

David Alexander Saran

Fungal Electronics: An exploration into the conductivity of mycelium

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School of Future Environments

Faculty of Design and Creative Technology

Auckland University of Technology

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ATTESTATION OF AUTHORSHIP

I hereby declare that this submission is my own work and that, to the best of my knowledge and belief, it contains no material previously published or written by another person (except where explicitly defined in the acknowledgements), nor material which to a substantial extent has been submitted for the award of any other degree or diploma of a university or other institution of higher learning

Abstract

This Thesis explores the emerging field of Fungal Electronics, a domain that remains vastly under-researched despite fungi outnumbering plant species in global biodiversity. Motivated by this imbalance, the research combines hands-on experimentation, cultivating and monitoring fungal growth, with digital translation methods that convert raw bioelectrical data into sonic and visual formats. Using a PicoLog data logger, voltage signals from various fungi are transformed into MIDI compositions, forming the basis for experimental musical tracks that are further refined in audio workstations. The project also incorporates speculative design through macro videography and environmental soundscapes, presenting fungi as both biological agents and creative collaborators. The final output includes a multi-sensory installation where fungal music synchronizes with color-coded visual overlays and ambient footage, offering audiences a new lens through which to interpret nonhuman intelligences. These processes and findings are critically examined and contextualized within a written exegesis, with the aim of contributing novel insights into the interface between biology, sound, and digital media.

Contents

F. Figures List

1. Introduction

2. Literature Review

- 2.1 Fungi in Microelectronics
- 2.2 Electrical Properties of Fungal Mycelium
- 2.3 Conductivity and Environmental Influences
- 2.4 Applications of Fungi in Microelectronics
- 2.5 Bio-Computing
- 2.6 Sensors and Actuators
- 2.7 Advancements in Mycelial Electronics
- 2.8 Hybridization and Enhanced Conductivity
- 2.9 Mycelium as Medium: Boddy and Ashby's Influence on Creative Bioelectronics
- 2.10 Fungi and Music: Translating Bioelectric Activity into Sound
- 2.11 Acoustic Ecology: Context and Foundations
- 2.12 Experimental Sound and 20th-Century Composition
- 2.13 Intersections with Creative Technology Practice
- 2.14 Conclusion

3. Methodology

- 3.1 Methodological Framing
- 3.2 Research Design
 - 3.2.1 Fungal Cultivation and Monitoring
 - 3.2.2 Signal Conversion and Sound Design
 - 3.2.3 Audio-Visual Composition
 - 3.2.4 Speculative Installation Design
- 3.3 Technologies and Tools
- 3.4 Methodological Alignment and Limitations

4. Experimental and Creative Work

- 4.1 Introduction
- 4.2 Experiment One: Initial Cultivation and Contamination
- 4.3 Experiment Two: Pre-fruiting Blocks and Data Recording
- 4.4 Results: Voltage Fluctuations and Environmental Correlations
- 4.5 Reflections on Experimental Work
 - 4.5.1 Growth and Contamination Reflections
 - 4.5.2 Electrical Activity Measurements
 - 4.5.3 Nocturnal Electrical Activity
 - 4.5.4 Response to External Stimuli
 - 4.5.5 Summary of Results
- 4.6 Challenges in Bioelectronic Fungal Media

4.6.1 Variability and Standardization

4.7 Interpreting Electrical Signals Through Music

4.8 Video Work

4.9 Installation: Speculative Design and Spatial Engagement

5. **Discussion**

6. **Conclusion**

7. **References**

8. **Appendices**

Figures

- Figure 1 Saran, D. 2025. Fungi Blocks in situ consolidating [Photograph].
- Figure 2 (A,B) Saran, D. 2025. Fungi Blocks with Picolog wires inserted [Photograph].
- Figure 3 (A,B) Saran, D. 2025. Fungi Blocks Fruiting [Photograph].
- Figure 4 (A-J) Saran, D. 2025. Picolog Tables Showing the changes in Voltages.
- Figure 5 Saran, D. 2025. A still from the video work.

1. Introduction

Fungi are emerging as powerful agents in both scientific and artistic research, offering alternative frameworks for thinking about communication, intelligence, and sustainability. Mycelial networks, the intricate, underground systems that support fungal life, are increasingly recognised not only for their ecological importance but also for their capacity to conduct electrical signals and respond to environmental stimuli. These dynamic properties position fungi at the intersection of biology and technology, inviting creative practitioners to explore their potential as living interfaces, responsive materials, and speculative collaborators.

This thesis investigates the role of fungi as both biological conductors and creative co-authors within an interdisciplinary context that combines bioelectronic experimentation, data sonification, and audiovisual installation design. Drawing on recent developments in fungal electronics and the growing field of bio-sonification, the research seeks to explore how mycelial voltage activity can be recorded, interpreted, and reimaged through artistic processes. By treating fungal signals not only as data but as expressive materials, the project bridges empirical science and speculative media art.

Grounded in a creative technologist's methodology, the work proceeds through cycles of cultivation, recording, and translation. Electrical activity was harvested from native New Zealand oyster mushrooms and pink oyster mushrooms using a PicoLog data logger. These millivolt signals, often triggered by hydration, temperature, or diurnal shifts, were mapped into musical compositions using Python scripts, MIDI generation, and modular synthesis techniques. Simultaneously, mushroom footage and data-driven visuals were combined into a dual-screen installation that invites viewers to engage with fungal rhythms both sonically and visually.

The research is informed by theories of human–nonhuman interconnectedness, post-anthropocentric design, and new materialism, situating fungi not merely as objects of study, but as participants in meaning-making processes. The speculative nature of the work foregrounds imaginative inquiry, asking not just how fungi signal, but what it might mean to interpret those signals artistically. Through this approach, the thesis contributes to the fields of media arts, environmental aesthetics, and experimental bioelectronics, offering new ways to think, listen, and collaborate with the living world.

Key research questions include:

How can the electrical activity of fungi be translated into meaningful musical or visual forms?

What new aesthetic or conceptual understandings emerge from engaging with fungal data through creative practice?

In what ways does speculative design allow for alternative forms of human–fungal interaction and communication?

In pursuing these questions, the thesis aims to extend the conversation around sustainability, interspecies communication, and the future of media art, rooted in a methodology that is at once scientific, speculative, and deeply collaborative.

2. Literature Review

This review explores the emerging field of fungal bioelectronics, with a particular focus on the electrical properties of fungi, their potential for integration into microelectronic systems, and speculative creative applications, such as music generation. Despite fungi constituting a vast and ecologically crucial kingdom, outnumbering plant species, they remain significantly underexplored in both biological and technological domains. This imbalance has driven a surge in interest in fungal properties, especially their capacity for electrical conductivity, environmental sensitivity, and structural adaptability.

Beyond empirical research, this review also positions fungi within broader theoretical frameworks that highlight the interconnectedness between human and more-than-human systems. Concepts such as the "wood wide web" and the distributed intelligence of fungal networks offer compelling parallels to emerging bioelectronic paradigms. Scholars such as Adamatzky (2020, 2021) have demonstrated that fungal electrical signalling can be harnessed for data processing and sensor development, while theorists of posthumanism and eco-technological design have speculated on fungi as mediators in rethinking agency, communication, and technological futures.

Recent publications, including Phillips et al. (2024), Dehshibi and Adamatzky (2021), and the review by Boddy and Ashby (2008), offer a foundation for understanding fungi as computationally active, sustainable substrates. At the same time, artistic projects using fungi to generate music, through voltage-to-MIDI translations, open new creative-technological avenues, merging speculative design with empirical inquiry. However, significant gaps remain in understanding how such sonic experiments relate to ecological behaviour, cultural interpretation, and the role of technology in mediating interspecies communication.

The review concludes by drawing together the technical, philosophical, and creative strands that inform this project's exploration into fungal music and its broader significance. These multiple perspectives support a research trajectory that is not only scientific but also speculative and experiential, asking not just what fungi do, but what they might mean in a more-than-human, electrically connected world.

2.1 Fungi in Microelectronics

Fungi have emerged as promising candidates in the field of bioelectronics and microelectronics due to their unique biological properties. Mycelium, the vegetative part of a fungus, is characterized by its biocompatibility, sustainability, and structural adaptability, offering alternatives to traditional electronic materials (Danninger et al., 2022). These biological networks not only grow on renewable substrates but also possess the ability to form complex, interconnected systems, making them suitable for hybrid electronic platforms.

The use of fungi in electronics is supported by growing evidence of their electrical activity and responsiveness to environmental stimuli. Unlike conventional materials, fungal mycelium exhibits

dynamic behaviour, adapting its electrical properties in response to mechanical, thermal, and chemical changes (Adamatzky, 2018). These characteristics suggest that fungi are not merely passive materials but active participants in signal processing and sensory applications.

Interest in fungal electronics has increased due to the broader context of sustainable technology development. As the demand for environmentally responsible materials intensifies, mycelium presents a scalable and biodegradable alternative that aligns with circular economy principles (Vasquez & Vega, 2019). In addition, its potential for integration into soft robotics, wearable sensors, and adaptive computing systems has positioned fungi as a transformative element in the next generation of electronic design (Phillips et al., 2023).

The interdisciplinary nature of this field draws from biology, materials science, and electronics, positioning fungal microelectronics at the frontier of speculative design and applied research. As Boddy and Ashby (2008) emphasized, the intricate behaviour of fungal networks, particularly their decentralized coordination and responsiveness, opens new directions for exploring distributed intelligence and biological computation.

2.2 Electrical Properties of Fungal Mycelium

Action Potentials and Signal Propagation

The electrical activity of fungal mycelium, particularly its action potential-like spikes, has drawn comparisons to neural signalling in animal systems. This activity enables fungi to transmit electrical signals through their networks, suggesting potential for information processing and communication. Olsson and Hansson (1995) first identified these spikes and demonstrated their sensitivity to environmental conditions such as mechanical stimulation and temperature fluctuations. Their findings established a foundation for fungi as dynamic biological conductors. This concept is central to my own project, which treats fungi not merely as passive subjects but as active agents in a creative, bio-electrical system that can be sonified and visualised.

Adamatzky (2018) explored these electrical spikes in *Pleurotus djamor*, revealing that fungal electrical activity is modulated by external stimuli such as changes in humidity and nutrient availability. This research emphasized the adaptability of fungal networks, which can serve as real-time sensors in electronic systems. Further studies by Gandia and Adamatzky (2022) showed species-specific variations in electrical activity, opening avenues for tailoring fungi to specific bioelectronic applications. In my research, I engage with these variations creatively by mapping them onto musical parameters such as pitch and harmony, generating audio-visual interpretations of species-specific responses.

The complexity of fungal electrical activity has been further analysed by Dehshibi and Adamatzky (2021), who applied computational modelling to decode the information embedded in fungal spikes. Their findings suggest that fungal mycelium could function as a natural computational medium capable of processing data in a decentralized and energy-efficient manner. This understanding informs my approach to treating fungal electrical signals as not only data but as expressive media, capable of being translated into speculative musical structures.

In the context of this research project, these insights form a conceptual and practical basis for exploring fungi as conductors not only of electricity but also of meaning. By capturing and translating their bioelectrical rhythms into MIDI data, this work interprets fungal communication through sound, amplifying their hidden languages in a format perceptible to humans. This creative interpretation serves as a bridge between scientific investigation and experiential design, aligning my work with interdisciplinary frameworks in bio-digital art.

2.3 Conductivity and Environmental Influences

The conductivity of fungal mycelium is influenced by both structural properties and environmental conditions. Phillips et al. (2023) demonstrated that increased moisture levels significantly enhance the conductivity of fungal networks, while Mayne et al. (2023) identified branching density and substrate composition as critical factors affecting signal propagation. These findings underscore the capacity of fungi to behave as self-regulating materials in dynamically shifting environments. Importantly, this inherent sensitivity and adaptability is central to my own research, which involves converting recorded voltage fluctuations in fungi into audio-visual outputs.

Importantly, this inherent sensitivity and adaptability is central to my own research, which involves converting recorded voltage fluctuations in fungi into audio-visual outputs. The ability of mycelium to respond to changes in its environment, such as shifts in humidity, temperature, or chemical composition, forms the basis of its expressive potential in interactive systems. For example, Adamatzky and Gandia (2021) found that electrical activity in *Ganoderma resinaceum* can be modulated by exposure to specific compounds, reinforcing the notion of fungal systems as biosensors. In my project, this responsiveness is creatively interpreted: the microvolt-level data from mycelial substrates is translated into MIDI signals, allowing the fungi's changing electrical states to drive a musical or visual experience. By harnessing these modulated voltage signals and translating them into MIDI for musical expression, my work explores how fungal responsiveness can be interpreted not just as data, but as an emergent artistic language in speculative bio-digital interfaces. This approach positions the mycelium not simply as a material with conductive potential, but as a dynamic interface between biological reactivity and digital creativity.

2.4 Applications of Fungi in Microelectronics

Sustainable Electronics

Fungi's renewability and biodegradability have spurred growing interest in their use as sustainable materials in microelectronics. Mycelium is a low-cost, scalable material that can be cultivated on agricultural byproducts, thus reducing reliance on traditional, resource-intensive substrates (Danninger et al., 2022). For example, the MycelioTronics platform developed by Danninger et al. demonstrated applications of fungal mycelium in energy storage devices, wearable electronics, and flexible circuits, offering functional alternatives that contribute to reducing e-waste and advancing sustainable design. Similarly, Vasquez and Vega (2019) explored the integration of mycelium into

DIY electronics, promoting low-cost and decentralized device fabrication. Weiler et al. (2019) further highlighted the versatility of mycelium in bio-fabrication, showcasing its potential for scalable, eco-conscious production.

This emphasis on sustainable, living substrates directly informs my own project, which aims to reimagine electronic expression through bio-derived materials. By using mycelium as both a biological sensor and data source for generating sound, my research investigates how fungal systems can function as not only sustainable platforms, but also as agents of creative output. The use of fungal-generated voltage data, rather than traditional sensors, underscores a shift toward eco-integrated bioelectronics, systems that not only reduce waste but are actively shaped by the living organism itself. In this way, my project aligns with and extends the sustainability-focused applications of fungal electronics into speculative artistic domains.

2.5 Bio-Computing

Fungal mycelium's ability to process and transmit electrical signals has positioned it as a viable medium for bio-computing. Adamatzky et al. (2020) demonstrated that fungal colonies could emulate Boolean logic gates, including AND, OR, and NOT operations. These gates form the building blocks of traditional computing systems, suggesting that fungal networks could replace or augment silicon-based technologies.

Beasley et al. (2021) extended this concept by creating adaptive fungal circuits capable of self-repair and environmental responsiveness. Roberts and Adamatzky (2023) integrated fungal logic gates into computational systems, highlighting their potential for decentralized decision-making and low-energy operations. Such systems could be particularly valuable in scenarios where traditional electronic devices face challenges, such as extreme environments or resource-constrained settings.

While my project does not simulate logic gates, it intersects with bio-computing in its speculative framing of mycelium as a signal processor, capable of translating environmental input into creative digital output. Rather than executing formal logic, my fungal substrates produce complex, non-linear electrical responses that are creatively interpreted as MIDI data. This reframing of bio-computing opens space for new applications of fungal systems, not only for utilitarian computation but also for generative artistic processes grounded in biological rhythms.

2.6 Sensors and Actuators

The sensitivity of fungal mycelium to environmental changes makes it an ideal material for sensors and actuators in microelectronics. Dehshibi and Adamatzky (2021) demonstrated that fungal electrical activity could detect variations in temperature, chemical composition, and mechanical stress. These properties open possibilities for ecological monitoring, medical diagnostics, and industrial applications.

In robotics, Gandia and Adamatzky (2024) proposed the use of fungal skins for adaptive systems. These skins, derived from mycelium, offer flexibility and sustainability while providing dynamic responsiveness to external stimuli. Mishra et al. (2024) explored fungal mycelium in sensorimotor

systems, demonstrating its potential for mediating robotic control through electrophysiological measurements. This work underscores the potential for integrating fungi into biohybrid robotic systems, which could revolutionize how robots interact with their environments.

In a parallel but more speculative trajectory, my work adopts this sensing function of mycelium not for robotics or diagnostics, but for creative expression. The data captured from the fungal networks' real-time voltage fluctuations are used to drive a multimedia experience, an audiovisual composition shaped by biological activity. This approach treats fungal sensors as narrative and aesthetic agents, enabling a non-verbal, cross-species form of expression through music and visuals. By exploring fungi's potential as real-time signal generators for creative output, my work extends sensor-based research into the domain of experiential, artistic research methodologies.

2.7 Advancements in Mycelial Electronics

Signal Transmission and Integration

Understanding how fungal networks propagate electrical signals is critical for integrating them into electronic systems. Mayne et al. (2023) investigated the pathways of signal transmission within fungal networks, emphasizing structural features such as branching density and network connectivity as critical factors. Their findings suggest that optimizing fungal geometries could enhance their conductivity and reliability in electronic applications.

Phillips et al. (2024) explored hybrid systems that integrate fungal mycelium with synthetic components. Their research demonstrated that mycelium composites can reliably transfer electrical signals, enabling applications in sensing, actuation, and communication. These biohybrid systems offer a unique combination of adaptability and precision, bridging the gap between biological and synthetic technologies.

These insights are highly relevant to my research, which translates fungal electrical activity into data streams for MIDI composition. Although my project does not aim to develop fully integrated biohybrid circuits, it is based on the assumption that fungal signal transmission is stable and interpretable enough to support sound generation. In this way, I am evaluating the communicative potential of fungal signals in a creative rather than utilitarian framework, treating fungal output as both data and aesthetic form. This supports an emerging model of integration, where fungi are not merely embedded into technical systems but are collaborators in speculative media art.

2.8 Hybridization and Enhanced Conductivity

To overcome the inherent limitations of fungal mycelium, such as its relatively low conductivity, researchers have explored hybridization techniques. Danninger et al. (2022) proposed integrating conductive polymers or nanoparticles into fungal networks to create bio-composites with enhanced electrical properties. Geara et al. (2023) demonstrated the use of mycelium as a "living electrical conductor" in biohybrid systems, where it bridges biological and electronic components seamlessly.

Elsacker et al. (2021) focused on scaling these innovations for industrial applications, emphasizing advanced fabrication techniques such as 3D printing and robotic assembly. These methods enable the

production of robust, scalable systems that leverage the ecological benefits of fungi while meeting the demands of modern electronics.

While my project does not incorporate hybridization techniques or nanomaterials, it operates within the same conceptual framework, seeking to bridge biological and digital systems through fungal electrical activity. Rather than enhancing conductivity through external means, I have worked within the natural voltage ranges generated by living fungi. This constraint has shaped my creative methodology, requiring sensitivity to the nuanced patterns within raw fungal data and experimentation with software translation methods such as MIDI conversion and sound synthesis. In this sense, my work complements hybridization research by demonstrating that even without enhancement, fungal signals can produce meaningful output when interpreted through creative-technological processes.

2.9 Mycelium as Medium: Boddy and Ashby's Influence on Creative Bioelectronics

In *Fungi* by Lynne Boddy and Ali Ashby (2008), the authors delve deeply into the fascinating world of fungal biology, offering valuable insights into the interconnected nature of fungal networks and their role in ecological systems. Mycelium, the filamentous and often hidden component of fungi, is presented as a dynamic and highly adaptive structure capable of sensing, processing, and responding to environmental stimuli. The authors discuss how mycelial networks detect changes in their surroundings, such as variations in nutrient availability, the presence of physical barriers, or microbial competitors, and respond through precise adjustments in growth and resource distribution. Central to these capabilities is the transport of chemical and electrical signals within the network. These electrical impulses, often compared to neural activity in animals, allow the mycelium to propagate information across large areas, effectively coordinating behaviour and decision-making without a central control system.

The book also explores the biophysical mechanisms underlying these processes, including the role of ion fluxes and membrane potentials in signal transmission. These findings not only illuminate the sophisticated communication strategies of fungi but also draw intriguing parallels to human-designed systems, such as neural networks and bio-inspired computing models. By framing mycelium as a biological conduit for information and energy flow, Boddy and Ashby provide a conceptual foundation for the emerging field of fungal electronics.

This perspective is especially relevant to my research, which seeks to explore mycelial signals not only as data but as expressive, communicative phenomena. The idea of fungi as decentralized communicators aligns with my project's speculative goal: to sonify and visualize fungal voltage patterns in ways that render them perceptible and meaningful to human audiences. In this sense, the work of Boddy and Ashby supports the argument that fungi can be understood as nonhuman agents of information transfer, offering both a scientific basis and a philosophical rationale for treating fungal signals as material for creative interpretation. Their account justifies an approach that blends ecological awareness, biosemiotics, and sound design to explore human–fungal interactions through technology.

2.10 Fungi and Music: Translating Bioelectric Activity into Sound

Recent explorations into bio-sonification have positioned fungi as active participants in musical creation rather than passive biological subjects. For example, Nayar (2025) provides a comprehensive

field guide on real-time fungal music, in which mushroom bioelectrical activity is converted into MIDI data using on-site biodata devices and synthesizers. These musical manifestations closely follow voltage fluctuations within living fungal tissues (Nayar, 2025). Similarly, The Octopus Project's 2021 "Mushroom Bio music" project involved using a MIDI biodata sonification device attached to mushrooms to generate live audio-visual performances, with fungal spikes modulating musical parameters and accompanying visuals (Levy, 2021; The Octopus Project, 2021).

These projects suggest fungi can function as collaborative sonic agents in performance contexts. Nayar asserts that fungi-generated electrical signals are "live" material for composition and improvisation, while The Octopus Project frames mushrooms as direct contributors to musical texture and structure (Levy, 2021; Nayar, 2025). These approaches exemplify fungi-mediated music as not merely conceptual but performative, underscoring the interplay between biology and technology.

The practice aligns with broader theories on non-human agency in music and posthumanism, suggesting that listening to fungi opens new sensory pathways to the more-than-human world. As Sheldrake (2023) notes, fungal electrical signalling occurs within vast subterranean networks that already evoke deep ecological connections, as in the "wood-wide web." Transforming these signals into sound invites a rethinking of agency, fungi become interlocutors rather than subjects of human interpretation (Sheldrake, 2023).

Crucially, these methodologies engage both scientific rigor and creative speculation. By capturing fungal electrical spikes in real time and translating them into musical form, these works offer experiential insight into fungal temporality and responsiveness. According to Brattico et al. (2011), music is one of the most neurologically engaging stimuli for humans; thus, presenting fungal signals as music not only makes bioelectrical data accessible, but also emotionally resonant and cognitively immersive.

2.11 Acoustic Ecology: Context and Foundations

Acoustic ecology is an interdisciplinary field examining the relationship between humans and their sonic environments. Emerging in the 1970s from the World Soundscape Project under the leadership of R. Murray Schafer, this field positioned sound as both a sensory and ecological concern. Schafer's foundational text, *The Soundscape: Our Sonic Environment and the Tuning of the World* (1977), introduced terms such as *soundmark*, *keynote*, and *signal*, providing a vocabulary for identifying and analysing environmental sound phenomena. He distinguished between hi-fi soundscapes, where acoustic signals are clear and layered, and lo-fi soundscapes, where signals are masked by noise—a distinction that remains central to contemporary soundscape analysis.

Barry Truax extended Schafer's framework by integrating technological mediation and communication theory into the field. His work emphasized how listeners interact with their environment through contextual listening, advocating for soundscape composition as a creative and critical act (Truax, 2001). Truax also explored electroacoustic methods for ecological composition, directly influencing the development of sound-based practices in contemporary media art.

Hildegard Westerkamp's contributions further grounded acoustic ecology in feminist, urban, and activist perspectives. Her practice emphasized *soundwalking* and narrative reflection as methods of engaging listeners with their environments, positioning listening as a political act (Westerkamp, 2002).

More recently, acoustic ecology has expanded to include Eco acoustics, where bioacoustics techniques are employed to monitor ecosystems and biodiversity, particularly in the context of climate

change. This scientific turn has merged acoustic ecology with conservation biology, while also reinforcing the role of sound as ecological data (Sueur & Farina, 2015).

Acoustic ecology's relevance to creative technology lies in its conceptualization of listening as inquiry. For practice-based research into fungal sound translation and environmental sonification, it provides a grounding in non-anthropocentric auditory engagement and multispecies soundscape interaction.

2.12 Experimental Sound and 20th-Century Composition

The 20th century saw radical transformations in how sound, music, and noise were defined. Composers such as John Cage, Karlheinz Stockhausen, Pauline Oliveros, Pierre Schaeffer, and La Monte Young shifted the focus from harmonic structure to auditory experience, often engaging philosophical, technological, and ecological themes in their work.

John Cage and Sonic Indeterminacy

John Cage is arguably the most influential figure in this transformation. Cage's *4'33"* (1952), often mischaracterized as a silent piece, invites audiences to attend to the ambient sounds of the performance space. The work encapsulates Cage's commitment to chance operations, drawn from his study of Zen Buddhism and the I Ching, which rejected hierarchical composition in favor of indeterminacy and openness (Cage, 1961).

His prepared piano works, such as *Sonatas and Interludes* (1946–48), reconfigured the piano into a percussive instrument using objects placed between the strings, revealing new textures from traditional instruments. Cage also employed graphic notation and text scores to distribute interpretive agency to performers. These methods prefigure data sonification, where input values (biological or environmental) are translated into open musical forms.

Other Experimental Composers

- **Pierre Schaeffer** pioneered *musique concrète*, a compositional practice using recorded environmental sounds manipulated on tape. His *Traité des objets musicaux* (1966) proposed a taxonomy of sound objects that separated musicality from traditional performance.
- **Pauline Oliveros** developed *Deep Listening*, a practice blending environmental sound, improvisation, and mindfulness. Oliveros (2005) emphasized the social and ecological implications of sonic attention, arguing for inclusive, resonant systems of engagement.
- **Karlheinz Stockhausen** fused electronic sound with spatial dynamics in works such as *Gesang der Jünglinge* (1955–56), and his later pieces reflected an interest in cosmology and human transcendence through sound.
- **La Monte Young** and **Steve Reich** contributed to minimalism and phase music, using extended durations, repetitive patterns, and phase shifts to generate evolving sonic environments.

These composers, though stylistically diverse, share an interest in **expanded listening, nonlinearity**, and the **aesthetic potential of noise and environment**. Their work disrupted the boundaries between sound and music, performer and system, and ultimately laid the groundwork for sonic practices in installation, data-driven art, and bio-electronic media.

2.13 Intersections with Creative Technology Practice

The convergence of acoustic ecology and 20th-century experimental music informs the creative and methodological foundations of fungal electronic research. John Cage's indeterminacy parallels the responsive behavior of mycelial networks, where electrical signals are contingent on environmental and internal conditions. Schafer's concept of the *soundscape* maps well onto the fungal infosphere, where electrochemical signaling can be reinterpreted as sonic landscape.

In practical terms, this synthesis justifies the translation of fungal voltage data into musical or sonic form, aligning with both artistic and ecological inquiry. The use of field recordings, real-time sensor input, or speculative sonification practices situates the work within a lineage that values **nonhuman agency**, **processual aesthetics**, and **environmental embeddedness**.

By embedding data into audiovisual formats—such as MIDI composition, waveform animation, or spatialized installation—this research extends the concerns of acoustic ecology and experimental composition into new material contexts. The fungi become **both medium and co-creator**, contributing to a broader critique of human exceptionalism and proposing new modes of listening across species boundaries.

2.14 Conclusion

This literature review has examined the expanding field of fungal electronics, focusing on the electrical properties of mycelium, its applications in sustainable and biohybrid microelectronics, and its potential as a responsive medium within speculative creative practices. The discussion has drawn from a range of interdisciplinary sources, including biological studies on fungal conductivity and signalling (e.g., Adamatzky, 2018; Phillips et al., 2023), sustainability-driven material research (e.g., Danninger et al., 2022; Vasquez & Vega, 2019), and emergent work in fungal-based computing and sensing technologies (e.g., Dehshibi & Adamatzky, 2021; Gandia & Adamatzky, 2024). The review also acknowledged foundational ecological and philosophical concepts such as the "wood wide web" and the agency of more-than-human systems, which frame fungi not only as materials but as active collaborators in new forms of design and communication.

The integration of fungal music into this review highlights a developing yet underexplored strand of creative research that translates fungal electrical signals into sound. Projects such as those by The Octopus Project and Modern Biology exemplify how fungal voltages can be interpreted as compositional input, allowing for new sensory engagements with fungal behaviour. These works demonstrate the potential of fungi not only as biological sensors but also as co-creators in human–nonhuman expression.

This review identifies a research gap at the intersection of empirical fungal signal studies and their cultural, artistic translation. My project addresses this gap by using recorded fungal voltages as a source of musical and audiovisual output. Through MIDI sonification, experimental visualisation, and installation design, the project positions fungi as active participants in speculative bio-digital interfaces. This research contributes not only to emerging mycelial electronics but also to creative technology practices that foreground ecological agency and multispecies communication in human–fungal relations.

3. Materials and Methods

3.1 Methodological Framing

This research adopts an interdisciplinary methodology grounded in the perspective of a creative technologist, a framework that embraces both scientific inquiry and speculative practice. As discussed in the literature review, much of the current research into fungal electronics operates within the boundaries of applied science, encompassing domains such as electronics, photonics, spintronics, mechanics, and quantum fluidics (Adamatzky, 2022). In contrast, my project draws from the creative technologies tradition, where experimental making, media aesthetics, and computational processes intersect with biological systems.

My methodology aligns with the approach described by Cleveland (2024), who situates creative technology as a form of practice-led inquiry that assesses the limits of existing media tools and systems through artistic intervention and hybrid experimentation. In this case, the medium is fungal electrical activity, interpreted not solely as data but also as creative material capable of generating speculative sonic and visual outputs.

3.2 Research Design

The project was conducted in four iterative phases:

3.2.1 Fungal Cultivation and Monitoring

For this research, native New Zealand oyster mushrooms (*Pleurotus* species) and pink oyster mushrooms (*Pleurotus djamor*) were selected for cultivation due to their rapid growth rates, well-documented electrical responsiveness, and contrasting phenotypic characteristics. The native species provided a local ecological context, while the pink oyster mushrooms offered a vibrant and visually distinct counterpart, supporting both scientific and aesthetic components of the project.

Cultivation took place in a controlled indoor environment to ensure consistency in temperature, humidity, and sterility. Conditions were maintained between 22–26°C. Pre-fruiting blocks were purchased from a certified supplier to reduce contamination risks. These blocks were placed on top of a counter, equipped with a heating mat and a humidity veil for constant environmental monitoring. The setup was located in a low-traffic, medium to low-light room to minimize external disturbances.

Figure 1:

Mushroom Blocks underneath a moisture capturing veil



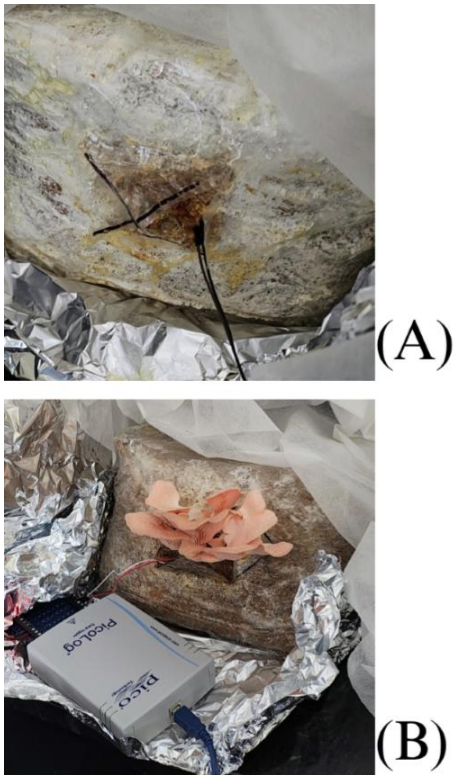
Set up for fruiting of *Plurotus Djamor* (Pink Oyster) and *Plurotus Pulmonarius* (Phoenix Oyster)

The focus was placed on the fruiting phase of the fungal lifecycle, as this stage is known to involve heightened metabolic activity and dynamic physiological changes, which are likely to produce the strongest and most detectable electrical signals. Additionally, the fruiting phase aligns with observable outcomes (mushroom growth), allowing for direct visual and measurable correlation between environmental stimuli, growth behaviour, and electrical output.

Electrical activity was recorded using a PicoLog 1000 Series data logger, with electrode pairs inserted into the mycelial substrate. The device was configured to record microvolt-level fluctuations at one-millisecond intervals, generating detailed time-series datasets for analysis. By limiting recordings to the fruiting stage, the study maximised its ability to capture moments of biological significance while maintaining manageable data volumes.

Figure 2:

Mushroom Blocks undergoing testing



PicoLog set up to capture voltage spikes with a PicoLog in (A) Phoenix oyster and (B) pink oyster

Voltage readings were exported as CSV files for further processing.

3.2.2 Signal Conversion and Sound Design

A custom Python script was written to convert raw voltage data into MIDI files.

Notes were derived based on normalized voltage values, with three-note chords representing spikes in activity.

MIDI files were imported into Reaper, where VSTi plugins were used to refine the sonic output, and then exported as WAV for use in the final installation.

3.2.3 Audio-Visual Composition

Video footage of mushrooms in natural environments was filmed and edited in Adobe Premiere Pro.

Using voltage-to-colour mapping in Python, overlaid visuals displayed shifting hues and text indicators tied to real-time fungal signal values.

Frame matching, aspect ratio adjustments (2112x1408), and layered visual bars were used to spatially and aesthetically align the video with the sonic material.

3.2.4 Speculative Installation Design

The final work took the form of a dual-screen installation: one screen displayed macro footage of mushrooms accompanied by a musical composition generated from fungal voltage data, while a second display presented a real-time visualisation of the raw voltage signals. This arrangement was intended to emphasise the interplay between nonhuman and human systems, inviting viewers to consider fungal agency as both aesthetic and communicative.

This installation was framed through the lens of speculative design, which Dunne and Raby (2013) define as a practice that uses design proposals to challenge assumptions, provoke debate, and explore alternative presents and possible futures. Rather than providing solutions, speculative design offers material fictions that encourage reflection on emerging technologies and our relationship to them. In this context, the installation functioned as a form of material speculation, translating the otherwise imperceptible signals of fungi into sensory experiences that engage human imagination and empathy. The work aimed to question not only how we design with living systems, but also how those systems might, in turn, communicate or collaborate with us.

3.3 Technologies and Tools

This project employed a combination of low-cost, accessible hardware and interdisciplinary software tools that reflect the ethos of creative technology research. The PicoLog 1000 data logger was chosen for its high-resolution multi-channel input, allowing reliable long-term recording of microvolt fluctuations in fungal substrates. Its compatibility with USB interfaces made it suitable for integration with custom-built monitoring setups, including homemade grow bags and commercial spawn bags, which provided both experimental control and practical cultivation advantages.

On the software side, Python was selected due to its flexibility in data handling and availability of scientific libraries. Pandas enabled efficient time-series analysis of the fungal voltage data, while Mido and MoviePy supported MIDI generation and audiovisual conversion, respectively. Reaper, a low-cost, highly customizable digital audio workstation (DAW), was used for MIDI editing and synthesis because of its support for third-party VST instruments, including the Bobsitron VSTi, a custom plugin used to sonify fungal signals. Audacity was used for final layering and editing due to its open-source accessibility and ease of use.

Premiere Pro was selected for video editing because it allowed precise integration of RGB visual data with macro fungal footage, while voltage-to-colour mappings were developed in Python to create animated overlays that visually represent real-time fungal behaviour. Finally, VCV Rack was incorporated as a modular synthesizer platform, by converting MIDI signals into dynamic, analogue-style synthesis. The modular nature of these tools reflects the experimental, responsive, and iterative methodology central to speculative bio-digital practice.

3.4 Methodological Alignment and Limitations

The methodology adopted in this research, grounded in a creative technologist's interdisciplinary approach, was carefully designed to align with the research questions posed: Can fungi and humans communicate with the aid of technology? and What might fungal-generated sound and image offer us as a new mode of interspecies expression or encounter? By combining scientific experimentation with speculative and artistic practice, this methodology allowed for the exploration of fungal voltage as both a measurable phenomenon and a potential communicative medium.

The experimental cultivation and data logging of fungal species addressed the biological and technical dimensions of fungal conductivity, supporting the investigation into fungi's responsiveness to environmental stimuli. This data was then translated into music and visual formats using software tools, opening a speculative space in which fungal behaviour could be interpreted as a form of nonhuman expression. The inclusion of sonification and installation design as integral components of the methodology provided a framework to render fungal agency perceptible to human audiences, thus directly responding to the project's central inquiry.

However, this approach is not without limitations. The creative-technological methodology privileges interpretation and translation over objectivity; as such, the sonification of fungal data remains an artistic, not empirical, representation. While the translation of voltage into MIDI provides a perceptible medium, it cannot capture the totality or true intention, if any, of fungal signalling. Additionally, the choice to focus on only the fruiting phase of the mushroom lifecycle may limit understanding of how electrical activity varies across other developmental stages.

Further, while the software and hardware tools were chosen for their accessibility and experimental flexibility, they required extensive manual calibration and interpretation, which introduces subjectivity into the process. Environmental factors such as temperature, humidity, and contamination were also difficult to control with complete consistency, impacting the replicability of the data.

Despite these limitations, this methodology successfully opened up a novel dialogue between fungi and humans, reframing fungal data as both scientifically valuable and artistically resonant. It contributes to an emerging field of fungal electronics and speculative bio-design by demonstrating a pathway for interdisciplinary exploration that is rigorous, imaginative, and grounded in ecological awareness.

4. Experimental and Creative Work

4.1 Introduction

This chapter documents the experimental and creative phases of this research project, which explores the electrophysiological activity of fungi and its translation into sonic and audio-visual formats. Drawing on the interdisciplinary approach of a creative technologist, this work combines biological cultivation, empirical voltage data collection, and artistic interpretation to investigate the communicative and expressive capacities of fungal systems.

The experimental phase involved cultivating various mushroom species under controlled conditions and measuring their electrical activity using a PicoLog data logger. These recordings formed the foundation for subsequent data analysis and interpretation. The voltage data, reflective of fungal responses to environmental stimuli such as hydration and temperature, were then processed and mapped onto musical and visual representations.

The creative component of the research builds upon speculative design methods and bio-sonification practices, translating fungal voltages into MIDI compositions and audiovisual works. These outputs serve as both artistic artefacts and experimental interfaces, enabling human-fungal interaction through mediated, multisensory experiences.

This chapter is organised according to the stages of the research design introduced in Chapter 3. Each section outlines the processes, tools, and decisions involved in cultivating fungi, recording signals, interpreting data, and producing sonic-visual outputs. Reflections on challenges, environmental responsiveness, and limitations are included to contextualise the findings and inform future iterations of this practice-led inquiry.

4.2 Experiment One

To investigate the electrical properties of mycelium, I began by cultivating Shiitake and Phoenix oyster mushrooms from grain spawn. The Shiitake mushrooms were grown in a homemade mono-tub, while the Phoenix oyster mushrooms were cultivated in filter patch bags. For the substrate, I used a mixture of pine woodchips, wheat bran, and water. The dry weight composition consisted of 20% wheat bran and 80% woodchips. Water was added until the substrate was fully hydrated, which was determined by squeezing a handful to ensure water was not released but was close to saturation.

To minimize contamination risks, I sterilized the substrate using my university's autoclave. After sterilization, I inoculated the bags by adding 25% spawn by weight. During the entire process, I maintained strict cleanliness protocols, including wearing clean clothes and spraying both work surfaces and myself with 70% isopropyl alcohol.

The filter patch bags containing the substrate were sealed using an impulse sealer, ensuring an airtight environment. For the Phoenix oyster mushrooms, I experimented with an alternative substrate using Orb 101 Fairtrade espresso used coffee grounds to assess the impact of a different growing medium. The same sterilization, hydration, and inoculation process was followed.

However, this attempt was unsuccessful due to contamination, as another type of green mould began growing on the spawn, likely from lack of airflow as it was placed in a greenhouse within a box with bamboo cotton filters.

4.3 Experiment Two

I shifted to using pre-fruiting mushroom blocks purchased from a commercial supplier to mitigate further issues.

These blocks were placed on a heating mat set to maintain a consistent temperature of 26°C. A Picolog data logger was connected to the blocks to record electrical pulses at one-millisecond intervals. To assess the impact of temperature on voltage output, the heating mat was periodically turned on and off during the recordings.

To maintain optimal humidity levels, I placed a humidity veil over the blocks and sprayed water onto the X-shaped incisions cut into the blocks twice daily. These measures were essential to ensure conducive conditions for mushroom growth while simultaneously enabling accurate recording of their electrical activity.

4.4 Results

Figure 3:

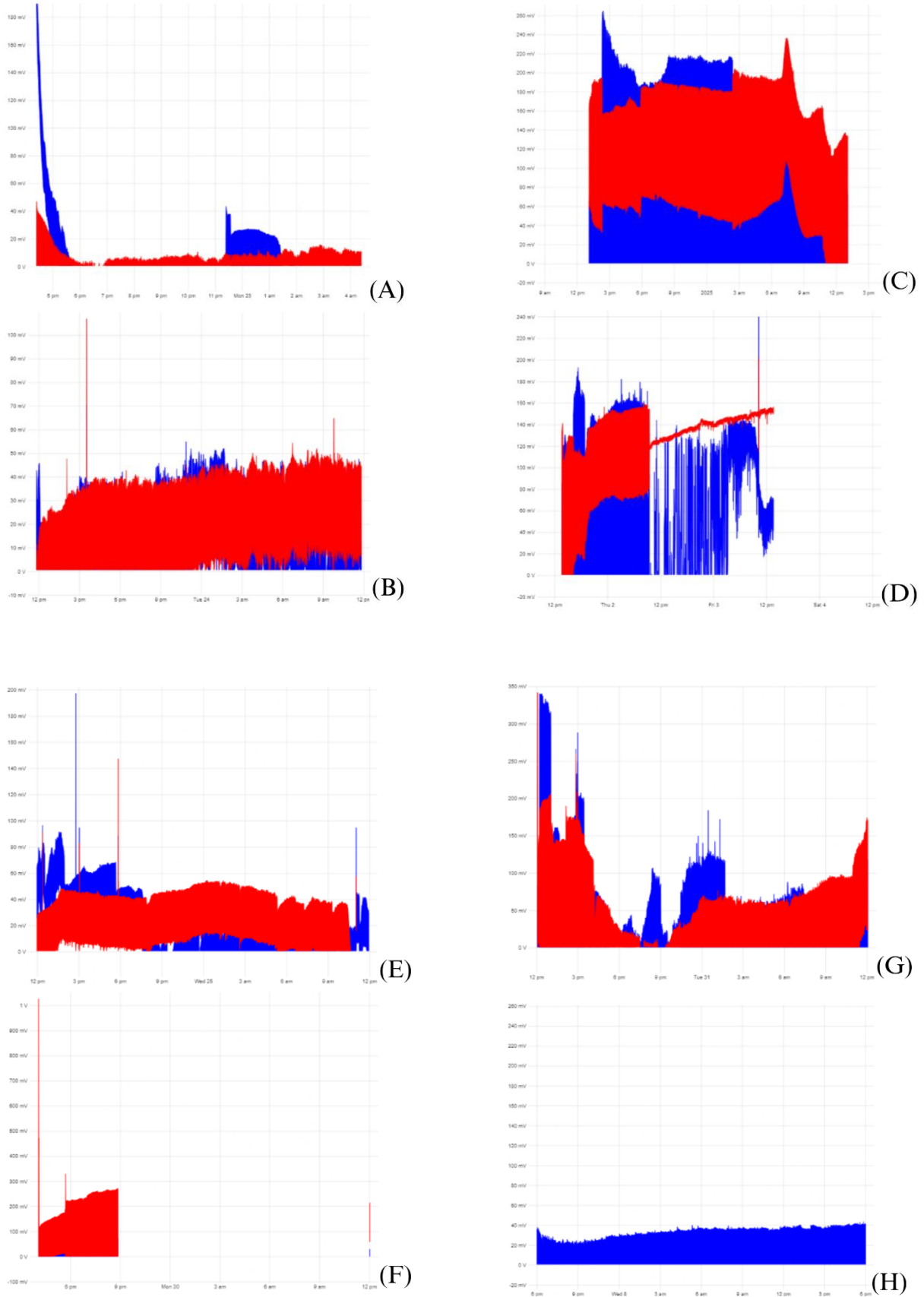
Pink and Phoenix oyster mushrooms

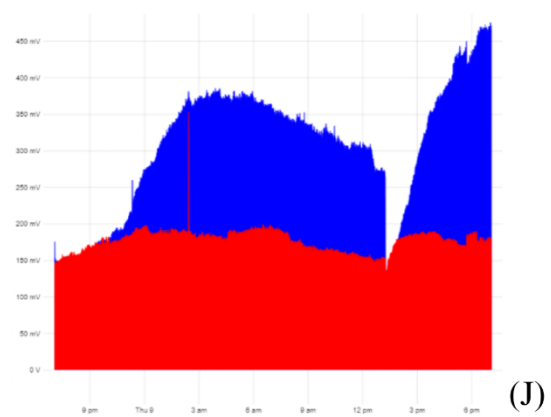
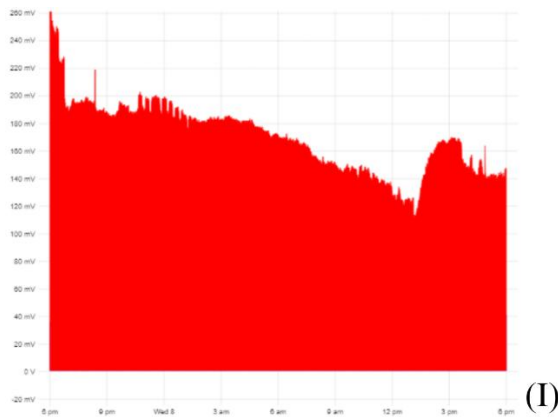


(A) Pink Oyster Fruiting. (B) Phoenix Oyster Fruiting.

Figure 4

Captures of Voltage Fluctuations in Mycelial Substrates During Fruiting Stages





(A-J) Recording taken with the Picolog, the recordings differ from 12, 24 to 54 hours. Red signifies Pink Oyster and Blue Phoenix Oyster.

General Observations

Electrical activity within the mycelial substrate exhibits significant variations over time, suggesting a dynamic and responsive biological system. The recorded voltage fluctuations indicate ongoing metabolic and environmental interactions.

Key Trends in the Graphs

Initial Drop and rises in Voltage

A noticeable steep decline and rise in voltage is observed throughout the measurement period. Especially in the period surrounding midnight. This phenomenon may be indicative of an initial settling phase, during which the substrate undergoes adaptation to its environment. Factors influencing such changes may include:

Moisture redistribution within the mycelial network

This is known to impact electrical conductivity due to changes in ion flow and membrane potential (Adamatzky, 2021). Fungi require a moist environment for metabolic activity, and fluctuations in water content can directly influence electrical signalling.

Mycelial adaptation

Adaptations were evident as the fungal network establishes electrical stability, potentially linked to the formation of conductive pathways within the hyphal network during early colonisation. This hypothesis is informed by Adamatzky's (2018) studies on the stabilisation of voltage pulses in growing mycelium and the emergence of repeatable electrical patterns as the network matures.

Cycle Switching

The switch in the day–night cycle of the mushrooms indicating when sporing begins, as some species, including *Pleurotus* spp., are known to release spores at night under high humidity and cooler temperatures (Stamets, 2000). This circadian-linked activity could correlate with bursts of metabolic and electrical activity.

Stable & Fluctuating Phases

After the initial drop, the recorded voltage trends demonstrated both periods of stability and phases of rapid oscillations. These fluctuations may correspond to key biological processes, such as:

The establishment of mycelial networks, which rely on coordinated electrical signalling (Adamatzky, 2021).

The onset of mushroom fruiting body formation, potentially linked to changes in metabolic activity (Stamets, 2000).

Moisture dynamics, where hydration and dehydration cycles alter conductivity (Jones, M., et al, 20)

Sudden Voltage Spikes

Several instances of sharp voltage increases were observed, which may correspond to mycelial bursts of activity. These spikes could be driven by:

Nutrient redistribution occurred within the fungal network.

Increased metabolic rates, potentially due to enzymatic or respiratory activity.

Environmental disturbances, such as airflow variations or temperature shifts, which could induce physiological responses in the mycelium.

Human error occurred from the removal and replacing of the picolog.

Interpretation of Fruiting Stages

Changes in the data collected appear to co-relate to various stages of fungal fruiting. In considering this phase I deduced the following:

Voltage fluctuations during these phases may provide insight into the role of electrical signalling in fungal development.:

A drop in voltage following fruiting may indicate electrical activity guiding hyphal aggregation and fruit body formation.

A rise in voltage prior to fruiting could suggest a shift in energy allocation towards spore production or water uptake, impacting conductivity.

The Role of Environmental Conditions

Native Oyster vs. Foreign Oyster

A key variable in the dataset is the distinction between Native Oyster and Foreign Oyster samples. The differences in voltage trends between these conditions may be influenced by species-specific metabolic and physiological responses.

Temperature and Humidity Factors

If environmental data (temperature, humidity, CO₂ levels) was available, further analysis could establish correlations between external conditions and voltage fluctuations. This may help determine the impact of abiotic factors on fungal electrical behaviour.

Conclusion

The observed voltage fluctuations in mycelial substrates suggest complex biological and environmental interactions. Further investigation into species-specific responses, environmental influences, and electrical rhythms will contribute to a deeper understanding of fungal bioelectricity and its role in developmental processes.

4.5 Reflections on experimental work

4.5.1 Growth and Contamination Reflections

The initial experiment with Shiitake and Phoenix oyster mushrooms resulted in complete contamination due to green mould, likely caused by external interference, insufficient sterilization protocols or lack of fresh air. Following this setback, I shifted focus to testing electrical activity in native New Zealand oyster mushrooms and pink oyster mushrooms. These were cultivated from pre-fruiting blocks, ensuring minimal contamination risk. Both species demonstrated robust growth, with the mycelium rapidly colonizing their respective substrates within days of introduction to optimal conditions. The native New Zealand oyster mushrooms exhibited more robust growth, with thicker mycelial networks and faster substrate colonization compared to the pink oyster mushrooms.

4.5.2 Electrical Activity Measurements

Electrical pulses were recorded over several days using the Picolog data logger at one-millisecond intervals. The native New Zealand oyster mushrooms consistently exhibited higher voltage outputs compared to the pink oyster mushrooms, with an approximate difference of 400 millivolts. This significant variance suggests inherent differences in electrical conductivity between the two species.

Detailed analysis of the recorded data revealed rhythmic patterns of voltage fluctuations, with peaks corresponding to periods of heightened metabolic activity. These fluctuations were more pronounced in the native species, which maintained stable and higher electrical outputs throughout the observation period. The pink oyster mushrooms, while less consistent, showed occasional surges in voltage, potentially linked to sporadic bursts of metabolic or environmental activity.

When the mycelium blocks were sprayed with water, an immediate increase in millivolt output was observed in both species. This response indicates a strong correlation between hydration and electrical activity, likely due to improved ion transport within the mycelium network. The effect was more pronounced in the native New Zealand oyster mushrooms, reinforcing their higher baseline electrical activity. Over time, the electrical activity gradually decreased after hydration, stabilizing at pre-spray levels within an hour.

4.5.3 Nocturnal Electrical Activity

Data recorded during nighttime revealed a notable increase in electrical activity in both mushroom species. This heightened activity may correspond to the release of spores, a process that typically occurs during nocturnal hours. The spike in electrical signals suggests that spore release could involve significant metabolic activity, influencing the electrical conductivity of the mycelium. The native New Zealand oyster mushrooms showed sharper increases in nocturnal electrical output compared to the pink oyster mushrooms, potentially indicating more active spore dispersal mechanisms.

4.5.4 Response to External Stimuli

Spraying water on the mycelium blocks was the most effective external stimulus, causing a measurable and immediate increase in electrical signals. This finding highlights the potential for moisture to function as a trigger for enhanced conductivity. Preliminary tests on other external stimuli, such as mechanical disturbance and temperature fluctuations, revealed promising results. Gentle tapping on the mycelium blocks resulted in transient spikes in electrical activity, suggesting a rapid but short-lived response to physical stimuli. Temperature changes, simulated by localized heating with a thermal probe, generated gradual increases in electrical activity, with signals peaking after 10 to 15 minutes of exposure. The effects of light exposure on electrical activity are planned for future investigation to broaden the understanding of fungal responsiveness.

4.5.5 Summary of Results

The experiments with native New Zealand oyster mushrooms and pink oyster mushrooms demonstrated significant differences in electrical activity, with the native variety showing consistently higher millivolt outputs and a more dynamic response to environmental conditions. Hydration emerged as a key factor in enhancing electrical conductivity, with immediate and sustained impacts on voltage output. Nocturnal spikes in activity suggest a potential link to spore release, highlighting the interplay between metabolic processes and electrical signalling. These findings provide valuable insights into the dynamic electrical properties of fungal networks and their responsiveness to environmental changes. Future studies will focus on a broader range of external stimuli and long-term data collection to further elucidate the potential of fungi in bioelectronics.

4.6 Challenges

4.6.1 Variability and Standardization

One of the primary challenges in adopting fungal networks for microelectronics is their variability. Conductivity can differ significantly between fungal species and is influenced by environmental conditions such as temperature, humidity, and substrate composition (Mayne et al., 2023). Developing standardized cultivation techniques and measurement protocols is critical for ensuring consistent performance across applications.

Additionally, the dynamic nature of fungal networks poses challenges for maintaining stable functionality. While adaptability is an advantage in many contexts, achieving predictable and reliable performance requires precise control over environmental factors.

4.7 Interpreting Electrical Signals Through Music

The interpretation of electrical signal data through music offers a unique pathway for understanding non-human biological activity in a sensory-rich format. While humans universally experience music emotionally, this capability is not widely shared across the animal kingdom (American Academy of Audiology, 2025). Neuroimaging research by Brattico et al. (2011) demonstrates that listening to music, particularly pieces we subjectively enjoy, activates more areas of the brain than any other human activity, engaging regions responsible for emotion, memory, and reward.

An intriguing, though speculative, conceptual framework to consider in this context is the Stoned Ape Theory, proposed by ethnobotanist Terence McKenna. The theory posits that the consumption of *Psilocybe cubensis*, a psychoactive mushroom containing psilocybin, played a pivotal role in the rapid neurological and cognitive evolution of early hominids. While lacking empirical evidence, the theory inspires provocative questions about how external biochemical stimuli might influence perceptual and cognitive complexity.

In this experiment, raw voltage data derived from mycelial activity was processed using a custom Python script that mapped the fluctuations to MIDI note values. The script converted microvolt readings into a defined pitch range, normalizing the values to avoid clustering around inaudible extremes. To explore how electrical energy could be interpreted as melodic gesture, I trialled multiple mapping techniques, initially assigning one MIDI note per voltage reading, then experimenting with

smoothing algorithms to generate more coherent sequences. The data were then structured into files with varying tempos, measured in beats per minute (BPM), to assess how pacing affected perceived mood and musicality.

Early iterations produced sparse and jittery outputs, prompting me to add harmonic structure. I began applying triadic chord structures, such as minor, diminished, and suspended chords, to evoke an eerie, ambient atmosphere aligned with fungal growth aesthetics. These chords were triggered according to predefined voltage bands, allowing electrical intensity to shape harmonic mood.

The MIDI sequences were then imported into Reaper, a digital audio workstation (DAW), where effects and dynamics were refined. In addition to using Reaper's native plugins (such as EQ, reverb, and delay), I explored the use of VCV Rack 2, a modular synthesizer environment, to convert the MIDI data into rich, evolving textures. By routing the MIDI signals into VCV Rack's MIDI-CV module, I was able to send note and velocity data into oscillators, filters, envelope generators, and sequencers. This setup transformed raw fungal data into a generative, analogue-style audio experience, blurring the boundary between biological signal and synthetic expression.

Within VCV Rack, I built several patch configurations that could respond dynamically to incoming MIDI from the fungal sonification files. Some patches emphasized drones and ambient tones, while others reacted to rhythm or voltage variability with gated pulses and modulated noise. This dual workflow, Reaper for linear sound design and VCV Rack for modular synthesis, allowed me to explore both structured and emergent sonic approaches.

To simulate a live performance or reactive installation context, I converted the MIDI files into audio tracks using real-time rendering tools. I also developed a method to send MIDI output from Reaper into VCV Rack via virtual MIDI ports, enabling live playback of the fungal MIDI files directly through the modular patches. This allowed for real-time improvisation, manipulation, and reprocessing of the fungal signals as a form of interactive, non-human-driven composition.

Dynamic compression and stereo panning were employed to shape the spatial field of the track, suggesting the lateral spread of mycelium across substrates. The final compositions were exported and prepared for audiovisual integration, with different versions created to suit either analytical listening or immersive environmental installation. This process ultimately framed fungal voltage not only as a data source, but as a performative signal capable of producing ambient, textured soundscapes through modular synthesis and DAW-based workflows.

The processed track was exported as a .wav file and imported into Audacity, where it was layered with a field recording of natural ambience. To match the temporal scale of the fungal-derived music, the 52-second natural soundscape was time-stretched by 4166.67%, corresponding to a temporal ratio of 0.024 seconds of audio per 1 second of playback. This transformation enabled the two tracks, biological voltage and natural sound, to align rhythmically, facilitating a novel audiovisual interpretation of fungal behaviour over an extended period.

4.8 Video work

Figure 5

A still taken from the project



A wild mushroom sitting in its natural environment.

The video component of this project was developed to visually represent fungal ecosystems while integrating real-time data aesthetics. Footage was captured using a Canon DSLR camera during field excursions to a farm on the outskirts of Auckland, where wild mushrooms were growing in shaded and humid areas. These natural environments provided a rich visual backdrop that underscored the ecological context of the fungi generating the electrical signals used in the sound component of the project.

The raw footage was imported into Adobe Premiere Pro, where it was first scaled to frame size and then stabilised to reduce the impact of handheld movement. This post-processing ensured a consistent and meditative viewing experience, echoing the slow, often imperceptible timescales of fungal growth and signalling.

To connect the video with the fungal voltage data, I developed a custom Python script that translated raw millivolt readings into RGB colour values. These colour values were used to generate animated horizontal bars positioned at the top and bottom of the screen. The bars pulsed and changed hues based on real-time fluctuations in the fungi's electrical output, forming a visual representation of invisible biological rhythms. This approach allowed the data to manifest both sonically and visually, reinforcing the multisensory interpretation of fungal behaviour.

Two final video files were exported: one in native resolution and another at 2112×1408 pixels, tailored for the large screen used in the final exhibition. The larger resolution was chosen to take full advantage of a custom gallery display, allowing the footage and data bars to remain crisp while occupying a visually immersive format. By visually encoding fungal voltage within a naturalistic frame, this video work acts as a bridge between documentary and data visualisation, communicating the hidden languages of fungi through both image and colour.

4.9 Installation

The final work was presented as a dual-screen audiovisual installation, designed to engage viewers in a speculative dialogue with fungal life and its latent communicative potential. This format was chosen to foreground the interplay between human and nonhuman systems by making invisible fungal signals tangible through synchronized sound, video, and colour (See appendix).

The primary display, projected at a resolution of 2112×1408, featured macro footage of wild mushrooms filmed in their natural habitat. Overlaid with animated bars that visually represented real-time voltage fluctuations, this footage offered both aesthetic immersion and scientific intrigue. These bars, generated from raw PicoLog data and mapped into RGB values using Python scripting, functioned as both compositional elements and conceptual devices, bridging biological processes and digital expression. As their colours shifted in response to electrical rhythms within the fungi, the top and bottom margins of the screen were transformed into dynamic, living data zones.

To the side of this dominant visual plane, a secondary screen, a standard HD television, presented a more intimate display: a real-time visualisation of the fungal voltage data, accompanied by a soundscape generated from those same signals. This spatial and sensory separation created a deliberate tension between the meditative, organic cadence of the macro footage and the minimalist, data-centric playback. In doing so, the installation encouraged viewers to move fluidly between two modes of engagement: contemplative observation of living fungi and analytical interpretation of their invisible bioelectrical activity.

The dramatic scale of the primary projection further heightened this dual experience. Magnified to colossal proportions, the mushrooms, normally small and easily overlooked, took on an almost mythic presence. Every pore, filament, and unfolding gill became a sweeping, high-resolution landscape that invited close scrutiny and awe. This shift in scale challenged the viewer's perceptual habits, recontextualizing fungi as monumental figures within both ecological and technological imaginaries. In contrast, the modestly sized data screen, with its subtle pulses and rhythmic light patterns, offered a quiet counterpoint. The juxtaposition between these two forms, one expansive and organic, the other restrained and computational, highlighted the dual nature of fungi as both living organisms and dynamic data sources. Together, they encouraged oscillation between macro and micro perspectives, between embodied sensation and computational abstraction, deepening the viewer's engagement with fungi as interfaces between natural complexity and digital representation.

The installation design was inspired by Dunne and Raby's (2013) concept of speculative design, which advocates for the creation of artefacts and experiences that question current technological paradigms and provoke reflection on alternative futures. In this context, the installation operates as a "what if" scenario: What if we could hear the silent language of fungi? What if mushrooms were composers? By materialising fungal data through sonification and visualisation, the work invites viewers to reconsider nonhuman agency and the role of fungi as active participants in ecological and aesthetic systems.

This spatial and multisensory format was intended to decentre the human gaze and suggest a more reciprocal engagement with the more-than-human world (Tsing, 2015). The dual-screen layout encourages nonlinear exploration and destabilises traditional narrative structures, aligning with the temporality and distributed intelligence of fungal life.

5. Discussion

The transformation of fungal voltage data into musical and visual expressions represents a compelling and emergent convergence of scientific inquiry and creative media. This project aimed to explore how minute bioelectrical signals generated by fungal organisms could be captured, translated, and reimagined as sound and colour through digital technologies. Using Python to convert voltage readings into MIDI files, the process enabled the raw electrical behaviour of mycelium to be mapped into musical pitch, rhythm, and harmony. These musical interpretations were further refined using digital audio workstations such as REAPER, where various synthesizer plugins (VSTi) enhanced the auditory experience, and later imported into Adobe Premiere Pro for synchronization with time-stretched footage of natural environments. This method posed a critical question: can the imperceptible electrical activity of fungi be made intelligible, and even emotionally resonant, through sound and image? The resulting audio tracks, composed of rapid, eerie, and often dissonant chord progressions, evoked an alien yet deeply biological character, challenging conventional notions of musicality and suggesting a speculative form of interspecies communication.

Yet, this interdisciplinary approach was not without its limitations. A significant technical constraint involved the data acquisition hardware. The PicoLog voltage logger, while accessible and relatively user-friendly, was unable to record negative voltages, thereby omitting half of the potential electrical spectrum in the recordings. This limitation could have suppressed essential fluctuations in fungal activity, potentially biasing the musical output toward a partial or distorted representation of the organism's electrical behaviour. Furthermore, the living nature of the biological subjects introduced temporal constraints. The fungi used in the experiments had a finite shelf life, and their health and growth varied over time. These biological limitations made it difficult to maintain a consistent experimental environment and complicated long-term data collection efforts. In one specific instance, the pink oyster mushrooms were prematurely and improperly harvested, leaving a physical void in the mycelial substrate during their initial fruiting stage. This unintentional damage likely disrupted the natural electrical flow within the mycelial network, possibly affecting both the quality and consistency of the recorded signals.

Another significant challenge lay in temporal synchronization. The fungal MIDI output operated at an extremely fast tempo, approximately 3 milliseconds per chord, requiring all supplementary audio, including natural ambient tracks, to be slowed dramatically to achieve coherence with the fungal rhythms. This necessitated precise mathematical scaling and digital manipulation to preserve audio quality while matching the fungal data's temporal resolution. Such a mismatch between biological time and human time raises philosophical questions about perception and translation: what does it mean to "listen" to fungi, and how much of what we hear is their voice versus our own interpretation?

Framing this through the lens of new materialism, Barad's (2007) notion of the "apparatus" becomes particularly useful. An apparatus, in this context, is not just a technological tool but a performative condition that both enables and constrains what can be known or perceived. In this project, the MIDI interface, sonification scripts, DAW, and human listener together form an apparatus that shapes how fungal electrical activity is rendered intelligible as sound. Thus, the resulting music is not simply a reflection of fungal life but a co-produced aesthetic artefact emerging from entangled human–nonhuman–technological relations (New Materialism Almanac, 2016).

Despite these hurdles, the project demonstrates how fungal bioelectrical signals, typically confined to scientific contexts, can be transformed into expressive, multisensory outputs, thereby pushing the boundaries of what constitutes a musical or artistic source. It contributes meaningfully to the emerging field of bio-sonification and fungal electronics by establishing a process through which raw microvolt data is cleaned, mapped, sonified, and integrated into creative workflows involving sound design, modular synthesis, and audiovisual composition. This methodological framework foregrounds fungi not merely as biological specimens but as co-creative agents in speculative media-making.

The project achieves this by treating fungal electrical rhythms not as metaphors or ambient noise but as structured data with the potential to shape form, tone, and affective experience. The data's irregular pulses, voltage spikes, and circadian rhythms were sonically interpreted using MIDI-based workflows, providing a scaffolding for listening to, and imagining, nonhuman activity. These translations invite viewers and listeners to experience fungal processes as events unfolding across sound and space, offering an alternative aesthetic lens on biological activity.

Moving forward, improvements in hardware, such as differential amplifiers or data loggers capable of capturing both positive and negative voltages, could offer a fuller representation of fungal electrical activity. Current systems (like the PicoLog 1000) are limited to measuring unipolar voltages, which omits certain phases of the fungal signal and potentially suppresses negative voltage patterns. Incorporating bipolar data capture could allow for more nuanced sonic interpretations, increasing the fidelity of the biological-to-musical translation.

In addition, a more refined biological protocol for fungal care and data harvesting could ensure consistency across experiments. This includes not only standardizing environmental conditions (e.g., humidity, temperature, substrate composition) but also developing a clearer understanding of fungal developmental phases and how these relate to electrical behaviour. Without this biological rigour, the resulting sound may be more reflective of environmental noise or error than of genuine fungal signalling.

However, the question remains: would a complete representation of fungal electrical activity ever be truly possible? While technological enhancements can improve resolution and accuracy, any act of translation, especially one involving creative tools, inevitably introduces interpretation, bias, and aesthetic filtering. From sensor placement to MIDI mapping, human decisions shape how fungal data is perceived. In this sense, the goal may not be absolute fidelity, but rather meaningful mediation: creating interfaces where human and fungal rhythms can co-exist and co-create, even if imperfectly. Ultimately, this work invites further inquiry into how the rhythms of non-human life might intersect with human creativity, offering new ways to think, listen, and collaborate with the living world.

Conclusion

This thesis has explored the potential of fungi as both biological conductors and creative collaborators through an interdisciplinary investigation combining experimental bioelectronics with speculative media practices. Grounded in the emerging field of fungal electronics, the research began with the cultivation and monitoring of oyster mushroom species, where bioelectrical signals were captured using a PicoLog data logger. These signals-sensitive to environmental changes such as hydration, temperature, and light-produced distinct electrical behaviours during fruiting and nocturnal cycles, particularly in the native New Zealand oyster mushroom.

These experiments responded to the initial research questions by demonstrating that fungi can indeed generate voltage patterns that shift in response to their surroundings, supporting the proposition that fungi are dynamic, responsive biological systems capable of being interfaced with through technological means. By recording and analysing their electrical activity, the research affirmed that human–fungi communication can be technologically mediated, not through language or intention, but through signal translation and sensory interpretation. Although direct fungi-to-fungi communication was not a focus of this study, the observed intra-organism signalling underpins the plausibility of mycelial responsiveness as a communicative system.

In doing so, the project addressed the central question: Can fungi and humans communicate with the aid of technology? While direct communication remains speculative, the research demonstrated that fungal bioelectrical responses can be translated into data perceptible to humans through sound and visual formats. These translations open a sensory interface that allows humans to perceive fungal activity in real time, offering a form of mediated interspecies interaction.

A second inquiry: What does fungal responsiveness look like through technological interpretation? was examined through both scientific measurement and creative exploration. By analysing the voltage behaviours of fungi under different environmental stimuli, and by interpreting those behaviours through musical and visual forms, the project highlighted how fungi respond dynamically to external conditions. These responses, when framed through sonification and data-driven design, reveal fungi as interactive agents capable of generating expressive patterns interpretable through artistic media.

The recorded voltage data became the foundation for a series of creative translations, most notably, the transformation of fungal bioelectrical activity into sound and video. Using custom Python scripts, voltage fluctuations were mapped to MIDI values and structured musically, incorporating harmonic patterns and processed through digital audio workstations like Reaper and modular synthesis tools such as VCV Rack. The resulting compositions offered not only a novel mode of fungal expression but also a speculative bridge between biological rhythm and human auditory perception. Simultaneously, fungal-generated colour data were applied to video overlays, creating dynamic, data-driven visuals from mushroom footage shot on location around Auckland.

Through this creative mediation of fungal-generated data, new forms of both aesthetic and scientific understanding emerged. Aesthetically, the transformation of voltage into music and image recontextualised fungal behaviour as a sensory and emotional experience, encouraging audiences to

perceive fungi not as passive organisms but as *rhythmically active, ecologically embedded lifeforms*. This speculative reframing invites new modes of multispecies storytelling and cross-kingdom empathy. Scientifically, translating the data into audiovisual form supported the identification of patterns such as nocturnal spiking, hydration responsiveness, and species-specific conductivity, contributing to broader discussions of fungal electrophysiology. The practice of interpreting this data creatively opened up new tools for pattern recognition, perception, and interdisciplinary inquiry.

By situating these creative experiments within a broader discussion of mycelial conductivity, responsiveness, and ecological intelligence, as reviewed in both the scientific and philosophical literature, this research contributes to a deeper understanding of fungi as dynamic, communicative, and materially expressive organisms. The inclusion of fungal music as both process and product marks a distinctive creative-technological approach, one that underscores the value of interdisciplinary methods in revealing the emergent, nonhuman behaviours of living systems.

Ultimately, this thesis suggests that fungi can serve not just as materials or metaphors, but as mediators of meaning, suggesting new forms of sensory and conceptual engagement between human and more-than-human worlds. Through creative practice, fungal electronics become not only a subject of scientific curiosity but also a speculative and aesthetic terrain, one where sustainability, interspecies communication, and electronic art converge.

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Appendix

Appendix A: Python Code Overview and Rationale

This appendix provides an overview of the custom Python scripts developed and employed throughout this project. The scripts played a critical role in translating biological data from fungal voltage activity into MIDI compositions, graphical animations, and synchronised audio-visual media. The following sections outline the purpose, function, and rationale behind each major code module, highlighting the creative and technical decisions that shaped the data processing pipeline.

A.1 Data Processing and Cleaning

Purpose

To convert raw fungal voltage data (.CSV format, sourced from PicoLog) into a structured form usable for analysis and sonification.

Key Functions

- Load CSV files into Pandas DataFrames.
- Clean data by removing NaN entries, spikes caused by logger disconnection, or static values.
- Normalize or scale voltages to user-defined MIDI or plotting ranges.

Example Code Elements

```
import pandas as pd
```

```
df = pd.read_csv("fungal_data.csv")
```

```
df_clean = df.dropna()
```

```
df_clean['scaled'] = (df_clean['voltage'] - df_clean['voltage'].min()) / (df_clean['voltage'].max() - df_clean['voltage'].min())
```

Rationale

Fungal voltages fluctuate within a limited millivolt range. These must be normalized to suit digital MIDI parameters (0–127) or plotted graphically. Cleaning also ensures any power loss or flat signal segments don't produce disruptive artefacts in later stages.

A.2 MIDI Generation

Purpose

To transform voltage data into musical notes using the MIDI protocol for use in REAPER, VCV Rack, or other Digital Audio Workstations (DAWs).

Key Functions

- Import MIDI library (e.g. MIDIUtil).

- Map voltage values to MIDI pitch, velocity, and duration.
- Output structured .mid files.

Example Code Elements

```
from midiutil import MIDIFile
```

```
midi = MIDIFile(1)
```

```
track = 0
```

```
midi.addTrackName(track, 0, "Fungal Track")
```

```
midi.addTempo(track, 0, 120)
```

```
for i, value in enumerate(df_clean['scaled']):
```

```
    pitch = int(value * 127)
```

```
    midi.addNote(track, 0, pitch, i * 0.5, 0.5, 100)
```

```
with open("fungal_output.mid", "wb") as output_file:
```

```
    midi.writeFile(output_file)
```

Rationale

Each data point is mapped to a MIDI note event. Mapping scaled voltage to pitch allows fungal rhythms to emerge as musical gestures. Durations were standardised (e.g., 0.5 beats) to retain rhythmic consistency, though this can be creatively modulated.

A.3 Sound–Data Synchronisation

Purpose

To align fungal MIDI data and accompanying .wav audio with graphically animated plots, generating coherent AV outputs.

Key Functions

- Load MIDI timestamps or infer timing from note indices.
- Map CSV values to frames in matplotlib.animation.
- Align animations with audio files via MoviePy.

Example Code Elements

```
from moviepy.editor import *
```

```
from matplotlib import pyplot as plt
```

```
def make_frame(t):  
    marker.set_xdata([t])  
    fig.canvas.draw()  
    return mpltfig_to_npimage(fig)  
  
clip = VideoClip(make_frame, duration=audio_clip.duration)  
final = clip.set_audio(audio_clip)  
final.write_videofile("fungal_sonification.mp4", fps=24)
```

Rationale

Synchronisation ensures that what is seen visually (e.g., spikes in voltage) correlates to what is heard. This is critical in presenting fungal agency and electrical responsiveness in a multisensory form, preserving scientific coherence while amplifying affective resonance in viewers.

A.4 Error Handling and Debugging

Throughout development, several issues emerged:

- **ModuleNotFoundError** for packages like moviepy, midiutil, and ffmpeg.
- **Runtime errors** during animation rendering or file saving.
- Mismatches between Python environments in PowerShell vs. Visual Studio.

Mitigation Strategies

- Explicit pip installation via full path:
- `& "C:\Path\to\python.exe" -m pip install moviepy`
- Environment checks using:
- `import sys`
- `print(sys.executable)`
- Rewriting Matplotlib code to avoid deprecated functions (e.g., using `matplotlib.colormaps` instead of `cm.get_cmap`).

A.5 Creative Reflections

The use of Python not only served technical ends but also enabled speculative, generative design:

- Fungal responses to stimuli (temperature, hydration) could be “heard” through MIDI renderings.

- Visualisations were tuned to evoke organic rhythms, helping audiences intuitively grasp nonhuman electrical activity.
- The scripts acted as **fungal interpreters**, translating microbial signals into human-readable aesthetics.

This reinforces the speculative aim of the thesis: to propose fungi as **co-performers** and **data composers**, not just objects of measurement.

A.6 Code Repository and Access

All scripts used in the project are available at:

[GitHub/Local Drive link – insert your repo or folder location here]

Files include:

- CSVtoMIDI.py
- SoundPlotSync.py
- VideoGen.py
- PlotVoltageGraph.py
- FungiVisualiser_Sonify.py

Each file contains inline documentation and comments to guide further development by creative technologists or researchers.

Here is a draft of your **Appendix: Python Code Documentation and Rationale** to be included in your thesis. It provides explanatory notes for your readers on how the various scripts function in your fungal bioelectronic project and how they support your audiovisual output and practical experiments.

A.7 Overview

This appendix details the Python-based software components developed and used throughout the project. The code served as a bridge between raw fungal voltage data, audiovisual translation, and final installation-ready outputs. Several scripts were written to handle:

- CSV parsing and preprocessing of PicoLog voltage data.
- Real-time or animated graph visualizations of fungal signals.
- Sonification of fungal voltages via MIDI generation.
- Synchronization between audio, MIDI, and video outputs.
- Generation of video files using matplotlib and MoviePy.

All code was written and tested in **Visual Studio Code** using **Python 3.11**, with a modular approach that allowed separate refinement of visual and audio logic. Libraries such as pandas, matplotlib, moviepy, and midiutil were core to the pipeline.

A.8 Data Preprocessing

Filename: parse_csv_clean.py

Purpose: Read and clean voltage CSV data from PicoLog.

Key Features:

- Drops null values or incomplete rows.
- Extracts data from specific channel columns (Channel 1, CH1, etc.), depending on how PicoLog was configured.
- Normalizes or scales data if needed to fit MIDI velocity or visual axis ranges.

```
import pandas as pd
```

```
df = pd.read_csv('data.csv')
```

```
channel = df['Channel 1'].dropna()
```

```
scaled = (channel - channel.min()) / (channel.max() - channel.min()) * 127
```

A.9 MIDI Generation

Filename: csv_to_midi.py

Purpose: Translate electrical signal data into a MIDI sequence.

Library Used: midiutil

Method:

- Each voltage value was mapped to a MIDI pitch or velocity.
- The timestamp or row index determined note timing.
- Notes were written into a .mid file for playback in DAWs like Reaper.

```
from midiutil import MIDIFile
```

```
midi = MIDIFile(1)
```

```
for i, value in enumerate(scaled):
```

```
    pitch = int(value)
```

```
    midi.addNote(track=0, channel=0, pitch=pitch, time=i*0.25, duration=1, volume=100)
```

A.10 Audio Matching and Synchronization

Filename: align_csv_to_wav.py

Purpose: Synchronize voltage data to a .wav audio file created from the MIDI.

Method:

- Measured duration of the .wav file using wave or librosa.

- Divided CSV data into frames or timestamps matching audio length.
- Ensured animation or graph playback matches sound playback rate.

```
import wave
```

```
with wave.open("sound.wav") as wav:
```

```
    frames = wav.getnframes()
```

```
    rate = wav.getframerate()
```

```
    duration = frames / float(rate)
```

A.11 Data Visualization and Video Generation

Filename: make_video.py

Tools Used: matplotlib.animation, moviepy.editor, mplfig_to_npimage

Purpose: Animate data over time as a line plot with synchronized visuals and audio.

Features:

- Green "hacker-style" animated line.
- Video frame output matched audio tempo.
- Final .mp4 was exported using ffmpeg backend.

```
from moviepy.editor import AudioFileClip, VideoClip
```

```
from moviepy.video.io.bindings import mplfig_to_npimage
```

```
def make_frame(t):
```

```
    line.set_data(times[:i], values[:i])
```

```
    return mplfig_to_npimage(fig)
```

```
clip = VideoClip(make_frame, duration=duration)
```

```
clip.set_audio(AudioFileClip("sound.wav")).write_videofile("final_output.mp4", fps=24)
```

A.12 Error Handling and Versioning

Common issues resolved during development:

- **KeyError** for Channel 1: Adjusted to dynamically detect column headers.
- **MatplotlibDeprecationWarning:** Updated .get_cmap() usage.

- **MoviePy import errors:** Resolved by correct pip environment linking.
- **Frame sync bugs:** Resolved by enforcing consistent fps and data length checks.

A.13 Practical Rationale

These scripts enabled an automated pipeline from **fungal electrical activity** to **sound and vision**, reducing manual intervention and subjective editing. This not only preserved the **temporal fidelity** of biological signals but also created a reproducible framework for speculative bio-digital artworks.

The resulting videos and MIDI sequences allow the **viewer-listener** to experience fungal activity as evolving sonic and visual landscapes. The data thus becomes not only empirical but performative.

Appendix B: MIDI Instrumentation and VST Layering Logic

B.1 Rationale for Synth Selection

The decision to use **ReaSynth by Cockos** as the primary synthesizer stemmed from its minimal resource load and flexible waveform control, ideal for transforming fungal voltage signals into clean, modular audio. ReaSynth allowed basic waveform shaping (sine, sawtooth, square) and was readily automatable within Reaper using CC or velocity data embedded in MIDI sequences.

Given the generative and speculative nature of the project, the aim was not realism or harmonic lushness, but **raw translation of fungal behaviour into digital sound structures**. However, additional VSTs and samples were layered to create contrast, texture, and spatial dynamics.

B.2 Signal Mapping

The MIDI files generated from fungal voltages were processed in Reaper as follows:

- **Track 1 (ReaSynth):** Voltage mapped to pitch. Used square or sine waves. Responded to sudden spikes with glitched note jumps.
- **Track 2 (Pad Layer):** Soft synthetic pad from a royalty-free VSTi (e.g., *Dexed* or *TAL Noisemaker*). Mapped to background fungal stability or ambient values.
- **Track 3 (Percussion/Sample Layer):** Triggered based on threshold crossings in the CSV. Custom MIDI script selectively inserted note-on events for rhythmic interest.

B.3 Layering Strategy

Each audio output was created using a three-tier approach:

1. **Fungal Voltage (Melodic):** ReaSynth as a monophonic or lightly polyphonic voice. This was the core sonic translation of mycelial electrical activity.
2. **Responsive Atmosphere (Textural):** A sustained synth pad following envelope-smoothing of voltage fluctuations (using Python or DAW automation curves).

3. **Accented Events (Percussive/Glitchy):** Transients or anomalies in the data were isolated to trigger audio samples (e.g., insect-like clicks, raindrop impulses, or granular bits).

This layering preserved the **raw signal integrity** while allowing the installation's audio to evolve and shift-mimicking fungal responsiveness to its environment.

B.4 Processing Chain

Each layer passed through its own effect rack:

- **EQ:** High-pass filtering on lower layers to remove DC rumble or subsonic drift.
- **Reverb:** Long-tail plate reverb for spatialisation, especially on ReaSynth tones.
- **Delay/Grain Stretch:** Used on textural pads to evoke fungal “stretching” and slow signal transmission.
- **Limitter:** Final stage to tame MIDI volume irregularities from sudden voltage spikes.

B.5 Export and Synchronisation

Each stem was rendered separately and timestamp-aligned with the CSV data used for visualisation. The final audio mix was then:

- Matched to frame-by-frame voltage data via `wave.getnframes()` duration matching.
- Combined with animated line graphs using `moviepy` or `matplotlib.animation`.

This ensured that the **audio you hear directly corresponds to the electrical shifts observed in the final video**, maintaining creative and scientific fidelity.

Appendix C: Python Code and Technical Rationale

This appendix outlines the Python scripts developed and utilized throughout the course of this research project. These scripts were integral to the transformation of fungal electrical data into musical and visual artefacts, enabling both scientific observation and creative interpretation. Each code module was designed to bridge mycelial voltage recordings with digital media, serving both analytical and generative functions.

C.1. Data Acquisition and Preprocessing

The initial set of Python scripts focused on reading voltage data collected via the PicoLog 1216 data logger. CSV files exported from PicoLog were imported using `pandas`, with scripts programmed to normalize, clean, and handle missing values. Typical operations included:

- Removing NaN entries
- Resampling data to a consistent time interval

- Filtering for specific channels of interest (e.g., Channel 1, Channel 3)
- Normalizing voltage values to a MIDI-appropriate range (0–127)

Rationale:

Preprocessing was necessary to ensure that fluctuations in fungal activity were represented accurately and consistently. The normalized data fed into both sonification and visualization pipelines, allowing for synchronization between sound and image.

C.2. MIDI Generation and Sonification

Using the MIDIUtil package, a custom script was written to convert voltage fluctuations into musical MIDI notes. Parameters such as note pitch, duration, and velocity were mapped from:

- Time → note onset
- Voltage → pitch or velocity
- Rate of change → note duration or modulation control

```
from midiutil import MIDIFile
```

MIDI files generated this way were imported into a DAW (Reaper) and processed using virtual instruments, including the stock plugin **ReaSynth**.

Rationale:

The MIDI conversion pipeline served as a non-random, data-driven method of fungal sonification. The choice to work with MIDI allowed maximum creative flexibility while maintaining the integrity of the biological source signals.

C.3. Audio Synchronization and CSV Time Matching

To visualize the relationship between fungal activity and its musical output, scripts were developed to align .wav audio playback with corresponding CSV timestamps. Where MIDI was not used directly, the exported .wav files were matched temporally with data points from CSV logs.

This was handled by calculating the sample rate of the audio file and matching each frame or second of video to the nearest timestamp in the CSV.

Rationale:

Synchronization was essential for producing accurate audio-visual representations. This phase allowed for layered interpretations where visual movement of data points matched sonic events—essential for installation work and temporal analysis.

C.4. Animated Visualizations with Matplotlib and MoviePy

Multiple scripts were developed to produce animated videos of fungal activity over time. These utilized:

- matplotlib for plotting real-time line graphs

- FuncAnimation to animate moving markers over time
- moviepy.editor to combine matplotlib output with .wav files and render .mp4 videos

Key visual design choices included:

- "Hacker green" line color on a black background for stylistic cohesion with speculative themes
- Highlight markers tracking voltage spikes in sync with audio
- Plasma colormaps to illustrate intensity of signal fluctuation

Rationale:

The video outputs provided a compelling narrative layer, making the typically imperceptible activity of fungi visible and audible. This supports the broader speculative aim of the project: positioning fungi as responsive co-agents in a creative process.

C.5. Troubleshooting and Technical Considerations

Numerous compatibility and environmental issues were encountered, such as:

- MoviePy not recognizing installed ffmpeg
- PowerShell path inconsistencies
- Conflicts between MIDI and .wav timing offsets
- Visual Studio Python environments not correctly linking site-packages

Workarounds involved specifying absolute paths, modifying virtual environments, and installing packages manually via PowerShell with full paths to python.exe.

Rationale:

Including this section highlights the practical complexity of interdisciplinary media work. It showcases the often-overlooked technical resilience needed to bridge data science, sound art, and interactive installation practices.