FACULDADE DE ENGENHARIA DA UNIVERSIDADE DO PORTO

Gate of Music: An Assistive Digital Web-Based Musical Instrument

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Abstract

This thesis presents the design and implementation of *Gate of Music*, a web-based assistive digital musical instrument that enables users to transform their smartphones into expressive musical interfaces. The system maps phone-based interactions, such as touch, motion, and orientation, into MIDI signals, which are received by a host computer and translated into musical output defined by a coordinator.

Gate of Music consists of two main components: a simple and colorful interface for players, designed around assigned interaction behaviors, and a control interface for the coordinator to manage mappings and structure musical performances in real time. The system was built to minimize setup complexity, eliminate the need for specialized hardware, and adapt to users with different cognitive and physical abilities.

The instrument was co-designed and evaluated in collaboration with inclusive music groups, including participants with mental and motor special needs, professional musicians, and educators. Real-world testing in workshops and live performances highlighted both the creative potential of the tool and its usability in inclusive contexts. Key limitations identified include touch latency and the need for more robust offline functionality.

Overall, the project contributes a flexible, sustainable, and socially grounded approach to accessible digital instrument design. It reinforces the value of participatory methodologies and proposes web technologies as a viable path toward inclusive musical expression.

Resumo

Esta dissertação apresenta o design e a implementação do *Gate of Music*, um instrumento musical digital assistivo baseado na web que permite aos utilizadores transformar os seus smartphones em interfaces musicais expressivas. O sistema mapeia interações feitas no telemóvel, como toque, movimento e orientação, em sinais MIDI, que são recebidos por um computador anfitrião e traduzidos em saída musical definida por um coordenador.

O *Gate of Music* é composto por dois componentes principais: uma interface simples e colorida para os músicos, desenhada com base nos comportamentos de interação atribuídos, e uma interface de controlo para o coordenador, que permite gerir os mapeamentos e estruturar performances musicais em tempo real. O sistema foi concebido para minimizar a complexidade da instalação, eliminar a necessidade de hardware especializado e adaptar-se a utilizadores com diferentes capacidades cognitivas e físicas.

O instrumento foi co-desenhado e avaliado em colaboração com grupos de música inclusiva, incluindo participantes com deficiências mentais e motoras, músicos profissionais e educadores. Os testes realizados em workshops e atuações ao vivo destacaram tanto o potencial criativo da ferramenta como a sua usabilidade em contextos inclusivos. As principais limitações identificadas incluem a latência no toque e a necessidade de uma funcionalidade offline mais robusta.

No geral, o projeto contribui com uma abordagem flexível, sustentável e socialmente fundamentada para o design de instrumentos digitais acessíveis. Reforça o valor das metodologias participativas e propõe as tecnologias web como um caminho viável para a expressão musical inclusiva.

UN Sustainable Development Goals

The United Nations Sustainable Development Goals (SDGs) provide a global framework to achieve a better and more sustainable future for all. They include 17 goals addressing the world's most pressing challenges, such as poverty, inequality, climate change, environmental degradation, peace, and justice.

The tool developed in this dissertation contributes to three of these goals: **SDG 4**, **SDG 10**, and **SDG 12**. These specific Sustainable Development Goals are addressed in the following ways:

SDG 4 Quality Education: By enabling interactive musical experiences using ubiquitous devices (e.g., smartphones), Gate of Music empowers educators and students to engage with music in inclusive and accessible ways. It promotes music education not only as a curricular subject but also as a participatory and expressive discipline.

SDG 10 Reduced Inequalities: The tool's design specifically targets inclusivity, offering low-barrier interfaces for users with physical or cognitive special needs. By removing the need for expensive hardware and embracing co-design methodologies, it fosters equal participation in creative musical contexts.

SDG 12 Responsible Consumption and Production: Gate of Music supports sustainable digital prototyping practices. As a free and open-source tool, it reduces the dependency on physical prototyping materials, such as sensors and custom-built devices, thus minimizing electronic waste and encouraging responsible experimentation.

SDG	Target	Contribution	Performance Indicators and Metrics
4	4.1	By leveraging Wi-Fi, students' smartphones, and an easy setup, Gate of Music transforms everyday devices into instruments for interactive classroom experiences, thereby enhancing music education quality and students' perception of learning.	Increase in the number of schools integrating the tool into classroom activities.
10	10.1	The widespread availability of smartphones and Wi-Fi facilitates participation in music-making across socioeconomic backgrounds, eliminating the need for costly equipment.	Number of inclusive projects adopting the tool.
	10.2	The simplicity-focused design reduces the skill threshold required to interact with the instrument, accommodating beginners and users with special needs. The option to assign tailored interfaces further increases adaptability.	Number of institutions incorporating the tool into Special Needs or inclusive programs.
12	12.1	Gate of Music, as a free open-source prototyping platform, enables musicians and instrument designers to test ideas without relying on physical components, thus reducing unnecessary purchases and minimizing electronic waste.	Reduction in the use of hardware components in prototyping musical instruments.

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This thesis has only been possible as a result of support from amazing humans and institutions, which I would like to personally thank:

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Vicente Lora

“Never lose the groove
in order to find a note.”

Victor L. Wooten

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List of Acronyms

GOM	Gate of Music
LaMs	Ligados às Máquinas
APCC	Associação de Paralisia Cerebral de Coimbra
CdM	Casa da Música
PEMS 2025	Porto Electronic Music Symposium 2025
DAW	Digital audio workstation

Chapter 1

Introduction

This thesis was developed within the scope of the Master's Degree in Informatics and Computing Engineering at the Faculty of Engineering of the University of Porto (FEUP). The project was carried out during a curricular internship at Casa da Música, Porto's main concert hall and cultural foundation. It originated from a proposal to explore accessible musical interfaces using web technologies, and was developed between September 2024 and June 2025 under the guidance of Prof. Gilberto Bernardes and Óscar Rodrigues. The work was informed by the needs of two inclusive music groups and culminated in the design, implementation, and testing of a new assistive digital musical instrument: Gate of Music.

This chapter introduces the context, motivation, and problem framing that guide the development of *Gate of Music*, an assistive web-based digital musical instrument designed to improve accessibility to music-making.

1.1 Context

"Casa da Música" (CdM) is a foundation and a concert hall based in the city of Porto. It hosts "Digitópia", a music platform that encourages collaboration, education, and social inclusion through digital tools. It has previously developed accessible and universal music instruments for people with specific needs, lowering their difficulty in entering this creative field. However, it continues to seek innovation and inventive changes to improve these instruments, focusing on increasing their accessibility, flexibility, and creative potential.

This project emerges from that context, building on past work while exploring the potential of new technologies in designing inclusive musical instruments.

1.2 Motivation

The motivation for this project comes from a need to make the world fairer by providing equal creative opportunity. Music is a discipline that has proved to go way beyond physical barriers, while bringing meaning to the lives of those who practice it.

Additionally, the widespread availability of smartphones and web technologies opens new perspectives in the development of accessible musical instruments. These tools allow for portable, scalable, and low-cost solutions that bypass the need for specialized hardware. At the same time, web-based tools have reached a level of maturity that allows for responsive, real-time interactions.

"Casa da Música" proposes exploring new universal interfaces as a means for musical expression that both lowers the skill floor while increasing the skill ceiling.

1.3 Problem

People with special needs often face significant barriers in accessing the traditional Western musical instruments canon, such as the piano or guitar. Challenges related to motor control, physical strength, or sensory impairments can make interaction with these instruments difficult or even impossible. As a result, there is a need for specialized interfaces that are both accessible and musically meaningful. Furthermore, it's difficult to design a solution that covers all the different contexts.

Despite notable progress in the field of Accessible Digital Musical Instruments (ADMIs), several limitations persist. Many existing tools involve technically complex setups requiring specialized hardware and software. They often lack flexibility, offering limited options for adapting interfaces to individual users. Furthermore, some tools prioritize therapeutic outcomes over creative or performative goals, which can limit the agency of the user as a musician. Finally, these instruments are frequently designed from a top-down perspective, with limited input from the actual users during the development process.

This project seeks to address these challenges by proposing a tool that prioritizes simplicity of setup (by avoiding external hardware), flexible interaction design tailored to each user, and the empowerment of users as active musicians rather than passive recipients of assistive technology.

1.4 Research Questions

The development of *Gate of Music* was guided by a set of research questions grounded in the challenges identified in the literature and observed in practice. These questions aimed to explore both the technical feasibility and the social impact of creating an accessible digital musical instrument based on web and mobile technologies.

- What is the current state of the art in accessible and digital musical instruments (ADMIs)?
- Can web-based mobile interfaces serve as viable musical instruments for people with special needs?
- Does simplifying the setup process improve usability and accessibility for users with special needs?
- Does co-design with target users result in more effective and meaningful musical tools?

1.5 Hypotheses

Based on the initial review of accessible digital musical instruments and early field observations, the following hypotheses were formulated to guide the design and evaluation of the proposed system:

- A web-based musical instrument running on smartphones can reduce barriers to participation by eliminating the need for complex hardware setups.
- Interfaces designed with simplicity and visual clarity (such as large buttons, motion-based controls) improve usability for users with motor or cognitive impairments.
- Prioritizing adaptability and modularity over rigid design increases the instrument's potential across a wide range of use cases, from education to performance.

1.6 Dissertation Structure

In addition to the introduction, this dissertation is organized into five main chapters, each addressing a key stage in the research and development process:

- **Chapter 2 - Literature Review and State of the Art**: Outlines the methodology for selecting relevant sources and presents a review of prior work in accessible digital musical instruments (ADMIs), web-based tools for musical interaction, and participatory design strategies.
- **Chapter 3 - Methodology**: Details the research approach, including co-design methods, development tools, participant involvement, and evaluation metrics.
- **Chapter 4 - Design and Architecture of the System**: Summarizes the main design, architecture and infrastructure choices behind the system.
- **Chapter 5 - Results and Discussion**: Presents the design and implementation process, field observations, and user feedback gathered during real-world testing. It also reflects critically on the outcomes concerning the initial research questions and hypotheses.
- **Chapter 6 - Conclusions and Future Work**: Summarizes the main contributions of the project, discusses its limitations, and proposes directions for future development and broader testing.

Chapter 2

Literature Review and State of the Art

This chapter surveys the key academic and practitioner literature informing the development of *Gate of Music*. It focuses on Accessible Digital Musical Instruments (ADMIs), inclusive and participatory design strategies, and the emerging potential of web-based musical tools. By critically examining these areas, this review highlights not only the technological landscape but also the design philosophies that underpin accessibility, expressiveness, and long-term usability in digital music-making.

2.1 Introduction

A literature review is essential to position this work within the broader context of research and practice. It ensures that the system proposed in this dissertation is grounded in established knowledge while also identifying gaps that justify new contributions. The development of *Gate of Music* is situated at the intersection of accessibility, musical interaction design, and web technologies. As such, this review draws from multiple disciplines to synthesize best practices and uncover underexplored opportunities for innovation.

2.2 Methodology for Literature Collection

2.2.1 Scoping Approach

Given the interdisciplinary nature of this work, a **scoping review** methodology was adopted. This approach is particularly suited to fields where innovation is rapidly evolving and knowledge is distributed across both academic and practitioner sources. In the domain of accessible music technology, impactful contributions often emerge from conference presentations, open-source communities, and informal media alongside peer-reviewed literature.

2.2.2 Sources and Search Strategy

Relevant literature was identified through a combination of formal and informal channels. Formal sources included journals and conferences such as NIME (New Interfaces for Musical Expression), ACM CHI, ICMC, and the Journal of New Music Research. Informal sources, such as GitHub, YouTube, and practitioner blogs, were also consulted, given their importance in shaping real-world practices and tools.

Keywords used in the search included: *"Accessible Digital Musical Instrument", "Assistive Technology in Music", "Web-Based Musical Instruments", "Inclusive Design in Music", "Participatory Design", "Music Interaction for Special Needs"*.

2.2.3 Inclusion and Exclusion Criteria

Publications were included if they addressed accessible instrument design, participatory methodologies in music technology, or web/mobile musical interfaces with relevance to inclusivity. Works focused solely on therapeutic or medical outcomes, without a creative or expressive component, were excluded, as the focus of this research is on musical empowerment rather than therapy.

2.3 State of the Art

2.3.1 Accessible Digital Musical Instruments (ADMIs)

Accessible Digital Musical Instruments (ADMIs) aim to empower individuals with special needs to engage in musical creation and performance. Frid (2019) [8] provides a comprehensive review of ADMIs, highlighting that most are hardware-based, relying on specialized sensors, tangible interfaces, or gaze tracking systems. These solutions often involve complex setup procedures and are seldom scalable across diverse user needs. It also highlights the limited focus on older adults and visually impaired users and the lack of a unified evaluation framework of the field. In addition, across studies, the design strategies varied widely and there's a lack of detailed description of the sounds produced and mapping of the instruments.

Förster and Schnell (2024) [6] propose a social-ecological design framework for ADMIs that emphasizes the importance of embedding instruments within the broader educational, social, and institutional contexts of special education. Their study demonstrates that technical success alone is insufficient if instruments do not meaningfully support pedagogical goals and inclusive group participation.

Building on these critiques, recent literature explores how disability studies can reframe design priorities in ADMI development.

Recent work by Duarte et al. [4] offers a detailed framework for analyzing ADMIs through the lens of medical, social, and cultural models of disability. Their study critiques the field's historic reliance on the medical model and introduces criteria to classify instruments based on user participation, inclusion philosophy, and impact. By applying this framework to eleven ADMIs for d/Deaf users, the authors highlight the importance of considering cultural and social dimensions in inclusive instrument design. Gate of Music aligns with this perspective by emphasizing user empowerment, participatory design, and diverse modes of interaction.

Taken together, these studies expose core limitations in current ADMIs:

- High reliance on physical hardware and cables.
- Design biases toward motor impairments, with limited cognitive inclusion.
- Therapeutic framing over creative or performative intent.
- Lack of scalability and long-term sustainability.

These insights shape the motivation for a lightweight, expressive, and browser-based instrument like *Gate of Music*.

2.3.2 The "Some for Many" Design Strategy

In response to the limitations of universal design in music technology, a new paradigm known as the "Some for Many" approach has emerged. Introduced by Förster and Schnell (2024) [7] in the context of the Harmonizing Abilities project, this strategy recognizes that attempting to design a single tool that serves all users equally often results in overly generic or compromised solutions.

Instead, "Some for Many" advocates for the development of multiple tailored instruments, each optimized for a subset of users with similar needs. This pluralistic approach improves usability, expressiveness, and adoption rates while still promoting inclusion. Importantly, it moves away from a one-size-fits-all ideal and toward a more ecosystemic view of accessible music-making.

A concrete application of participatory design in ADMI development is presented by Förster and Schnell (2024) [6], who co-designed digital musical instruments with children in a special education setting. Their findings highlight the importance of aligning technical design with pedagogical goals, emotional engagement, and the lived realities of school contexts. The process emphasized collaborative iteration and adaptability, underscoring how accessible instruments must fit within both social and institutional ecosystems. Similarly, Ward (2023) [15] documents a five-year participatory design process leading to the development of the MAMI Toolkit, a modular and sustainable framework for building customizable accessible musical instruments.

Gate of Music adopts this logic by offering a range of interaction modes, tapping, looping, motion, and orientation, each with distinct affordances. Rather than forcing users into a fixed model, the system allows facilitators and participants to select modes that suit individual abilities and preferences, reflecting the "Some for Many" ethos in both philosophy and implementation.

2.3.3 Web-Based and Mobile Musical Interfaces

While most ADMIs focus on hardware and native applications, recent advances in browser-based technologies have opened new possibilities for accessible instruments. The Web Audio API and Web MIDI API enable real-time audio synthesis and MIDI messaging directly within the browser, eliminating the need for external software or device drivers.

Despite these capabilities, accessible web-based instruments remain rare in the literature. While web-based collaborative music systems have shown potential for distributed music-making, research in this area has generally focused on technical implementation and musical outcomes rather than explicitly addressing accessibility or inclusion considerations.

This gap highlights a missed opportunity: web-based tools inherently lower barriers to participation by removing installation requirements, supporting cross-platform compatibility, and leveraging devices already owned by users. These advantages are especially relevant in institutional or community settings where technical support may be limited.

Recent developments also explore novel participatory methodologies. Aynsley et al. [2] introduced generative AI tools in speculative co-design workshops with disabled musicians, enabling rapid visual ideation of instrument concepts. Such methods expand the design toolkit for inclusive instruments and offer new pathways for engaging users early in the development process.

Gate of Music contributes directly to this underexplored area. It is designed to operate entirely within standard browsers on smartphones or tablets, enabling real-time, low-latency interaction without the need for specialized hardware. This web-based approach supports rapid deployment in workshops, classrooms, and inclusive performances, while remaining open-source and extensible for future development.

2.3.4 Limitations in Existing ADMIs

Across the surveyed literature, several recurring limitations are evident:

- **Setup Complexity**: Many ADMIs require complex installation procedures, hardware pairing, or calibration steps that act as barriers to participation.
- **Scalability Issues**: Instruments are often tailored to individual users or single contexts, limiting their reusability and transferability.
- **Underdeveloped Expressive Potential**: By focusing on functional access rather than musical nuance, some designs overlook the importance of expression, dynamics, and mastery.
- **Sustainability**: A large number of projects remain research prototypes, lacking the documentation, maintenance, or community support needed for long-term use. Lucas et al. (2020) [10] specifically examine this challenge, identifying factors that contribute to the abandonment of bespoke accessible music technology and proposing community-based approaches to achieve sustained use and long-term support.
- **Neglected Web-first Design**: Despite the power of modern web APIs, browser-based ADMIs are largely absent, leaving a significant innovation space unexplored.

These gaps reinforce the motivation behind *Gate of Music*, which was developed to address sustainability, accessibility, and expressive control through a browser-first, modular architecture. By emphasizing ease of use, open standards, and a participatory development process, the project seeks to offer a replicable model for future ADMIs.

Dimogerontakis et al.[3] present MusiCane, a digital instrument designed in collaboration with visually impaired users, inspired by the metaphor and form factor of a white cane. Their work emphasizes multisensory interaction and mutual play between sighted and blind participants, opening up new design spaces that remain underrepresented in traditional ADMI research.

A comparative overview of representative ADMI projects is presented in Table 2.1. It summarizes how key projects align with dimensions such as hardware dependency, web-based accessibility, participatory design, expressive potential, and long-term sustainability. This comparison helps contextualize *Gate of Music* as a web-first, participatory, and extensible instrument addressing critical gaps in the field.

2.3.5 Conclusion

This review has identified the main research trends and limitations in the field of accessible digital musical instruments. ADMIs have evolved significantly, yet challenges remain in balancing technical accessibility with creative empowerment and long-term viability.

Three guiding principles emerge from the literature:

- **Design with users, not just for them**, using participatory methods that transfer agency.
- **Support diversity over universality**, through modular systems and the "Some for Many" approach.
- **Prioritize sustainability**, by leveraging open technologies, avoiding hardware lock-in, and encouraging community stewardship.

The development of *Gate of Music* draws directly from these principles. It aims to contribute a practical, inclusive, and maintainable tool to the ecosystem of ADMIs, one that lowers the barriers to music-making for users with a wide range of needs, while remaining expressive, configurable, and ready for real-world use.

Table 2.1: Comparison of representative Accessible Digital Musical Instruments (ADMIs)

Project / Instrument	**Hardware**	**Web**	**Participatory**	**Expressive**	**Sustainable**
EyeHarp [14]	✓			✓	✓
MAMI Toolkit [15]	✓		✓	✓	✓
MusiCane [3]	✓		✓	✓	
Cyclops [12]	✓			✓	
Gate of Music (this work)		✓	✓	✓	✓

Chapter 3

Methodology

3.1 Research Approach

This project followed a user-centered and iterative design methodology, combining principles of Participatory Design (PD) and User-Centered Design (UCD). The development cycle included several prototyping stages, during which continuous feedback was collected from end users and domain experts. The emphasis was placed on co-creation with musicians with special needs, ensuring that design decisions were informed by their lived experiences, needs, and feedback.

The methodological approach involved:

- Field observations and contextual inquiry in music education and inclusive performance environments.
- Prototyping and testing of digital musical interfaces.
- Iterative refinement based on qualitative and informal quantitative data collected in real-world settings.

3.2 Participants

Three main groups participated in the research and testing process:

- **"Ligados às Máquinas"** - A music group composed of musicians with cerebral paralysis, operating under APCC ("Associação de Paralisia Cerebral de Coimbra").
- **"Somos Nós"** - A community of individuals with mental special needs engaged in music-making activities through Casa da Música's outreach programs.
- **Experts and Educators** - Staff members from Casa da Música (CdM), professional musicians, and attendees at the Porto Electronic Music Symposium (PEMS 2025).

Participants were engaged in different phases: observation, prototype testing, and feedback sessions. Participation was voluntary and informal, with informed verbal consent obtained in each case.

3.3 Development Tools

The system was developed using open and widely supported web technologies, to ensure cross-platform compatibility and ease of access:

- **Frontend:** HTML5, CSS3, JavaScript.
- **Backend communication:** Node.js[11], WebSockets for real-time interaction.
- **MIDI translation:** Custom node-based listener application translating web inputs into MIDI messages for use in Digital Audio Workstations (DAWs).

The backend server was deployed using `Node.js`[11] and hosted on `Render.com`[13], supporting persistent WebSocket communication between frontend clients and a listener desktop application.

A virtual MIDI interface (LoopMIDI) was used to route messages between the listener app and the Digital Audio Workstation (DAW), although this component was not part of the tool itself.

3.4 Data Collection

Data was collected through a combination of qualitative methods:

- **Field observations** during music sessions with "Ligados às Máquinas" and "Somos Nós", focusing on interaction challenges, user behavior, and contextual factors.
- **Semi-structured feedback sessions** during and after the public showcase at PEMS 2025, where users and musicians were asked to comment on usability, latency, and creative engagement.
- **Informal interviews** with educators, facilitators, and musicians on perceived value, accessibility, and integration into existing practices.

All observations were documented in the form of notes, photos (when permitted), and prototype usage logs.

3.5 Evaluation Metrics

The following evaluation criteria were used to assess the effectiveness and potential of *Gate of Music*:

- **Usability:** Ease of setup, interface clarity, intuitiveness of interaction.
- **Creative potential:** Expressiveness of controls, diversity of musical outcomes, participant enjoyment.

- **Technical stability:** Latency, signal responsiveness, and robustness during rehearsals and performances.
- **Adaptability:** Ability to configure behaviors per user and compatibility with diverse use cases and abilities.

Although no formal usability scales were applied due to the informal nature of participation, qualitative trends were triangulated to support insights and design decisions.

Chapter 4

System Design and Technical Architecture

This chapter presents the technical foundation of the *Gate of Music* system, detailing its requirements, architectural design, modular components, and the rationale behind key engineering decisions. This system was designed to be accessible, extensible, and easy to deploy across diverse usage contexts, including inclusive music education and live performance.

4.1 Requirements

4.1.1 Functional Requirements

The system was designed to fulfill the following functional requirements:

- Enable users to control and generate musical events via mobile devices.
- Support multiple modes of interaction (such as tapping, motion, orientation).
- Allow a coordinator to configure, assign, and monitor participant roles in real-time.
- Translate user interactions into MIDI signals compatible with DAWs.

4.1.2 Non-functional Requirements

The following non-functional requirements were identified:

- Low-latency interaction suitable for live performance.
- Cross-platform compatibility (Android and iOS).
- Minimal setup without installation for players (web-based, no apps or drivers required).
- Modular and extensible design for future behaviors or use cases.

4.2 Solution Design

The overall strategy prioritized modularity, flexibility, and simplicity. Web-based technologies were chosen to maximize accessibility and avoid installation barriers, while a coordinator-based model ensured centralized control over musical mappings and system state.

4.3 System Architecture

4.3.1 Overview

Gate of Music follows a distributed client-server architecture structured as a hub-and-spoke model, with the WebSocket server acting as a central hub and clients (players and listener) as spokes. The system comprises three key components:

1. **Player Interface (Client)** - A mobile web app that captures user interactions and provides real-time visual feedback.
2. **WebSocket Server** - A cloud-hosted hub that maintains connections, dispatches messages, and manages session state.
3. **MIDI Listener Application** - A local desktop application that receives messages from the server and converts them to MIDI signals sent to Digital Audio Workstations.

This architecture ensures modularity, low-latency performance, and centralized control. Figure 4.1 illustrates the message flow between these components.

4.3.2 Client Interfaces

Each player accesses a responsive web interface, served via HTTPS, and selects a unique ID. Based on the assigned role, the system activates one of the available behaviors:

- **Tapping** - Sends note-on/note-off MIDI messages. Captures touch or mouse down events and sends `type: "A", "H", "L"` messages to represent tap start, hold, and release. The interface can be seen in Figure D.2.
- **Looping** - Differentiates screen areas (top/bottom) to trigger `type: "P"` (play loop) or `"S"` (stop loop). The interface can be seen in Figure D.3.
- **Motion** - Reads device accelerometer data to calculate intensity and transmits acceleration vectors (`x, y, z`). The interface can be seen in Figure D.4.
- **Orientation** (1D/2D/3D) - Captures device orientation data (`alpha, beta, gamma`) with different degrees of freedom, mapped to visual cues and MIDI Control Change (CC) values. The interfaces can be seen in Figures D.5, D.6, and D.7, respectively.

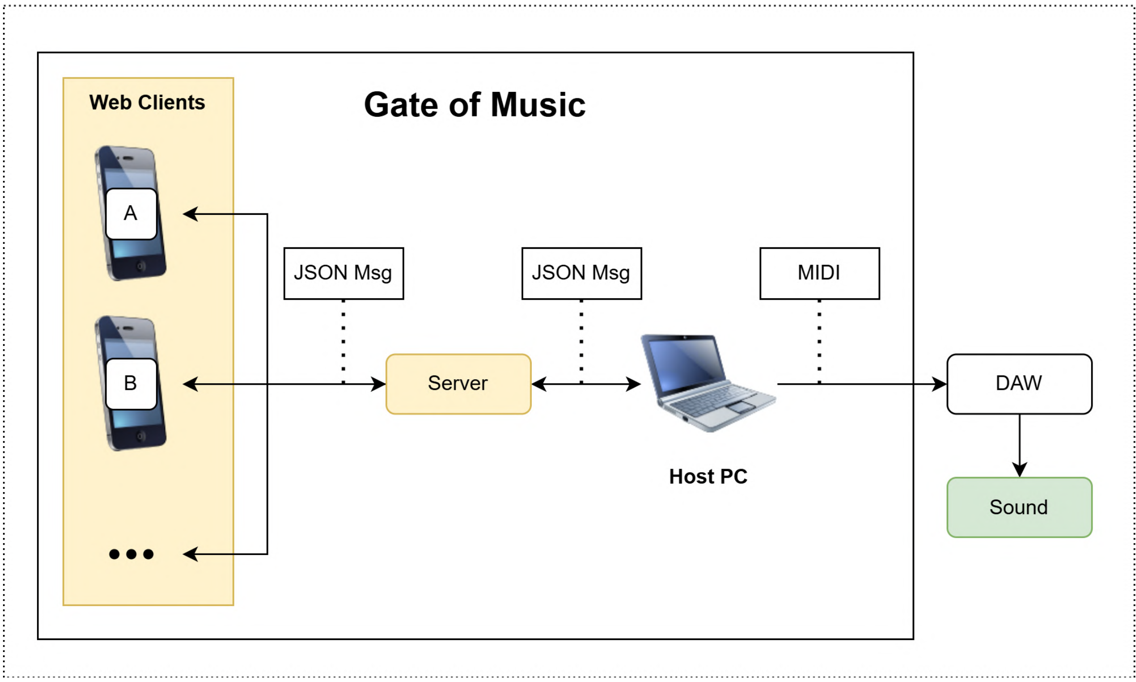

Figure 4.1: Gate of Music: High-level system architecture

Each interface includes visual feedback to reinforce user actions.

The web clients maintain persistent WebSocket connections with the server. The ping mechanism ensures that connections remain active.

4.3.3 Coordinator Interface

The *Gate of Music* system includes a dedicated web-based interface for the coordinator, allowing centralized configuration and real-time control of all player devices. This interface operates in two modes:

- **Setup Mode** - The coordinator assigns each player a unique ID (A–H), name, instrument, interaction mode, and MIDI mappings. This is stored in a dynamic `projectInfo` object. Modes can be one of six types: tapping, looping, motion, orientation-1D, orientation-2D, or orientation-3D. This interface can be seen in Figure E.1.

- **Control Mode:** During performance, the coordinator can mute/unmute players, solo their channels or individual orientation parameters (e.g., alpha or beta), and stop all playback. This level of control allows live shaping of the ensemble's behavior. This interface can be seen in Figure E.2.

Settings are stored in a JSON-based `projectInfo` object. The configuration is persisted using WebSocket messages sent to the server (for example `{action: "updateProject"}`), and downloaded or uploaded as JSON files, for reuse and sharing.

4.3.4 Project Configuration

Player behavior is determined by the`projectInfo` object stored on the server and sent to clients and the listener at runtime.

This example configuration shown in Listing 4.1 demonstrates a basic mapping of two users: one using tapping behavior and the other using motion, each with personalized settings.

Listing 4.1: Sample player configuration

```
{
  "players": {
    "A": {
      "name": "Alice",
      "instrument": "Drums",
      "mode": "tapping",
      "tappingNote": 36
    },
    "C": {
      "name": "Charlie",
      "mode": "motion",
      "motionCC": 11
    }
  }
}
```

This dynamic configuration supports different mappings, solo/mute states, and real-time updates.

4.3.5 MIDI Listener Application

Running locally, the listener app:

- Connects to the same WebSocket server as the clients.
- Receives and interprets player messages according to their assigned mode.
- Translates user actions into MIDI Note On/Off and Control Change messages using the `midi` Node.js library.
- Sends these messages to a virtual MIDI port, allowing real-time control of a DAW such as "Ableton Live"[1].

4.3.6 WebSocket Server

The central WebSocket server, implemented in `Node.js`, handles several responsibilities:

- Assigning modes to players based on preloaded `projectInfo`.
- Relaying player messages to all other connected clients (broadcast).
- Serving project metadata on request (such as player names, instrument assignments).
- Supporting updates to the project configuration in real time.

The server holds an in-memory representation of the current "project", including all participating players, their names, instruments, and mode-specific MIDI mappings.

4.4 Communication and Data Flow

All data exchanges are performed via WebSockets, ensuring bi-directional, low-latency communication between devices and the server.

When a user interacts (for example, tapping, motion), the message is sent to the server and broadcast to other clients (excluding the origin). This prevents feedback loops and ensures all interfaces remain synchronized.

4.4.1 Messaging Structure

Messages follow a lightweight JSON schema. Examples include:

- Player action: `{ "playerID": "A", "type": "A" }` (tap)
- Motion data: `{ "x": 0.2, "y": 0.3, "z": 0.1 }`
- Orientation: `{ "alpha": 120, "beta": 30, "gamma": 10 }`
- Configuration: `{ "action": "projectInfo", "project": {...} }`

4.4.2 Heartbeat and Connection Management

A *ping-pong* mechanism ensures stable connections:

- Clients periodically send: `{ "action": "ping" }`
- Server replies with: `{ "action": "pong" }`

This avoids timeouts and allows the coordinator to monitor active players.

4.5 Modular Components

Each system component is loosely coupled and can be independently modified or extended:

- **Behaviors** are modular JavaScript modules, allowing easy addition of new interaction types.
- **Coordinator logic** is abstracted into reusable templates.
- **MIDI Listener** interprets different message formats depending on the behavior and supports hot-swapping configurations.

4.6 Technical Choices and Rationale

4.6.1 Technology Stack

- **Frontend:** HTML5, CSS3, JavaScript
- **Backend:** Node.js with WebSocket support
- **Hosting:** Render.com [13] (EU deployment to reduce latency)
- **MIDI Output:** LoopMIDI [5] (virtual port), Node.js MIDI libraries

4.6.2 Design Decisions

- **Web-based deployment** ensures accessibility on any smartphone or computer with a browser.
- **JSON message structure** facilitates debugging, extensibility, and protocol transparency.
- **Decoupled listener app** allows integration with any DAW and simplifies performance configuration.
- **Open-source model** promotes community-driven evolution and long-term sustainability.

4.7 Summary

This chapter detailed the engineering foundations of *Gate of Music*. By emphasizing simplicity, modularity, and inclusivity, the architecture supports a wide range of use cases while remaining easy to extend. The next chapter presents the testing process and user evaluations, reflecting on how these technical choices played out in real-world contexts.

Chapter 5

Results and Discussion

This chapter presents the findings from initial observation, the resulting instrument implementation, its testing results, and further discussions.

5.1 Field Observations

5.1.1 Observing "Ligados às Máquinas"

I was invited to meet and observe how the musical group "Ligados às Máquinas" works. As stated before, they are a group composed of musicians in wheelchairs with cerebral paralysis, who have very limited motion capabilities. They can be seen rehearsing in Figure A.1.

Their coordinator and musician Paulo Jacob found a device called "Makey Makey" [9], seen in Figure A.2, that can convert conductive objects into interfaces that interact with the computer.

Through this device, he designed different palpable interfaces for each of his musicians based on each one's capabilities (images in appendix A). From aluminum surfaces placed on the wheelchairs' handles, metal tubes to grab onto, and a microphone stand with aluminum at the tip to trigger when in contact with the lips, each player can then play an audio sample. These samples are chosen in composition sessions where they all contribute with their opinions, and brings their favorite songs or decide how to use materials provided by external musicians.

Paulo found a solution, that through simplicity, gives power to the members to participate in the process of composition and performance of music. They all communicated with happiness when presenting the project to me.

After interviewing with the group I found that the biggest difficulties they had were: cracks in the audio due to latency; lack of visual output, during shows, leading to the public not knowing who plays what; how they can increase their creative potential, for example, triggering more than one sound using only 1 point of contact; and a long setup time each time they rehearse due to the amount of cables needed as seen in figure A.3.

Therefore, building a solution for LaMs should focus on a quicker and simpler setup, increased creative potential, and robust contact interfaces.

5.1.2 Observing "Somos Nós"

I also had the opportunity of witnessing the "Training Course for Musical Animators", hosted by Casa da Música, in action. In the current year's edition they were working and preparing a concert with an IPSS (Private Institution of Social Solidarity) for people with special mental needs, "Somos Nós".

At the session, different musical activities took place where I could observe how music can be used to increase the quality of life of the institution's members, and how professional animators interact with this specific public.

The key observation findings were:

- The tone of the session remained natural throughout. At no point did the organizers' words or approaches treat the group as special.
- The activities and instructions used many sensory stimuli, such as making wind sounds with their voice while dividing the groups.
- In a mirroring activity, where one person leads with movements and the rest imitate, the leaders were subtly and strategically chosen from participants without special needs. The focus was on the act of imitation, not on who was leading. This allowed for a smooth flow of the activity.
- When asked about balancing total freedom with premeditated experiences, the facilitators explained that, ideally, the activity is designed mostly around musical colors and melodies and less focused on rhythm, while leaving space for participants to explore intentions the designer may not have anticipated.

5.2 Gate of Music: Initial Prototype

Gate of Music (GoM) was based on my previous experience with both the "Ligados às Máquinas" and "Somos Nós" groups.

The goal of GoM was to allow controlling and triggering of MIDI signals in a computer, through an internet connection, and the personal smartphones of the performers. This would avoid the confusing logistics of setup and cable management. Furthermore, as seen in the field, the goal was to empower the coordinator with the tools to design and manage the experience for the players. Through control of the system the coordinator can remove complex setup tasks from the performers, who can solely focus on playing. Not removing the space for dialogue and their participation during the creation and composition phase. This architecture decouples the performer devices from the music production machine, allowing low-cost mobile interfaces to work as creative tools.

Through the ubiquitous smartphone, the system allows users to connect to the coordinator's computer, directly through a web application on the browser. When joining, each musician has their ID, which is reserved for specific device behaviors. In this context, I refer to behaviors as to what sensors and what roles their device is assigned to use and act as.

The whole interface design was based on simplicity, allowing users to either click on a screen, use the accelerometer of the mobile phone, or use the integrated gyroscope, sending that information directly through a server to the computer.

All the interactions have immediate visual feedback on screen, and all those visuals were designed as colorfully and simply as possible, based on the "Somos Nós" feedback. In addition, special care was taken to: use colorblind-friendly colors, with high contrast, and to develop a responsive fronted to work on different screens.

5.2.1 Users

The instrument considers two types of users: players (up to 8) and a coordinator.

5.2.1.1 Players

A player interacts directly with their mobile phone as an instrument that can either control continuous parameters, through rotating and shaking their phone; or triggering and stopping sounds and instant parameters through taps on the screen.

At the beginning of each session, they select an ID from the following: "A", "B", "C", "D", "E", "F", "G", "H". They can do this in a simple and colorful menu, as seen in the figure B.1.

IDs "A" to "F" are reserved for the tapping behavior, while "G" is reserved for motion, and "H" for orientation.

5.2.1.2 Coordinator

The coordinator is responsible for the setup and mapping of the signal into musical meaning. They host a "listener" app on their computer that receives messages as the players interact with their phones, translating them into MIDI messages. The creative potential falls completely into the hands of the coordinator through intentional musical choices on a DAW or digital instrument. As stated before, this process of musicality can be shared with more individuals but are dictated on the host's computer.

This initial version lacked an easy mapping tool for the coordinator, forcing him to understand the system and the technology behind the instrument, in order to edit MIDI values and behaviors.

5.2.2 Behaviors

Behaviors are defined as the assigned role of a player's device. Each one is described by the sensors it uses and the respective visual interface.

5.2.2.1 Tapping

The tapping behavior is quite simple; whenever the user taps the screen, a message with the respective player ID is sent to the computer. For example, for player "A", an "A" is sent and translated into the MIDI signal 36 when arriving. This behavior is the same for each player up to the ID "F", and the MIDI values are in the span of 36 up to 41, increasing as we go further into the alphabet IDs.

In this version, the system can only detect a single tap, not considering long taps, but only the instance when the finger initiates contact with the device's touchscreen.

The visual feedback is composed of colorful ripples that appear on the screen, at the last position the user tapped. As seen in the figure B.2. Their color is chosen randomly each time from a collection of selected colors.

5.2.2.2 Motion

The motion behavior receives the signal from the three accelerometers x, y, z integrated in the mobile device and normalizes them into a singular value, so that it can be used as an indication of how much the phone is moving. This value is then translated into a value from 0 to 127 inside the MIDI Continuous Controller 5. The value 0 means completely still, and 127 means the maximum amount of movement.

The output amount is visually translated into how bright the screen background color is, becoming the brightest with the highest amount of motion. An intermediate value visualization of motion can be seen in Figure B.3.

5.2.2.3 Orientation

The orientation behavior receives the gyroscope's values alpha (yaw), beta (pitch), and gamma (roll) and sends that information raw to the host computer. On arrival each value is translated into a value between 0 and 127 into MIDI continuous controllers 2, 3, and 4, respectively.

The orientation of the mobile phone is translated into the visual inclination of a red square centered on the screen, as seen in Figure B.4.

5.2.3 Workflow

A possibility of a workflow using this instrument could be:

- 1. Coordinator sets up a musical project on a DAW and maps each button manually to a musical interaction (for example, tapping on the screen triggers a sound)
- 2. Coordinator picks a role for each of his players
- 3. Each player enters the url of the web app and picks their ID
- 4. The page updates to the respective interface screen and behavior and the performance starts

5.3 Evaluation of First Prototype

5.3.1 GOM: Public Presentation at PEMS 2025

I was invited to attend and present the first prototype at the Porto Electronic Music Symposium 2025 (PEMS 2025) hosted by Casa da Música (CdM).

I attended the sessions: “Roundtable: Technology and Culture: Reinventing Roots?”, ”Workshop: João Carlos Pinto, “Break and Showcase” and a concert by Tiago Manuel Soares.

5.3.1.1 “Roundtable: Technology and Culture: Reinventing Roots?”

At the roundtable, several topics were covered surrounding the crossing of “traditional” and “computer-assisted” music.

This roundtable was composed of composer Ângela da Ponte, the duo “Musiscópio”: Diogo Novo Carvalho and Pedro João Rosário, guitarist and composer João Diogo Leitão and composer and host Óscar Rodrigues, as seen in C.1.

The artists reflected on how they apply computer assisted elements to their projects. Musiscópio, specifically, is a project that mixes elements of the traditional Portuguese instrument "cavaquinho" with computer textures.

This raises the idea that the system could be used in a mixed environment where the smartphone could be used to control sound qualities or trigger complementary sound to an analog instrument such as the "cavaquinho".

5.3.1.2 “Workshop: João Carlos Pinto”

This talk by João Carlos Pinto, one of CdM’s resident artist, was focused on his artistic process and showcasing one of his last projects “Player #1” and how it was made.

The project “Player #1” was based on the gaming aesthetics universe. Leading the artist to choose a PS5 controller as the interface for the musician, in addition to influencing the design choices in the sounds and lights, with a, in his own words, “glitchy” texture.

Its core technological structure was a PS5 controller mapped to sounds and lights triggered by its inputs.

He showed how the inputs were translated into MIDI signals in the DAW “Ableton Live” and a Digital Multiplex (DMX) control software.

This reinforced the idea that the GOM could also be used to map light signals. This has potential to solve, in the case of LaMs, the chance that the public looses track of who is playing what.

5.3.1.3 “Break and Showcase" - GOM

At the showcase session, participants were allowed to interact directly with the prototype of *Gate of Music*.

The prototype, while technically functional, lacked a clear musical experience to be tried on. The fact that it works as a white canvas that heavily depends on a premeditated composition phase of an experience, led the participants to feel like they understood the purpose, but couldn't really interact with the system, as noted by them.

The feedback emphasized the importance of designing for performance, creativity, or play, not just connectivity and control, and composition. Furthermore, the latency with touch triggers was noticeable enough to be a problem and affect performance; however, that was not perceptible in the motion controls, as expressed by the users. This could be due to the continuous flow of the movements that interact with the accelerometer and gyroscope.

Furthermore, in the casual environment of the break session, the digital characteristic of the instrument made it less appealing than the hardware devices also present at the conference, having fewer people asking about it.

Future showcases had to either be in less casual setting where user got enough time to try with the instrument potential, or deeply planned interactions that can spark curiosity on passerby.

5.3.1.4 “Break and Showcase" - "Scanner Voador"

At the showcase, I also got the opportunity to play and test the prototype “Scanner Voador” by David Amaral. This complex instrument translated the output of a scanner into sound, allowing players to draw into a sheet of paper or use abstract images to create predictable and unpredictable soundscapes.

This mechanism was supported by a visual graphics that allowed users to see the frequency spectrum of the sound generated and the visual input collected by the scanner. The setup can be seen in figure C.3

Experiencing it myself, the instrument wouldn't be very clear on how it works without the visual support. This example emphasized how important feedback is to feel like the interactions actually have an impact on the sound output.

5.3.2 Testing with Ligados às Máquinas

Further in the dissertation process I met, once again, with LaMs. This allowed me to further understand the efficacy of the instrument. *Gate of Music* proved to solve the setup problems they had, skipping the cable management steps; however, the latency was still relevant enough to affect performance, and a fear of networks failing, during performance, was expressed by Paulo Jacob. Cables, even if cluttered, transmit more confidence.

Furthermore, a concept of using the chair orientation of members as a way to influence parameters in audio effects was tested. This ideas was debunked as, after analysis, each motorized chair had different behaviors depending on the brand and model, some accelerate a lot than others, resulting in a need for further and deeper research on this specific kind of interaction with wheelchair users. A possibility would be to use machine learning tools to normalize the behavior of different wheelchairs, giving more control to the users.

5.4 Gate of Music: Final Prototype

After collecting feedback and observations of the previous prototype in action. Efforts were made to focus the development on musicality, instead of just the technology, of a new version of the prototype. This version should also provide more power to both the players and the coordinator.

5.4.1 System Implementation Summary

In this version, new behaviors were added: looping and three versions of orientation: Orientation 1D, Orientation 2D, and Orientation 3D. In the case of the orientation behaviors, the 1D, 2D, and 3D refer to the number of dimensions considered, in other words, how many gyroscope sensors should be collecting data. This provides more power to the coordinator and facilitates the setup of project as noise is reduced.

A new mechanism to detect when a player start tapping, holds and lets go of the screen, allows the instrument to also act on a new type of interaction: long taps, adding creative potential.

The player IDs are no longer hard-coded to certain behaviors, allowing the coordinator to define what each player does, making the system more flexible to specific situations.

Furthermore, now the coordinator has its own interface where they can setup the projects and control performances, and also set what MIDI channels each player influences, what behavior they should have. This dual-mode interface gives the coordinator more power and freedom, allowing them to assume more of a creative role similar to a conductor or composer, less technical.

One key improvement was the deployment of the server in a much closer location in Europe, which reduced the latency of the system. Now the input feedback latency is negligible.

The system architecture and implementation details of *Gate of Music*, including its modular components, communication protocols, and configuration mechanisms, are described in Chapter 4. The following sections focus on how this technical foundation performed during field testing and evaluation sessions.

5.5 Evaluation of Final Prototype

In order to further test the instrument, I got the chance to reunite with "Somos Nós" in two different sessions, and also asked some musicians on different levels to provide feedback on the instrument.

5.5.1 Testing with "Somos Nós"

5.5.1.1 First Day

When bringing the new version of GOM to "Somos Nós", precious information was collected that highlighted important weaknesses of the instrument in a live setting with special mental needs participants.

The lack of a well-configured experience took too much time, as the MIDI mapping wasn't fast enough, keeping the participants waiting. In this environment, boredom showed to have a severe impact on the participants' experience.

Furthermore, a group of characteristics of the system led to a constant need to support the participants in rejoining the session, wasting precious time and distracting them from the experience. These characteristics were: the phones kept locking on their own due to security settings, the system still didn't have the Ping mechanism to keep the connection of the web application to the server alive, frequently dying when inactive, and players unintentionally exiting the web browser.

On the other hand, the facilitators of the institution and the players stated that the visual interfaces were easy to use and provided useful feedback on user input.

Some recommendations were: to allow one button to trigger more than one sound, adding a global stop button, implementing haptic feedback so that blind users can also benefit from the instrument, and having QR codes printed on paper to facilitate the players joining.

5.5.1.2 Second Day

The next time GOM was tested with "Somos Nós", most of the recommendations and problems were fixed, opening for new problems to be seen.

I came with a printed QR code, implemented the Ping Mechanism and global stop button, and brought two experiences: a simpler one designed by Óscar Rodrigues and one more difficult, designed by me.

The first experience was a soundscape where:

- 4 players had the looping behavior assigned to different instruments. Each time they interacted with the start button, they would each trigger a random MIDI loop out of 4.
- 1 player had the tapping behavior, playing a raining texture while holding the finger on the screen and stopping when letting go.
- 2 players had the orientation 1D behavior, one controlling the delay level on the master channel, and one controlling the reverb amount also on the master channel
- 1 player had the motion behavior, increasing the chance of the instruments controlled by the other players to play random notes

This experience was well received, and the players showed curiosity and smiles while playing guided by the composer.

The second experience was a Drum and Bass composition to experiment with electronic music which is usually characterized by the usage of digital instruments. Here:

- 3 players had the looping behavior assigned to different instruments. Each time they interacted with the start button, they would each trigger violins, vocal samples they had recorded in the previous session and a common drum sample of the Drum and Bass genre: the "Amen Break".

- 5 players had the orientation 1D behavior, 1 controlling the low-pass filter on the master channel, and the other 4 controlling the volume of 4 different vocal synthesizers for them to act as maestro, playing their note louder the higher they pointed their hands.

This experience was conducted in a very short amount of time, as the first one had already taken a long time to be conducted. Due to the limited time, no practicing was done, which led to a bit of confusion from the participants in understanding the experience sequence, showing that complexity is a factor to take into account, showing that GOM can be practiced, a relevant characteristic of an instrument.

The mixture of the common drum and bass elements of the "Amen Break" sample and the low-pass filter was easy to hear in the overall output, and as the 2 assigned players interacted with them, it was possible to feel an obvious musical impact that could translate the intentions. This allowed the "Amen Break" to be richer as the low-pass filter set different levels of texture and energy to it, creating new sounds and variants.

One of the players playing a less obvious element showed visible boredom through yawns, while other elements were moving with excitement to certain changes to the sound.

In this testing session, the amount of help needed to reset the devices was due to players, once again, exiting the application, and during the transition between experiences. An implementation using a native mobile application instead of a web application could be a solution that provides more control over the devices, reducing the risk of these distractions from happening

Overall, both sessions with "Somos Nós" allowed me to understand key problems and strengths of the instrument. In addition, showed me the difficulty of designing a piece for it that is stimulating enough to the players, really depending on the talent and experience of the composer and coordinator.

5.5.2 Testing with a Higher Education Music Student

A higher education music student who teaches music to children and teens on his part-time, got excited about the instrument when testing it. He stated that it could be a great tool to teach harmony, as each student is assigned a note and they can trigger them together. Furthermore, it could be used to teach about effects and other specific music concepts, making the experience also more interactive.

He also argued that the naming of the orientation behaviors confused him, proposing that they be renamed to more abstract concepts, such as "Line" instead of orientation 1D, "Plane" instead of orientation 2D, and "Space" instead of orientation 3D.

Chapter 6

Conclusions and Future Work

6.1 Conclusions

This dissertation aimed to design, implement, and test *Gate of Music* (GoM), an accessible web-based digital musical instrument, capable of transforming smartphones into expressive tools for collaborative music-making. Developed through iterative prototyping and co-design with real users, including people with cognitive and motor special needs, educators, and musicians, the project explored how accessible technology can support both creativity and inclusion.

6.1.1 Addressing the Research Questions

The research questions posed at the beginning of this work have been systematically addressed:

What is the current state of the art in accessible and digital musical instruments (ADMIs)? The literature review revealed that most ADMIs are hardware-based, requiring specialized sensors and complex setups, with limited focus on web-based solutions and participatory design approaches.

Can web-based mobile interfaces serve as viable musical instruments for people with special needs? Yes, the development and testing of Gate of Music demonstrated that web-based mobile interfaces can effectively serve as musical instruments for people with special needs, providing real-time interaction and expressive control through touch, motion, and orientation inputs.

Does simplifying the setup process improve usability and accessibility for users with special needs? Yes, the elimination of hardware setup requirements and the use of readily available smartphones significantly improved accessibility and reduced barriers to participation, as evidenced in testing sessions with institutions like "Somos Nós" and "Ligados às Máquinas."

Does co-design with target users result in more effective and meaningful musical tools? Yes, the participatory design process involving users with special needs, educators, and musicians proved essential in creating contextually appropriate and meaningful musical experiences, highlighting features and interaction modes that would not have emerged from top-down design approaches.

6.1.2 Validation of Hypotheses

The hypotheses formulated at the outset of this research were largely validated through practical testing:

Hypothesis 1: A web-based musical instrument running on smartphones can reduce barriers to participation by eliminating the need for complex hardware setups. *Validated* - The system successfully demonstrated reduced setup complexity and increased accessibility in real-world testing scenarios.

Hypothesis 2: Interfaces designed with simplicity and visual clarity improve usability for users with motor or cognitive impairments. *Validated* - Large buttons, motion-based controls, and clear visual design proved effective for users with diverse abilities, though some limitations regarding touch latency were identified.

Hypothesis 3: Prioritizing adaptability and modularity over rigid design increases the instrument's potential across diverse use cases. *Validated* - The multiple interaction modes (tapping, motion, looping, orientation) and customizable mappings demonstrated versatility across educational and performance contexts.

6.1.3 Overall Contributions

Throughout the process, several goals were achieved. The system successfully removed the need for complex hardware setups, replacing them with mobile-friendly interfaces accessible via a web browser. Different interaction modes, such as tapping, motion, looping, and orientation (1D/2D/3D) were implemented and tested, offering a variety of input strategies that could be tailored to each participant's needs. The architecture, composed of a WebSocket server, a listener app, and mobile clients, allowed for real-time communication between players and a coordinator, who manages the musical mappings through a digital audio workstation.

In practical testing environments, including public showcases and music sessions with institutions like "Somos Nós" and "Ligados às Máquinas", GOM was shown to be both technically functional and musically meaningful. The results highlighted its potential as a flexible and low-barrier tool for inclusive music-making.

At the same time, several limitations emerged. Touch latency and unreliable network connections were mentioned as critical issues in live scenarios, particularly when comparing the system to wired solutions. In some sessions, a lack of preconfigured musical experiences and complex mappings caused frustration and loss of attention, especially in audiences with special needs. These challenges showed that the success of the instrument does not rely solely on its technical quality but also the quality of the experience design and the preparation of the coordinator.

Overall, GOM contributes to the field of accessible digital musical instruments by proposing a browser-based, open, and customizable tool that respects the diversity of musical backgrounds and abilities. It reinforces the idea that inclusivity in music technology must go beyond accessibility features, it must enable people to participate creatively and expressively on their own terms.

6.2 Future Work

6.2.1 Prototype Improvements

Several improvements could be considered to enhance the next iterations of the prototype. One suggestion is to move toward a native mobile application, which would provide better control over device sensors, support haptic feedback, and reduce issues such as screen auto-lock and accidental disconnection.

It would also be beneficial to allow players to combine multiple behaviors, for example, using both motion and tap in a single interface. Another idea is to develop an improved and more user-friendly version of the listener application, preferably packaged as a standalone tool, to make the setup easier for educators or performers without technical backgrounds.

Furthermore, reducing the reliance on internet connectivity by experimenting with local communication, such as Bluetooth or local Web Sockets, could increase confidence in live performance scenarios, especially in institutions where WIFI is unstable.

Finally, a more expressive interface design for the players could help reduce their dependence on the coordinator, offering them more autonomy and room for creativity during the performance.

6.2.2 Broader Testing

Future work should also explore how GOM performs in more diverse musical contexts. For instance, formal testing in schools could examine whether the instrument is helpful in music education for neuro-diverse and non-neuro-diverse students, or if it becomes distracting due to its digital nature.

GoM could also be tested in different types of performance setups, such as DJ environments, mixed ensemble performances, or experimental electronic music. Collaborations with composers, educators, and performers from different fields could help explore unexplored uses of the tool and develop a shared vocabulary around its creative potential.

In addition, building a small library of predefined musical experiences or templates could help new users get started quickly. This could be especially useful for music teachers or workshop leaders who want to focus on the music rather than the technical configuration.

In conclusion, *Gate of Music* is not just an instrument; it is a new proposal for how we think about accessibility, creativity, and musical expression in a digital world. The challenges ahead are real, but so are the possibilities for building more inclusive, participatory musical futures.

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Appendix A

"Ligados às Máquinas" Setup examples

Figure A.1: Ligados às Máquinas rehearsing

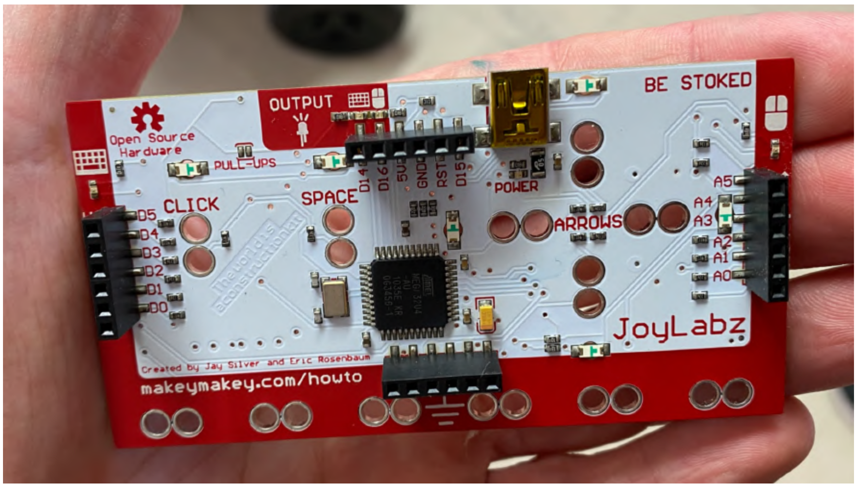

Figure A.2: "Makey Makey" by Joylabz [9]

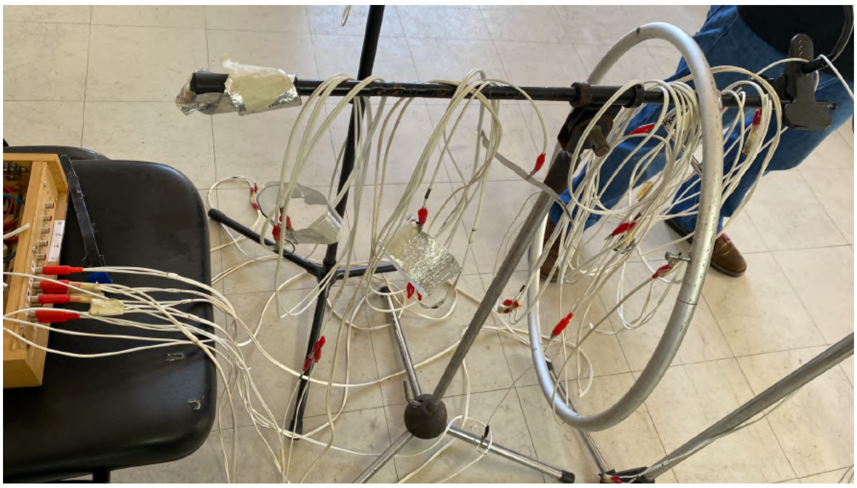

Figure A.3: LaMs' cable clutter

Figure A.4: Central Box that holds the system connected to each interface. The "Makey Makey" can be seen in the center under the cables

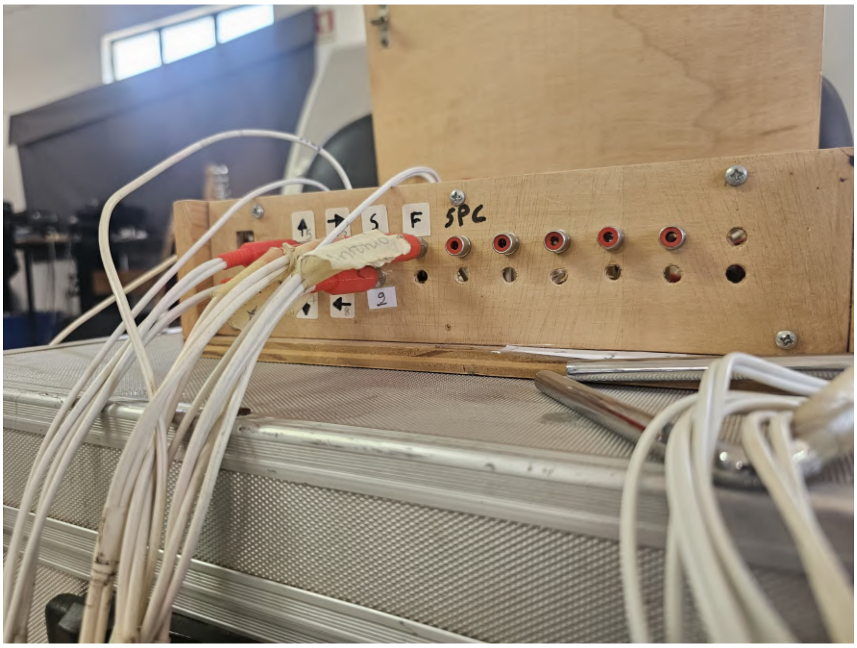

Figure A.5: Box inputs

Figure A.6: Circumference Interface, triggers when hand rests on circular metal bar

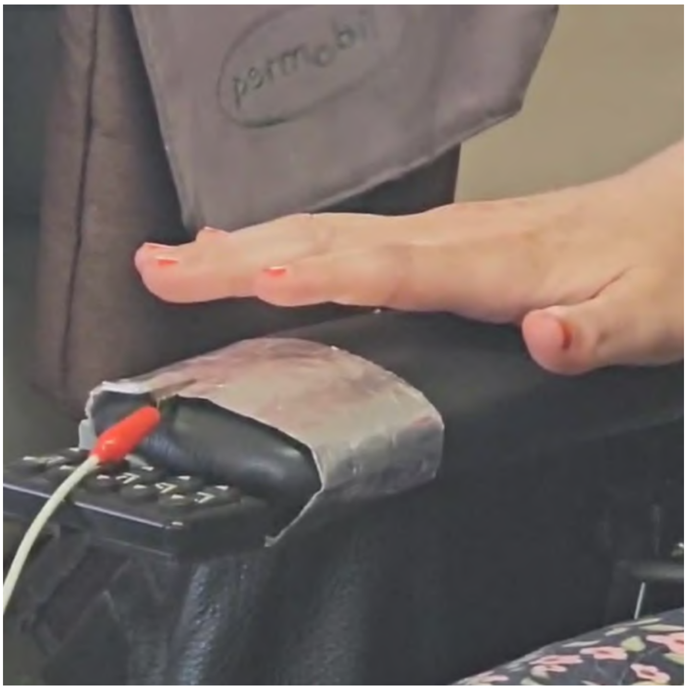

Figure A.7: Wheelchair Handle Interface, triggers when hand touches aluminum surface

Figure A.8: Keyboard Interface, can trigger different samples when certain keys are pressed with the help of a stick

Figure A.9: Keyboard Interface Top View

Figure A.10: Tube and Triangle Interface, Triggers when hand touches the tube

Figure A.11: Lips Interface, triggers when the lips enter in contact with the aluminum piece

Figure A.12: Lips Interface Top View

Appendix B

GOM: Player Interfaces (Initial)

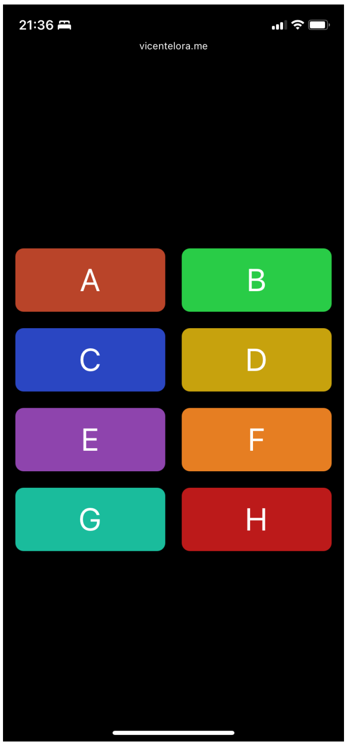

Figure B.1: GOM v.1: Player Menu

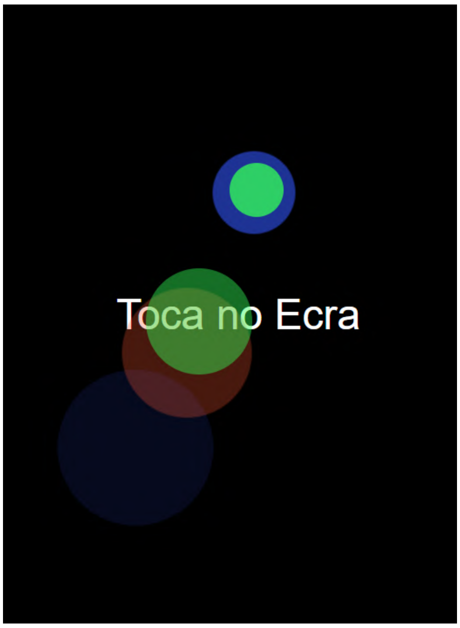

Figure B.2: GOM v.1: Tapping Interface

Figure B.3: GOM v.1: Motion Interface

Figure B.4: GOM v.1: Orientation Interface

Appendix C

PEMS2025 Sessions

Figure C.1: PEMS Roundtable

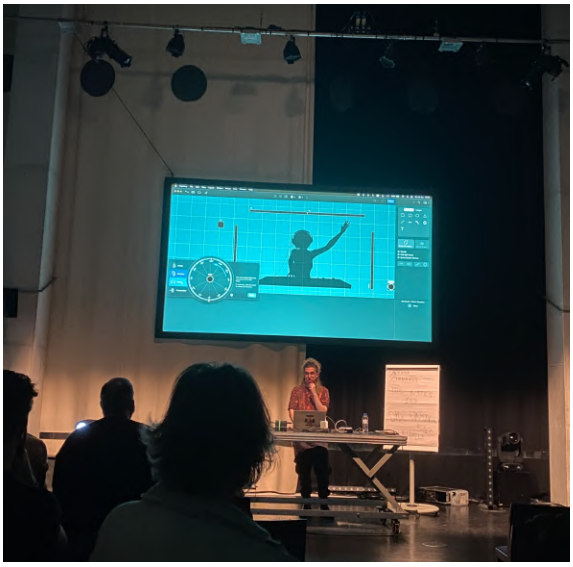

Figure C.2: João Carlos Pinto showcasing the light and audio setup

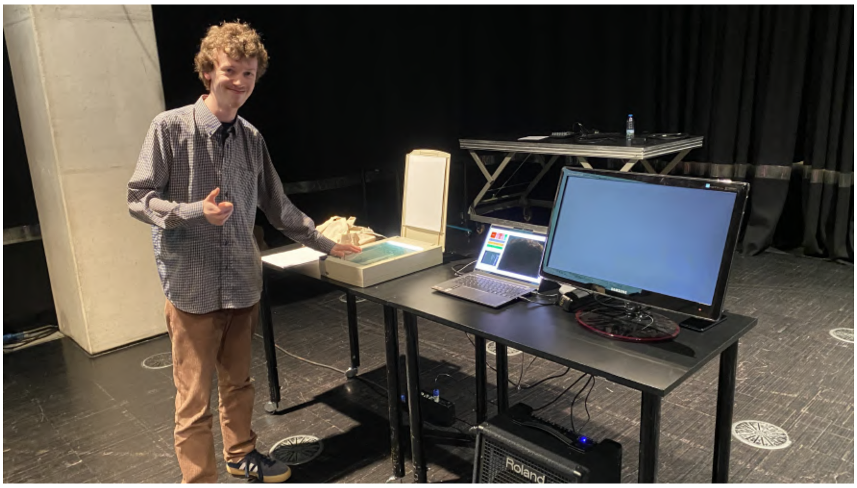

Figure C.3: "Scanner Voador" and its creator David Amaral

Appendix D

GOM: Player Interfaces (Final)

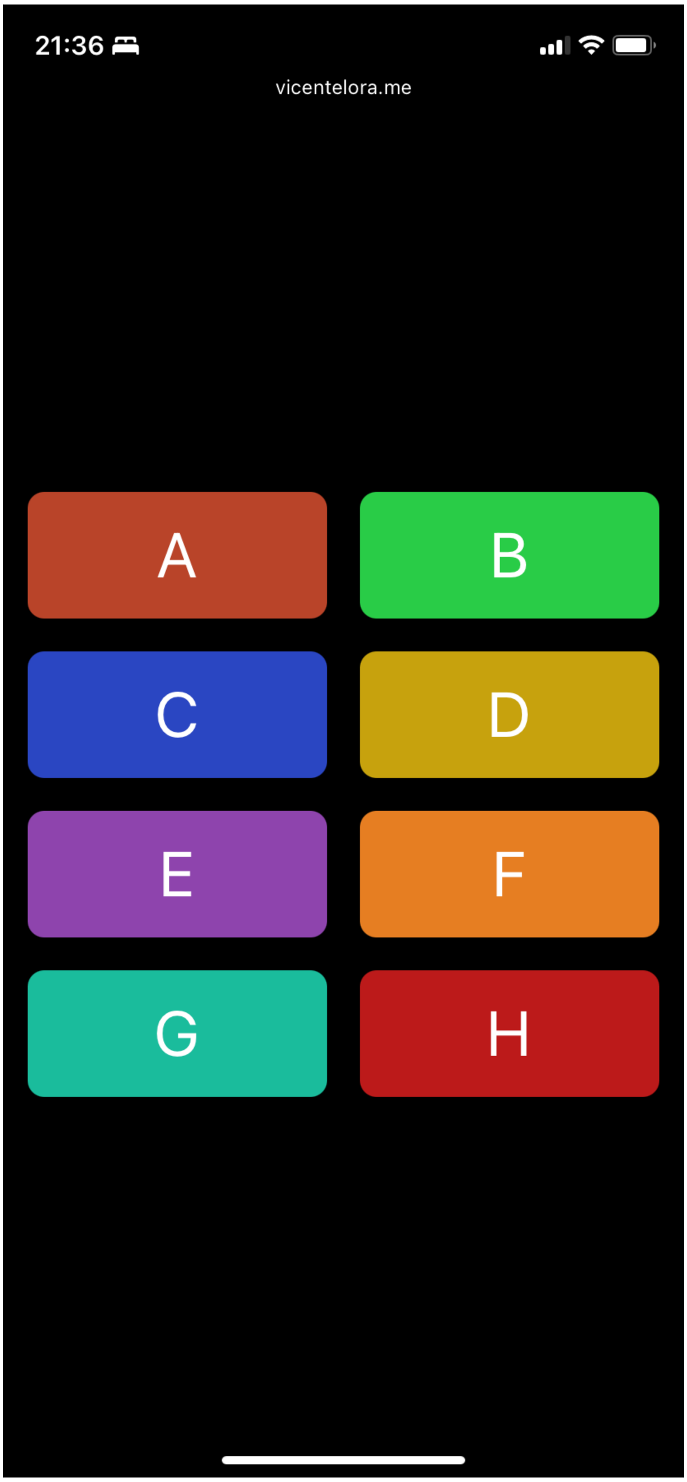

Figure D.1: GOM v.2: ID Selection Menu Interface

Figure D.2: GOM v.2: Tapping Interface

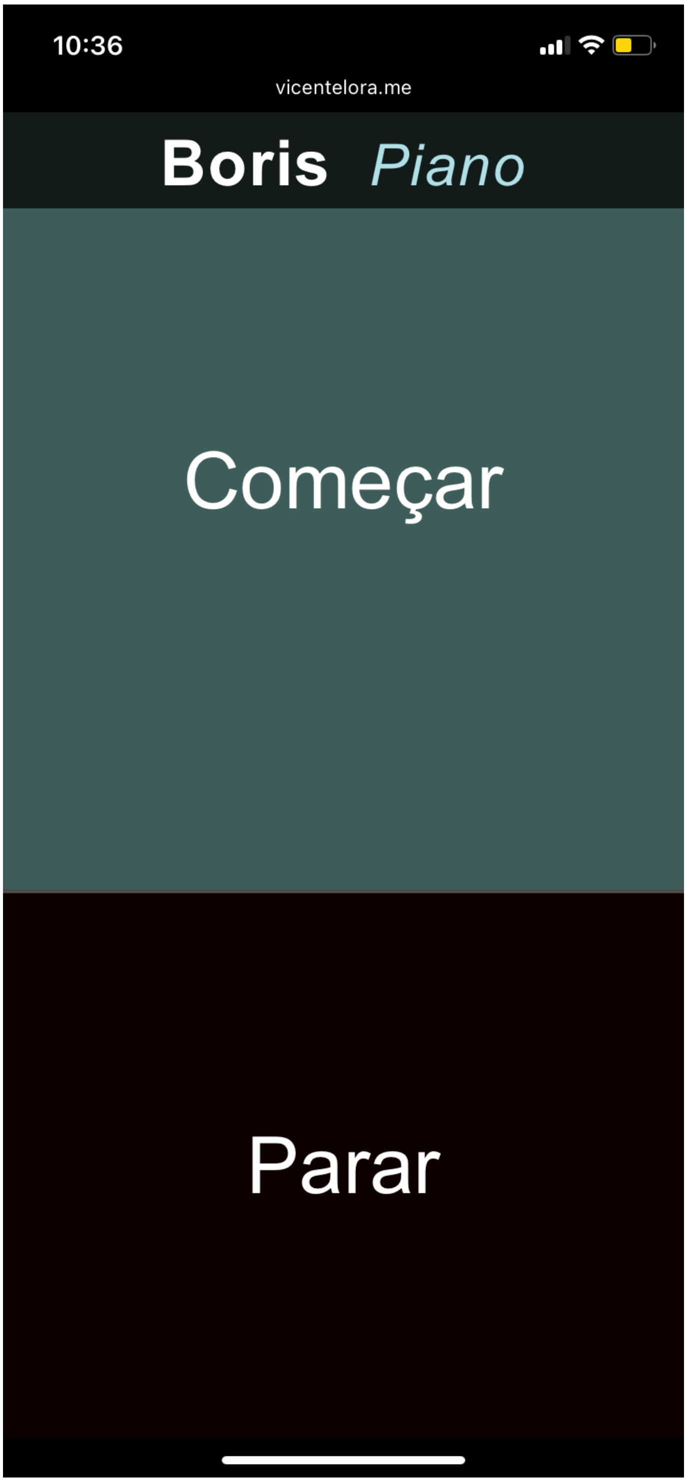

Figure D.3: GOM v.2: Looping Interface

Figure D.4: GOM v.2: Motion Interface

Figure D.5: GOM v.2: Orientation 1D Interface

Figure D.6: GOM v.2: Orientation 2D Interface

Figure D.7: GOM v.2: Orientation 3D Interface

Appendix E

GOM: Coordinator Setup and Control Interfaces

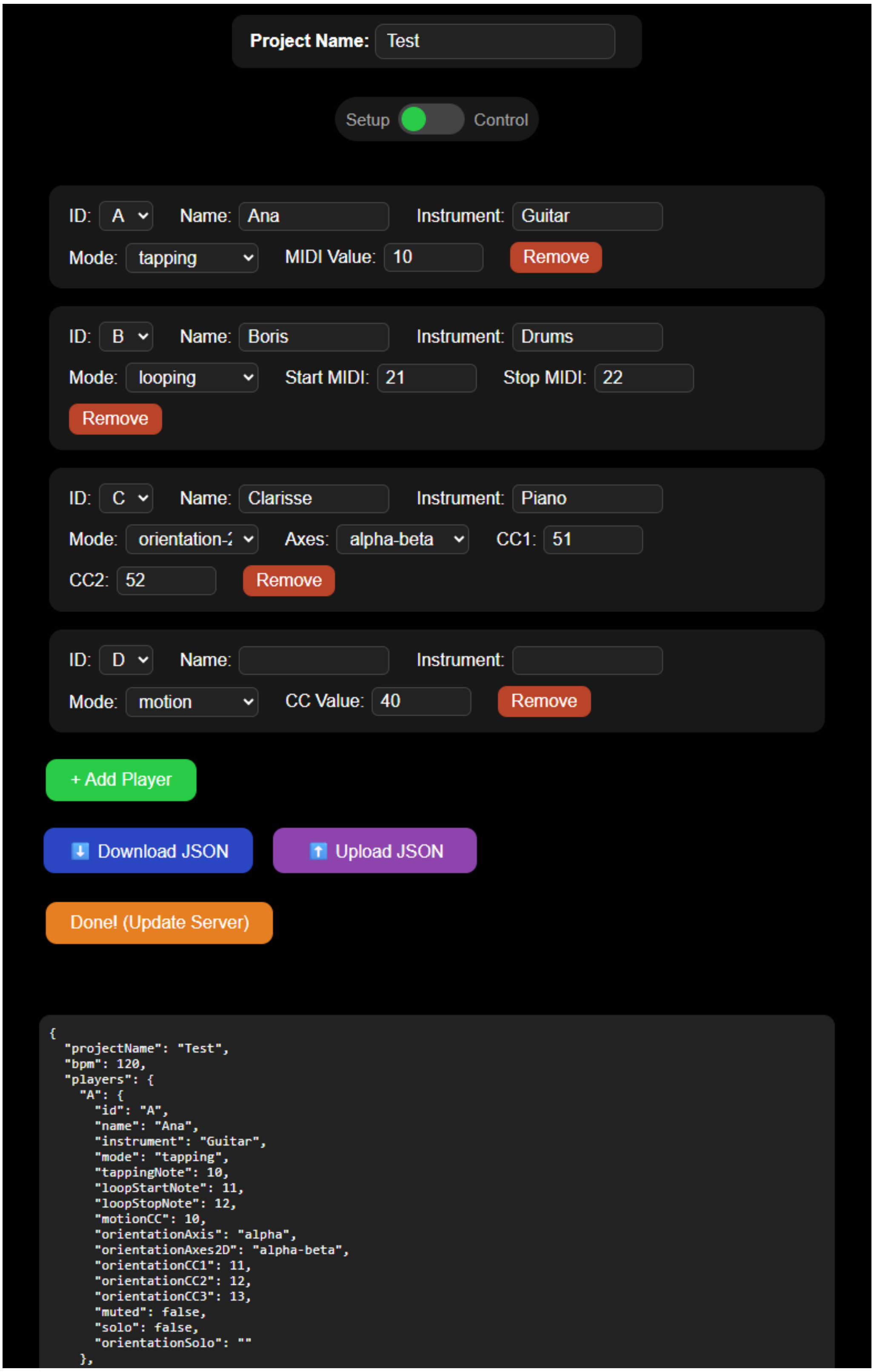

Figure E.1: GOM v.2: Coordinator Setup Interface

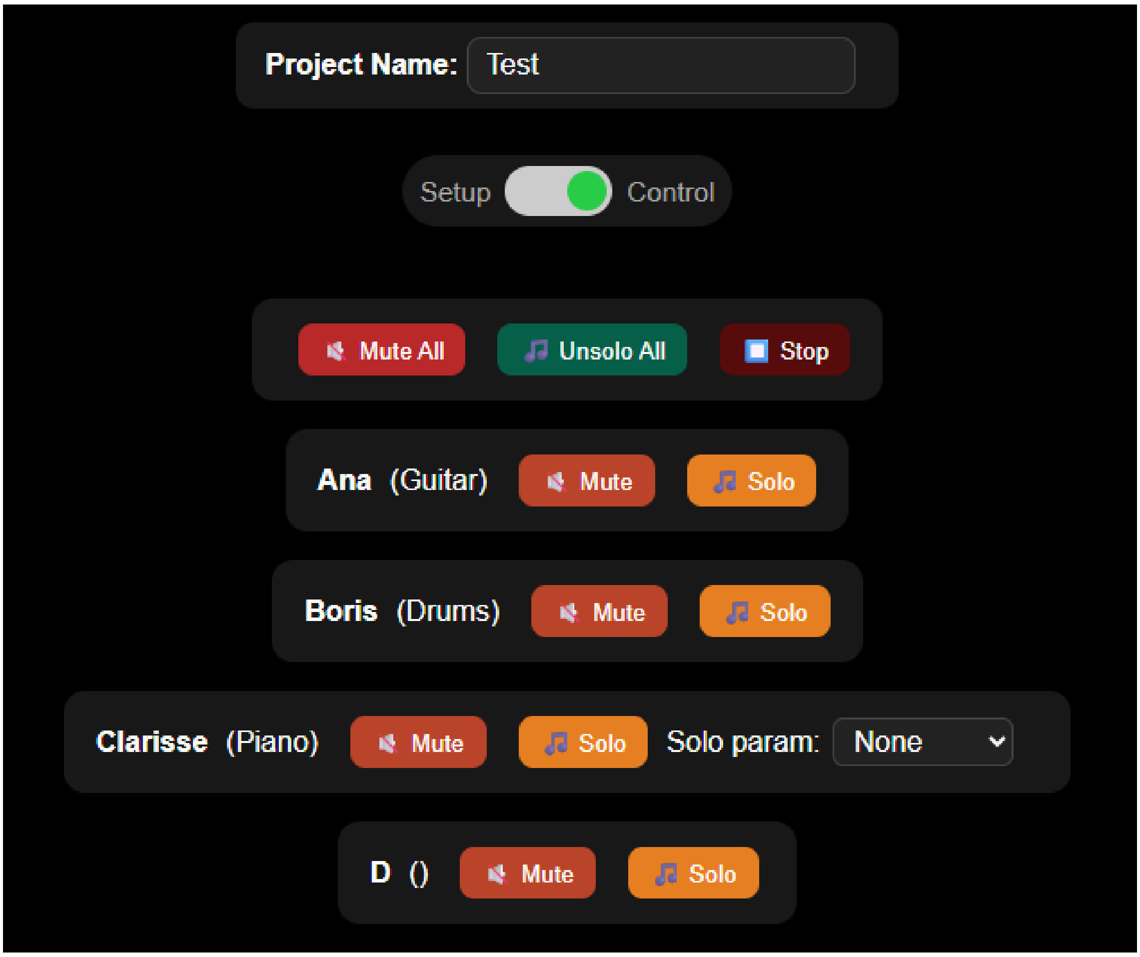

Figure E.2: GOM v.2: Coordinator Control Interface