described stakeholders? Substantiate your choice. (max 200 words)

Main problem: Both the musical instrument's tangible (e.g., appearance) and intangible heritage (e.g., the ways of playing, the music, the context of playing, the playing sensation) are in danger of disappearing. By promoting the rubab outside of Afghanistan, here in the Netherlands, its heritage can be preserved, and Afghan-Dutch people can connect with their Afghan cultural identity.

+ Research gap: VR has the opportunity to preserve the tangible playing sensation of playing non-percussion instruments like the rubab. The current VR string instrument employments fall short in preserving the playing sensation (see literature review).

Assignment

This is the most important part of the project brief because it will give a clear direction of what you are heading for. Formulate an assignment to yourself regarding what you expect to deliver as result at the end of your project. (1 sentence) As you graduate as an industrial design engineer, your assignment will start with a verb (Design/Investigate/Validate/Create), and you may use the **green text format**:

Design an interactive technology experience to meaningfully convey the tangible and intangible heritage of the Afghan rubab in a way that contributes to the user's exploration of Afghan culture, for the Afghan diaspora and other people with an interest in Afghan culture.

Then explain your project approach to carrying out your graduation project and what research and design methods you plan to use to generate your design solution (max 150 words)

"Graduation-in-a-day" exercise; main method will be rapid prototyping. Wizard of Oz, interview with rubab players + observe, co-design with Afghan-Dutch youth, youtube observations, desk research literature research, prototype with Unreal Engine, autobiographical heritage analysis of my oboe. Interaction Vision, Emotion Design method by Studio Louter. For ideation I'll use excursion techniques from "Road Map f. creative problem solving". Harris profiles, 3D scanning + Methods from the book Culture Sensitive Design. The target group is still to be decided with Stichting SOLH. Will either be: "Afghan-Dutch youth interested in exploring Afghanistan's cultural heritage, and with it, a part of their own cultural identity", or Dutch people in public spaces (libraries).

Project planning and key moments

To make visible how you plan to spend your time, you must make a planning for the full project. You are advised to use a Gantt chart format to show the different phases of your project, deliverables you have in mind, meetings and in-between deadlines. Keep in mind that all activities should fit within the given run time of 100 working days. Your planning should include a **kick-off meeting, mid-term evaluation meeting, green light meeting and graduation ceremony**. Please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any (for instance because of holidays or parallel course activities).

Make sure to attach the full plan to this project brief. The four key moment dates must be filled in below

Kick off meeting 24 feb 2025

Mid-term evaluation 1 May 2025

Green light meeting 17 juli 2025

Graduation ceremony 21 aug 2025

In exceptional cases (part of) the Graduation Project may need to be scheduled part-time. Indicate here if such applies to your project

Part of project scheduled part-time	<input type="checkbox"/>
For how many project weeks	
Number of project days per week	

Comments:

Planning can be found in separate document

Motivation and personal ambitions

Explain why you wish to start this project, what competencies you want to prove or develop (e.g. competencies acquired in your MSc programme, electives, extra-curricular activities or other).

Optionally, describe whether you have some personal learning ambitions which you explicitly want to address in this project, on top of the learning objectives of the Graduation Project itself. You might think of e.g. acquiring in depth knowledge on a specific subject, broadening your competencies or experimenting with a specific tool or methodology. Personal learning ambitions are limited to a maximum number of five. (200 words max)

During my graduation project, I aim to learn more about the technological side of design for cultural heritage preservation. I want to learn how to prototype extended reality experiences (in Unreal Engine), and combine what I learned during my internship (storytelling, emotion design, exhibition narrative) with interactive technology, and design for (human-computer) interaction. Moreover, I want to practice culture sensitive design.