


SYMBIO- PHONE

Interfaces for Unheard
Communications

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ABSTRACT

Considering the vital role of fungi in biological communities and their capacity to detect sound-induced vibrations from the environment, this study draws from scientific and artistic methodologies to initiate a discussion on how sound can shape and help restore ecosystems. Fungi establish mycorrhizal networks, an intricate communication system created by mycelium interweaving with the roots of various plants and trees, linking entire ecological communities. Understanding how sound influences the symbiotic dynamic of these networks offers a non-traditional approach to ecosystem restoration, aiming to nurture ontologies of care and encourage ethical practices for multispecies interactions. To uncover and address the hidden dialogues in which we unwittingly engage, this article presents an introductory study on mycelium's responsiveness to specific sound frequencies, pursued during the development of the installation *Symbiophone*.

Keywords: Symbiosis; Mycorrhizal Network; Sound; Growth Pattern; Bioart.

1. INTRODUCTION

Symbiosis characterises intimate and vital relationships between two or more organisms from distinct kingdoms. This term applies not only to mutually beneficial exchanges, such as associations between fungi and trees, but also to commensalism or parasitism interactions (Timurgalieva *et al.*, 2022). In such a bounded existence, the association is vital for survival of at least one of the species involved. Hybrid organisms such as lichens developed from a continuous process of symbiotic mutualistic interaction between fungi and algae or cyanobacteria. But these are not the only organisms that evolved through processes of symbiogenesis. The permanent incorporation of multiple bacteria as mitochondria inside animal and plant cells is a key factor in supporting theories of evolution through endosymbiosis (Margulis, 2013/1998), which attributes the development of all life forms to symbiotic processes.

When considering symbiosis as a crucial evolutionary force and a core dynamic in multispecies relations, the term expands to signify an underlying nature embedded in the entanglement of all living and non-living entities. To exist in symbiosis implies that entities and substances experience ongoing

intra-actions, a term employed by Karen Barad (2007) to emphasise how entities mutually constitute each other through their interrelation. Symbiosis, therefore, recognises how living and non-living agents are porous systems that experience a permanent state of *trans-corporeality* (Alaimo, 2010). For Stacy Alaimo (2010), *trans-corporeality* refers to how bodies are plural entities with permeable physical boundaries in continuous exchanges with others. Importantly, exploring agency as a symbiotic dynamic offers a valuable framework for multispecies interactions. A framework that emphasises the importance of mutually beneficial encounters by addressing how organisms engage not only in mutualistic relationships but also in parasitic hosting, cautioning against the exploitation of others as a result of this interaction. Existing in symbiosis, therefore, calls for awareness in our *intra-actions* (Barad, 2007) insofar as they are entangled within a broader ecological and relational network.

When considering human agency and its impact within the biosphere, the primary focus often rests on direct mechanical changes. Subtler impacts of set entanglements often go unnoticed and may have unforeseen consequences for biological communities. However, by attending to the distinct ways organisms perceive their surroundings, we might begin to recognise invisible forces shaping the symbiotic dynamics of ecosystems. What humans perceive as sound can be sensed by mycelium as electrical impulses. Fungi can perceive sound stimuli and vibrations from the environment (Roberts & Adamatzky, 2022) by receiving and transmitting information through electrical impulses across thread-like filaments called hyphae (Dey *et al.*, 1996). These filaments can form vast underground webs of mycelium, which link different fungal colonies and connect individual plants and trees, creating a mycorrhizal network (Dey *et al.*, 1996). This network promotes the transference of water, nitrogen, carbon, and other minerals, especially during times of environmental stress, such as droughts (Das & Sarkar, 2024). While current research may not yet fully attribute forest management to the mycorrhizal network (Karst, 2022), it is clear that this network enables symbiotic interspecies *intra-action* (Barad, 2007), vital for ecosystems.

If fungi are capable of perceiving sound stimuli from their environment to what extent are mycorrhizal networks affected by sounds created by human agency? Consequently, do these disturbances affect entire biological communities? What interesting insights does the entanglement between sound and fungi reveal on symbiotic dynamics, and how can this knowledge contribute to nurturing ethics of care for multispecies relations? How to make these processes tangible?

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First of all, it seemed straightforward to limit the scope of this introductory research to the exploration of how mycelium alone is affected by sound, particularly sine wave frequencies. Additionally, to identify appropriate methodologies for exploring intra-actions between sound, mycelium, and human agency, it was fundamental to think of communication not only as a verbal and human-centred phenomenon but also as a multispecies relational force capable of mediating interactions and influencing biological development. Accordingly, the installation *Symbiophone* (figure 1) functions as an interface between humans, machines, and mycelium, wherein sound actively elicits observable responses in mycelium growth. An interface can be defined as “a system or device through which unrelated entities can interact”, simultaneously presenting “characteristics that are common to each of the entities it connects” (Sá, 2019, pp. 479-482). In this context, *Symbiophone* proposes non-verbal communication with fungi, where the responses to this communication become visible through the shifting patterns created by mycelium.

Furthermore, this installation establishes a space of mutual exposure, where the invisible effects of sound are made perceptible in different mycelium morphologies. At the same time, human participants are subjected to the invasive sound reproduced by the system, highlighting the entangled nature between distinct organisms. The project aims to address the disruptive intra-actions between humans and non-human life forms while questioning how sound contributes to shaping ecosystems. Ultimately, *Symbiophone* situates itself at the intersection of speculative biology, ecological ethics, and installation art, opening possibilities for using sound as a tool in ecosystem restoration.



Fig.1 - Symbiophone installation, photographic documentation. Universidade Católica Portuguesa, Porto. © Author.

2. STATE OF THE ART

In regions characterised by high industrial activity and dense population, noise pollution has risen significantly and is now recognised as a serious threat to the health of ecosystems. To understand how city noise affects urban plant species, researchers examined how “growth, hormonal balance, oxidative damage, and activity of antioxidant systems” (Kafash *et al.*, 2022, p. 1) varied in plants exposed to daily traffic noise. The researchers identified that urban sounds induced stress response mechanisms in the exposed plants. Triggering these mechanisms led to “significant decrease in growth indices” derived from “oxidative damage and interference with hormonal balance” (Kafash *et al.*, 2022, p. 1).

On the other hand, playing specific frequencies, music, or natural sounds to plants can affect their growth and improve their resistance to diseases. Studies conducted on cabbages and cucumber plants showed that exposure to 20 kHz sound waves and to “green music” (compositions with classical music and natural sounds such as birds, insects or water) “caused significant elevations in the level of polyamines (PAs) and increased uptake of oxygen O₂ in comparison with the controls” (Qin *et al.*, 2003, p. 407). This correlates with plant’s health improvements, leading to the conclusion that “sonic exposure, particularly to ‘green music’, could increase the yield of the crops and control some insect pests in several vegetables” (Qin *et al.*, 2003, p. 407).

Responses to sound stimuli are similarly observed in bacteria. Some frequencies can trigger stress mechanisms that induce the synthesis of compounds with growth-inhibiting properties, while others boost the growth of bacterial colonies. Research conducted on *E. coli* K-12 exposed to different frequencies indicates that the exposed samples “owned a higher biomass and a faster specific growth rate compared to the control group” (Gu *et. al.*, 2016, p. 1). It was also reported that the “biomass of *E. coli* K-12 increased more than 13.3%, 15.3% and 6.8% for the sound treatment at 1 kHz, 4 kHz and 10 kHz” (Gu *et. al.*, 2016, p. 9) in comparison with a control sample.

Regarding fungi, it has been hypothesised that some species are induced into producing fruit bodies by environmental vibrations from falling trees or rain (Kobayashi *et.al.*, 2023). To identify if specific frequencies could represent a possible alternative to chemical fungicides that control plant diseases, researchers exposed the fungus *Botrytis cinerea* to frequencies ranging from 1 to 5 kHz. The results show that samples exposed to wave

frequencies of 5 kHz exhibited “morphological changes, including low mycelial density, swollen mycelial tips, and irregular mycelial surfaces” which translates into “significantly inhibited mycelial growth and spore germination” (Jeong et al, 2013, p. 377). It has also been observed that different species react differently to the same sound stimuli, where a “frequency of 250 Hz over a period of 10 days proved to be more effective in inhibiting the growth of *A. niger* and *B. cinerea*” (Razavizadeh et al., 2024, p. 1705). Furthermore, recent observations, yet to be peer reviewed, on *Trichoderma Harzianum* also suggest that exposure to 8Hz at 70dB and 90dB during 5 days resulted in increased biomass, greater decomposition, and enhanced spore activity (Robinson & Cando-Ducancela, 2024). These studies propose that fungi’s responses to sound can vary in particular ways within each species, changing with the characteristics of the sounds reproduced and from organism to organism.

Despite growing research in the field, the vast diversity within the fungi kingdom highlights a significant gap in our understanding of how sound affects different species. This raises the question of which sound characteristics determine the inhibition or enhancement of growth in fungi? Is there a distinction between the sounds that enhance pathogenic species and the sounds that enhance the growth of species beneficial to the ecosystem, such as those part of the mycorrhizal network? There is a lack of documentation that specifically analyses the effects of sound on the morphology of mycelium, as well as a lack of exploration of many different fungal species. Namely, there are few analyses on arboreal fungi, which play a crucial role in the mycorrhizal network by directly connecting to the roots of trees. There are also no references to how saprophyte parasitic species, such as *Armillaria mellea*, are affected by sound. From an ecological perspective, understanding the responses of parasitic species to sound appears to be a promising approach as a substitute for pesticide use, proposing sound as a path for the restoration of biological communities. Furthermore, the focus of the mentioned research is purely scientific. How can this relation between sound and fungi become tangible through an embodied practice?

Invested in exploring entanglements with the non-human, the artist Theresa Schubert combines academic investigation with direct engagement with the forest to develop a multidisciplinary approach to fungi. Fuelled by a series of walks in the forest, Schubert focuses on exploring the effects of sound frequencies on the arboreal fungus *Pleurotus Ostreatus* as a direct medium for interaction and communication. Attending to previous research on plant acoustics where “a measurable response in roots occurs at 220Hz”, Schubert exposes

these fungi to 220 Hz, 110 Hz, and 440 Hz frequencies (Schubert, 2020, p. 73). Her observations indicated that some samples had strong responses to sound exposure while others were inconclusive. Upon translation of the laboratory results into the development of her artwork, the artist encounters a profound contradiction at the heart of her creative process. Although Schubert intended to engage in an embodied communication with fungi, she became aware of an inherent tension caused by the “unavoidable anthropocentrism” embedded in scientific experimentation. For the artist, the gesture of collecting, isolating, and studying species in a laboratory setting, separated from their habitat, is an “act of human-imposed control and reduction in contrast to nature’s freedom and complexity” (Schubert, 2020, p. 73). These processes stand in contrast to the unpredictable and intricate ways in which fungi interact. Hence, this research was expanded into an aesthetic experience entitled *Sound for Fungi. Homage to Indeterminacy* (2020). Instead of including live organisms, the multiplicity of fungi’s agency becomes visible through digital mediation. Visitors were encouraged to interact with a 3D code-based generative video simulation of mycelium’s growth in real time, complemented with arrangements of photos, drawings, and diagrams from the research process.

Also working through digital mediation, in the workshop *Radio Mycelium*, Martin Howse reimagines the mycorrhizal network’s role in ecological and technological contexts. Adopting direct engagement with living fungi in their natural habitat, Howse assists participants to build DIY radios and sculptural antennas that reproduce the signals emitted by growing fungi (Art Laboratory Berlin, 2022). Within this collective project, fungi are not passive organisms but active agents in direct co-creation with humans. Through this interface, knowledge and techniques concerning inter-species communications are brought into discussion. Both of these distinct practices render invisible biological processes into tangible experiences, offering compelling modes of interaction and engagement with non-human organisms.

Yet much remains to be explored. A substantial path lies ahead in understanding how different sounds affect mycelium, mycorrhizal networks, and, by extension, the broader forest ecosystem. Questioning the impacts of anthropogenic sound on living organisms and uncovering these dismissed dialogues may hold the potential not only to restore damaged ecosystems but also to deepen our understanding of the interconnectedness of all life forms. This focal point precedes a central question to the present research: how to experience the entanglement between fungi and sound in an embodied manner?

3. INSTALLATION DEVELOPMENT

To explore the entanglement between sound and mycelium through an embodied approach, the research to develop *Symbiophone* required a hybrid methodology that combined experimental laboratory procedures with aesthetic and creative decision-making. The complexity of working with living organisms also demanded attentiveness to material and sensory dimensions, which played a crucial role in shaping key aspects of the installation.

The steps outlined in this article aim to clarify the procedures undertaken before the assembly of the installation in order to prepare mycelial samples for exposure and to develop a sound reproduction system. Furthermore, this documentation also presents and discusses the first trial of this installation as well as the insights gained for further research.

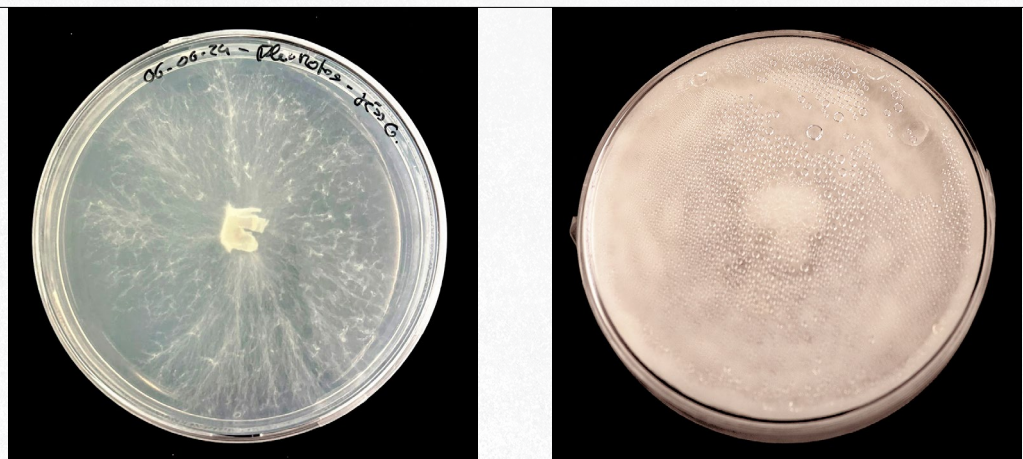
3.1. LABORATORY PROCEDURES



Fig. 2 - Samples in the climate chamber (06/06/24), Conservation and Restoration laboratory at Universidade Católica Portuguesa, Porto. © Author.

This project naturally began with a process of familiarisation with laboratory techniques, procedures, and safety protocols to avoid any dangerous contaminations, especially when handling *Armillaria mellea*. This process included the inoculation and isolation of various fungal species, such as *Ganoderma*, *Trametes*, *Bjerkandera*, *Lentinula*, *Pleurotus*, and attempts to inoculate *Armillaria mellea* (one of the species of special interest for its voracious parasitic behaviour). Different forms of fungal matter were used to do so, including live matter, spores, hyphae, and, in some cases, mushroom powder.

Each species was inoculated into Petri dishes with nutrient solutions of agar and placed in a thermal chamber (figure 2). The composition of the agar medium has a deep influence on the mycelium's morphology. The growth rate and hyphae spread vary in function of nutrient availability; the fewer nutrients, the more mycelium has to spread to feed. As such, the species were inoculated in solutions of agar Czapek Dox Agar (CDA), with fewer nutrients, and Potato Dextrose Agar (PDA), richer in nutrients, for comparison. It was decided that the most favourable structures for direct observation were those that spread wider on the dish, exhibited better-defined rhizomes or a less dense growth, which were more consistently observed in the CDA medium across the majority of the species tested.



Figs. 3-4 - *Pleurotus* sample from live matter (inoculation on 06/06/24) CDA medium. © Author.

As observed in the figure 3, the sample of *Pleurotus Ostreatus* exhibits a more well-defined radicular pattern dispersed throughout the Petri dish in comparison to the sample in the PDA medium of the figure 4.

A different medium was also tested, Czapek Dox agar with yeast (CDA + yeast), for added nutrients. This experiment showed faster growth, slightly less stretched through the Petri dish in most species. In the *Bjerkandera* sample, denser and less dispersed growth can be observed in figure 5 compared to figure 6, which led to further confirmation of the chosen medium.

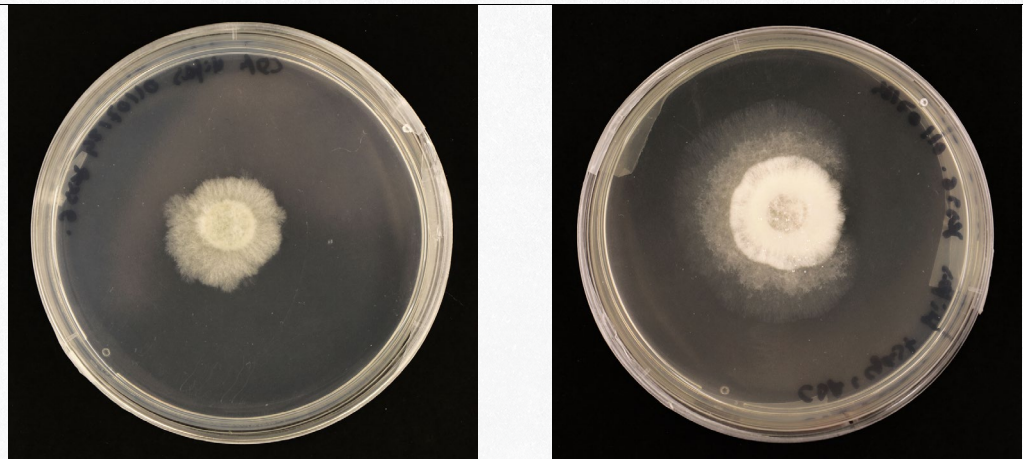


Fig. 5 – Bjerkandera sample (inoculation on 01/07/24) CDA medium. © Author.

Fig. 6 – Bjerkandera sample (inoculation on 01/07/24) CDA + yeast medium. © Author.

Unavoidable contaminations of *Trichoderma* and *Aspergillus* were growing in some of the samples, particularly in species inoculated from powder and wood pallets (figure 7 and 8). The inoculations with *Armillaria mellea* were also contaminated, making it difficult to distinguish *Armillaria* from the contaminating species (figure 8). This led to the conclusion that in future experiments it would be necessary to either collect samples from a natural environment in the fruiting body season, or to grow the mushroom bodies before inoculation. Despite this decision, there were still attempts to isolate the species, but none yielded positive results.

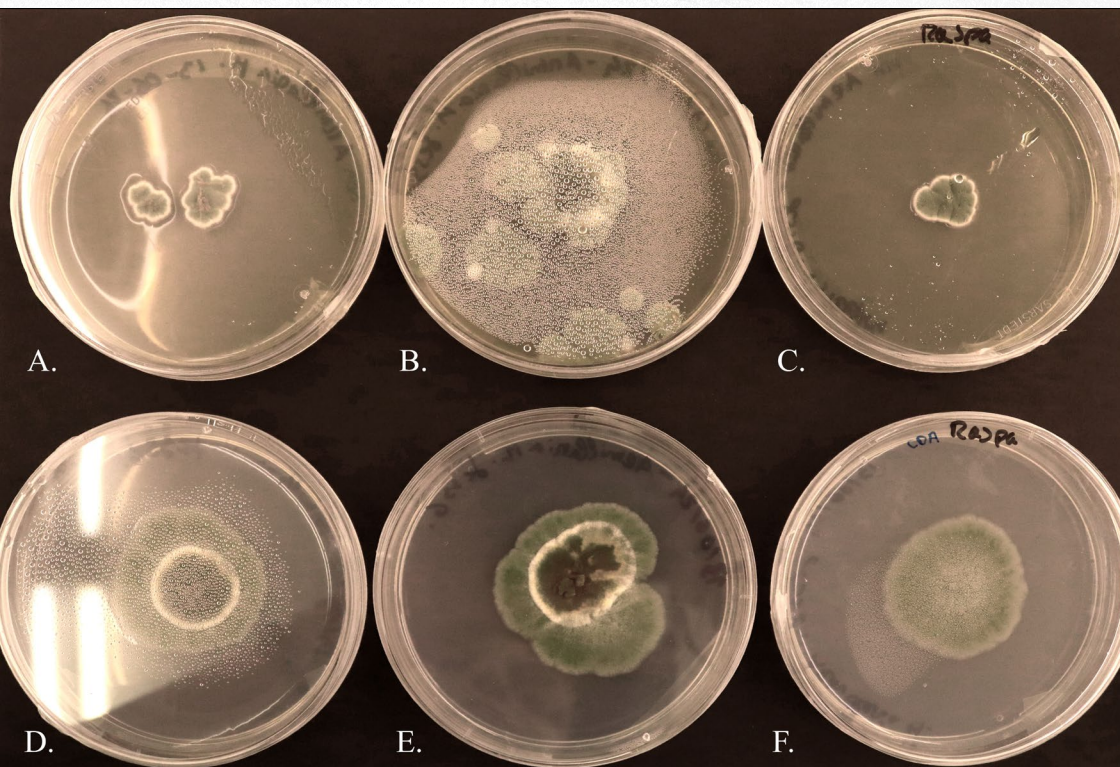
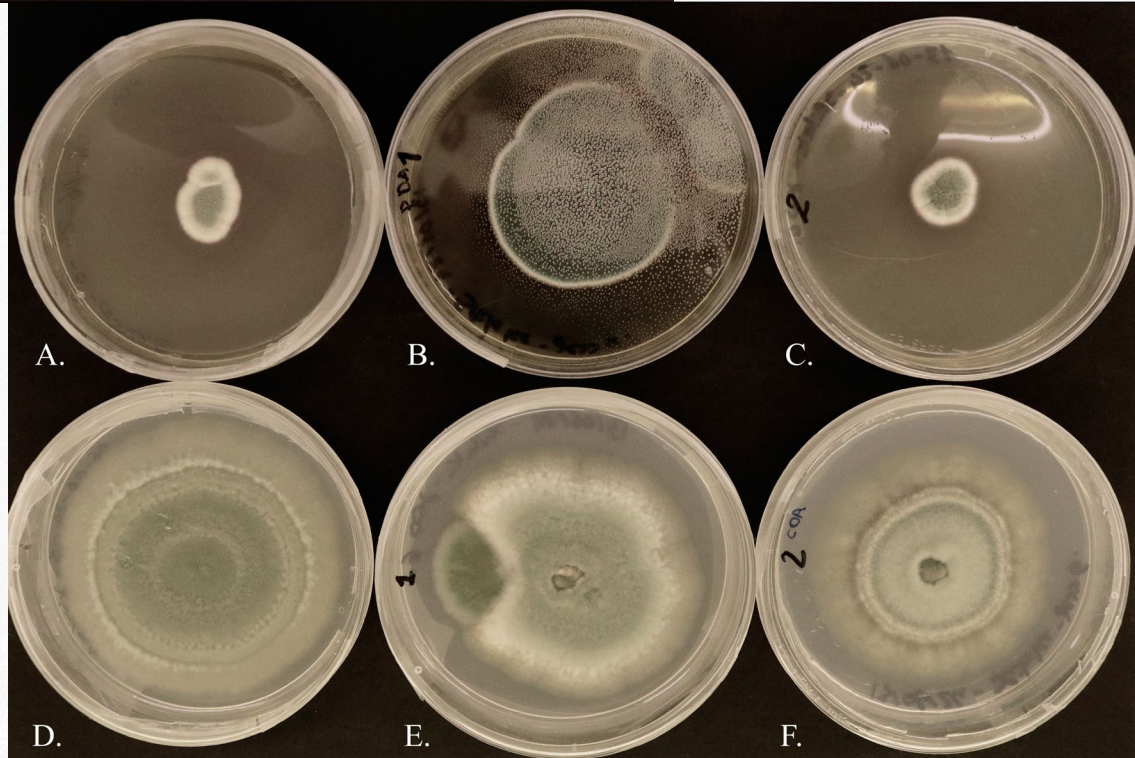


Fig.7 - *Armillaria mellea* samples from wood pellets (inoculation on 13/06/24) CDA medium. © Author.

Fig. 8 - *Lentinula* samples from powder and *Trametes* samples from powder (inoculation on 13/06/24) PDA medium. © Author.



The growth of these unexpected organisms evidences a clear process of transculturality and intra-action between different species, where invisible and unforeseen relations become tangible. This entanglement is especially observed in samples where the development of contaminating species directly influences, and in some cases inhibits, the growth of the inoculated fungi. In some instances, this entanglement completely inhibits the growth of the inoculated fungi. These multispecies dynamics are also tangible in samples where more than one species grows interwoven, forming a hybrid colony (figure

7, sample D and E) or co-existing separately in the same Petri dish (figure 8, sample E).

In light of the observation of the distinct characteristics of different species, it was decided that the first frequency test would be performed using a species considered a contaminant. As shown in figures 9 and 10, when cultivated on CDA medium, *Trichoderma* exhibits a circular growth pattern marked by white stripes and green pigmentation after spore maturation. These clear visual markers not only facilitate the observation of its growth pattern but also result in visually striking and compelling formations. Furthermore, certain *Trichoderma* species are recognised for their ecological benefits, particularly for promoting soil health and supporting plant growth, often acting as natural antagonists to parasitic fungi (Robinson & Cando-Ducancela, 2024). This decision deliberately subverts the conventional trajectory of laboratory research, opening space for divergence from initial preconceptions of the results, embracing the nature of biological processes. By working with what would be considered an error, the research foregrounds a methodology that values uncertainty and the productive potential of failure.

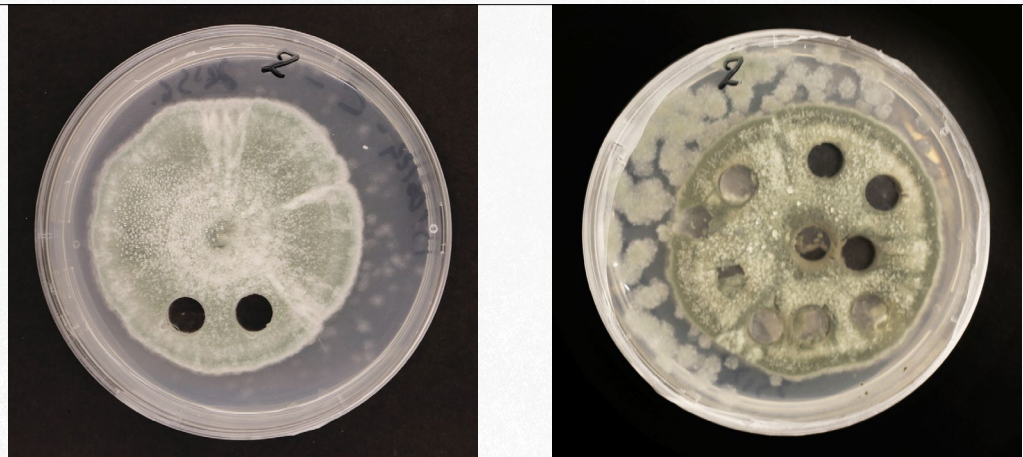


Fig. 9 - Contaminated Trametes sample from powder (inoculation on 13/06/24) CDA medium. © Author.

Fig. 10 - Trametes sample from powder (inoculation on 13/06/24) CDA medium. © Author.

Through these laboratory procedures, it was observed that mycelium needed a period of at least 7 to 14 days to colonise most of the Petri dish. When co-creating with organic life, it is important to understand and respect different rhythms of growth, which do not align with the pace that human life has become accustomed to in today's digital landscape. This factor defined the length of this installation to seven days. Nonetheless, this time frame proved insufficient for

complete medium colonisation and mycelium maturing in the given conditions.

3.2. SYSTEM DEVELOPMENT



Fig. 11 – System assembly, photographic documentation. © Author.

Fig. 12 – Installation assembly, photographic documentation at Universidade Católica Portuguesa, Porto. © Author.

The system for reproducing the frequencies was assembled with five 165mm speakers connected to five mini audio amplifiers (figure 11). These mini amplifiers were in turn linked to a Focusrite soundboard connected to a computer. The frequencies were played from a Max patch (figure 13) built with six different possible sine waves to be played continuously. In the first assembly of this installation, only five channels were used to reproduce a frequency (figure 12).

The sixth speaker was independently connected to a mini audio amplifier equipped with a headphone output cable. This allowed visitors to connect the speaker to a portable device and could be used freely to reproduce music, voice, or other sound stimuli. Due to a malfunction on the mini sound amplifier of the sixth speaker, it was considered that this sample was not exposed to direct sound, and as such, it was documented as a control sample.

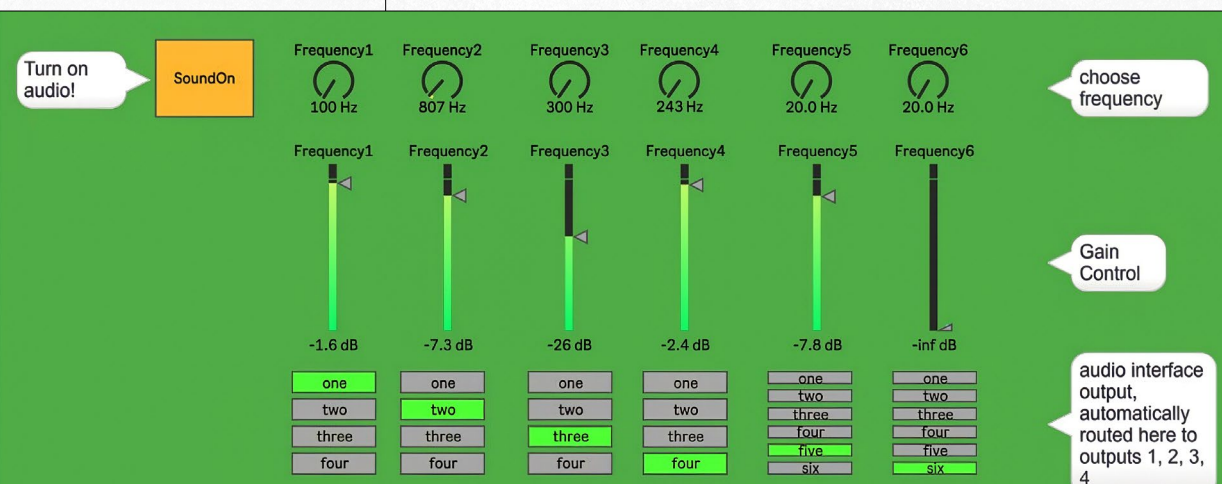


Fig. 13 - Max patch with the frequencies and dB used (designed by Guy Fleisher and adapted to this experiment. © Guy Fleisher.

Considering the circular shape of Petri dishes, the solo speakers were selected over conventional box speakers due to their round shape and placed above packed wood unpainted plinths. To foster a more embodied and exploratory engagement, the plinths were intentionally left unlabelled, withholding information about the frequencies reproduced. This decision encouraged visitors to navigate the installation space intuitively, relying on their senses to perceive differences in sound and vibration in the different speakers. Furthermore, inspired by fairy rings, a phenomenon where mushrooms grow in circular colonies, the speakers were displayed in a semi-circle, ddiviting visitors to walk to the centre of the installation.

The frequencies tested were 20Hz, 100Hz, 243Hz, 300Hz, and 807Hz. Rather than adhering to even intervals, these particular frequencies and dB were chosen based on their overall sonority when played simultaneously. The result was a composition that generated an acoustically intrusive, though still bearable, atmosphere, intended to evoke a sense of unease in human listeners.

3.3. EMBODIMENT AND EXPERIENCE

When entering the installation, a continuous and intrusive composition created by the simultaneously reproduced frequencies spreads throughout the room. Small focused lights illuminate the Petri dishes, allowing visibility against the low light emitted by the projector. The different frequencies emitted can be heard and also felt by touching the top of a speaker. When walking around, visitors hear the composition change with their position in the space. The affective dissonance generated by the reproduction of these continuous frequencies is crucial to create a disconcerting environment where both human visitors and mycelium are affected by the shared sound environment. For human visitors the soundscape changes by moving in the room, while the development of the fungi is deeply tied to a direct, continuous frequency, highlighting how sound is an invisible, yet sometimes pervasive force, which shapes spaces, organisms, and ecosystems. Revisiting Barad's concept of intra-action, mycelium is directly entangled with sound, where it emerges through its relational becoming within this manipulated environment. Sound becomes a visible agential force shaping living matter, initiating discussion as to how these often-overlooked interactions are intra-actively entangled within organisms and substances becoming.

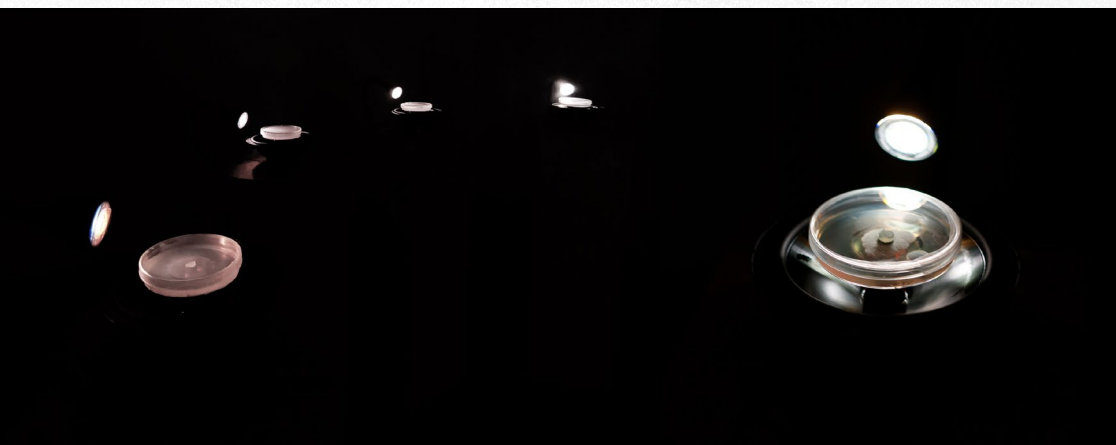


Fig. 14 - Symbiophone, photographic documentation at Universidade Católica Portuguesa, Porto. ©Author.

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To foster a more embodied and exploratory mode of engagement, the samples cultivated throughout the investigation were displayed as part of the installation, forming a visual glossary that showcased different expressions of fungi growth (figure 15). Visitors were invited to interact with the samples using a Dino-Lite digital microscope. The live image was projected onto the surface behind the speakers, allowing the installation to evolve in real time in response to visitors' interaction with the samples. The macro view enabled by technology provides a more intimate visual encounter with these fungi. This integration of tactile exploration transforms each act of observing into a generative moment, making visitors' engagement an active component of the installation's audiovisual ecosystem.



Fig. 15 - Symbiophone documentation at SEMIBREVE Festival in Braga. Photography: Courtesy of SEMIBREVE Festival.

4. DOCUMENTATION OF RESULTS

Due to a system malfunction on the second day of the installation, the accuracy of the results became compromised in their scientific reliability. Despite this setback, the installation ran for the seven days expected, beginning on 05/07/24 at 16:45 and ending on 12/07/24 at 13:00.

After the first 24h of the experiment (figure 16), it was noticed that all samples had accumulations of water droplets on the lid of the Petri dish, aside

from the control sample. The 20Hz frequency sample exhibited a larger water content than any of the other samples. The droplet size and water content decreased with the increase of frequency. There was no mycelial growth visible in any of the samples.

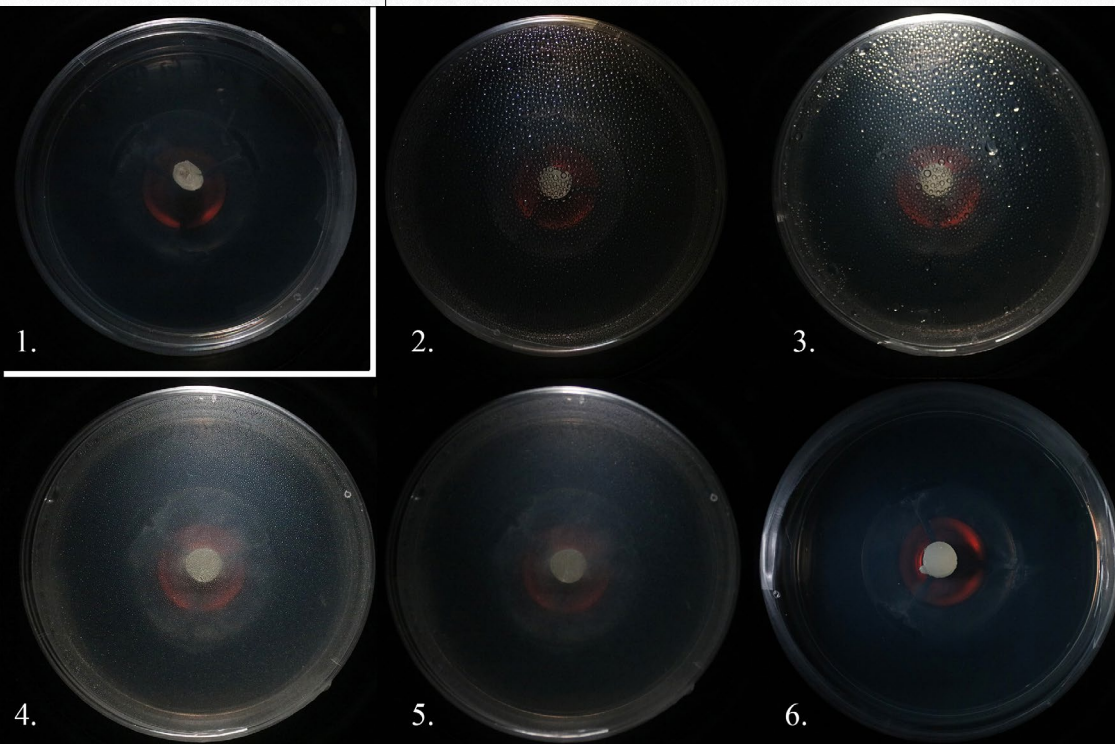


Fig. 16 - Day 06/07/24: 1. Control sample; 2. 20Hz; 3. 100Hz; 4. 243Hz; 5. 300Hz; 6. 807Hz. © Author.

Due to closure of the university facility, there was no documentation on the second day of the installation. Further documentation was conducted in intervals of two days.

When the system was revisited on the third day of exposure, 08/07/24, one of the sound amplifiers had fallen and altered the sound produced by the 243Hz and 300Hz speakers, which disturbed the experiment. Nonetheless, all of the samples showed small mycelium growths, except for the 100Hz frequency sample. A decrease in water content was still observable with the increase of frequency, as shown on figure 17.

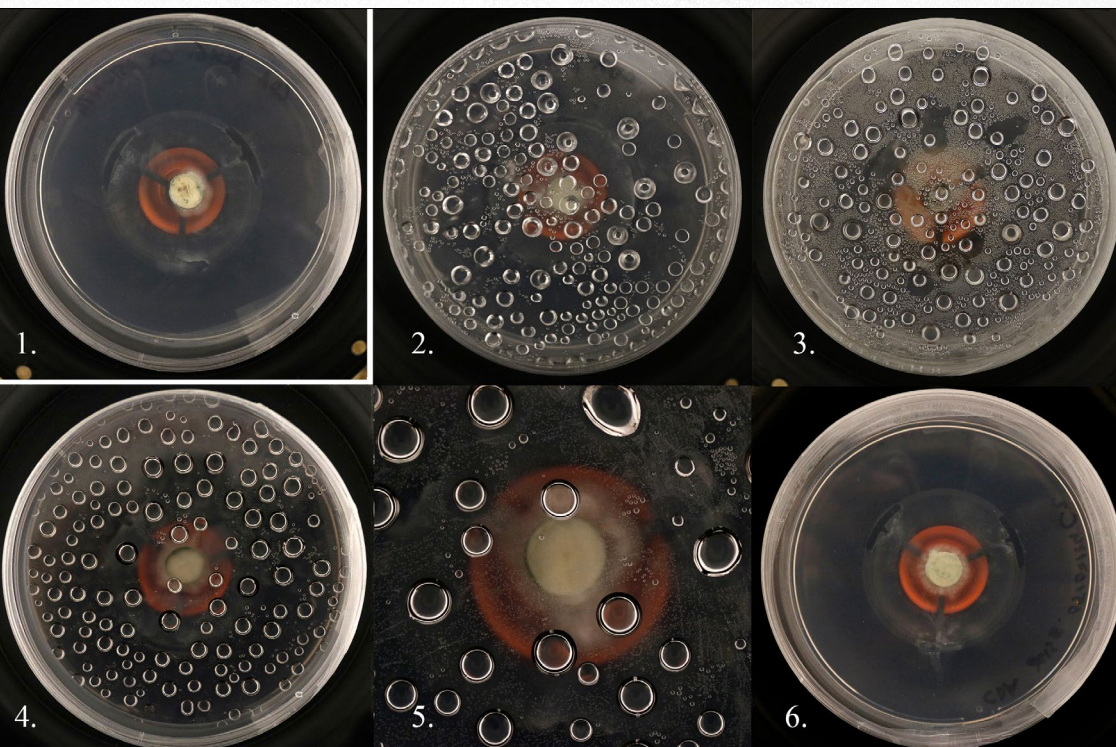
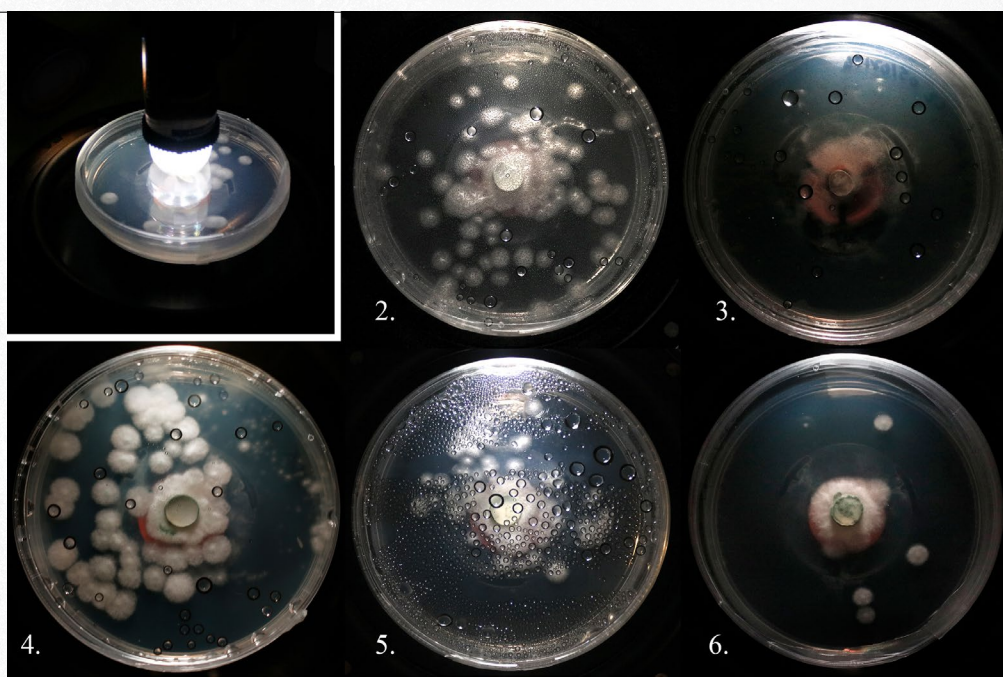


Fig. 17 - 08/07/24: 1. Control sample; 2. 20Hz; 3. 100Hz; 4. 243Hz; 5. 300Hz; 6. 807Hz. © Author.

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On 10/07/24 (figure 18), the decrease in water content with the increase of frequency was still visible and there was still no presence of water on the 800Hz frequency sample or the control sample. The 20Hz speaker had the most water and some irregular growth. The multitude of colonies present in the same sample made it difficult to verify if there was an alteration to the growth pattern, nonetheless there were visible distinctions in between samples. To observe and document the mycelium growth, some of the water was shaken off the top of the Petri dishes for better visibility. An exponential growth in all samples was visible, except for the 100Hz frequency sample. The plug of inoculation of this sample looked shrunken. The 807Hz sample had the fastest growth with the biggest centre colony. The control also had fewer colonies than the remaining samples, but a higher number than the 807Hz, which might be directed to spore dissemination during inoculation.

Fig. 18 - Day 10/07/24: 1. Control sample with dino light; 2. 20Hz; 3. 100Hz; 4. 243Hz; 5. 300Hz; 6. 807Hz. © Author.



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On 12/07/24 (figure 19), the last day of the experiment, there was a noticeable growth in all samples. All of them had multiple colonies. The lower frequencies resulted in a higher number of colonies, possibly due to the dispersion of spores by water droplets. This can also happen from dissemination during the inoculation process or as a result of dispersion of spores by the vibrations, as seen on the control sample and the 807HZ sample. However, it was evident that the 100Hz sample exhibited the least growth, featuring the fewest colonies and almost no mycelium extending from the inoculated central piece. The 20Hz sample had the widest spread of colonies, followed by the 243Hz sample. The 807Hz sample had the lowest number of colonies, with mostly central growth. In comparison with the control sample, the 807Hz sample shows the widest growth.

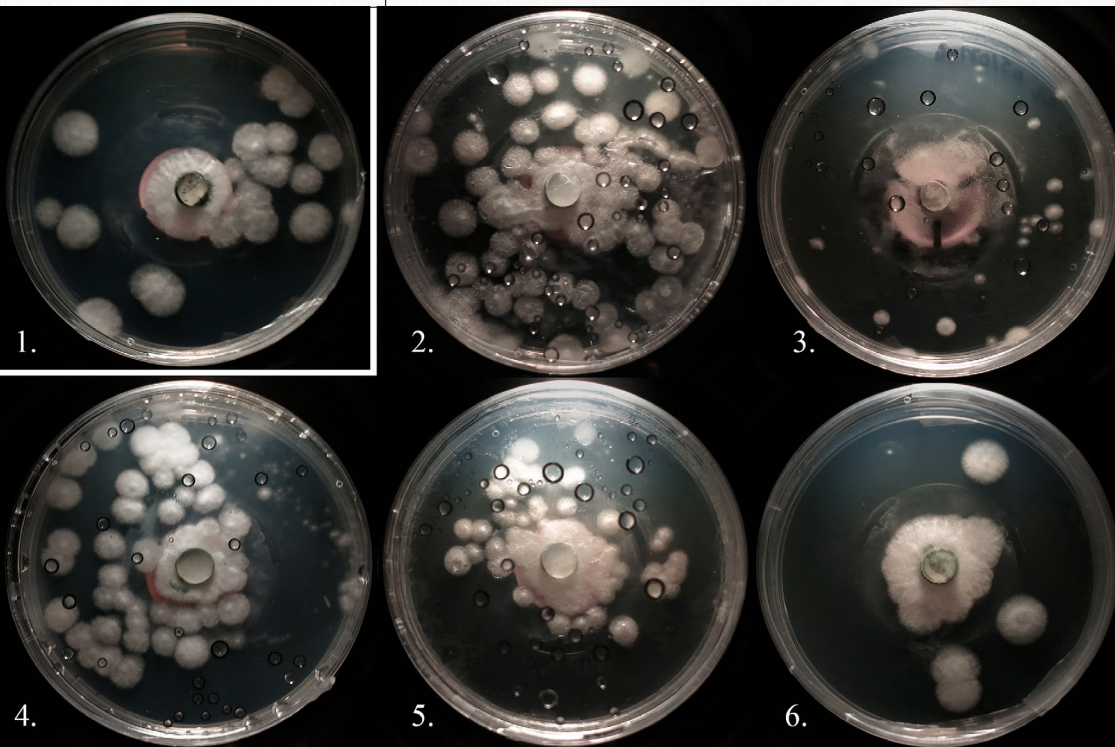


Fig. 19 - 12/07/24: 1. Control sample; 2. 20Hz; 3. 100Hz; 4. 243Hz; 5. 300Hz; 6. 807Hz. © Author.

5. DISCUSSION

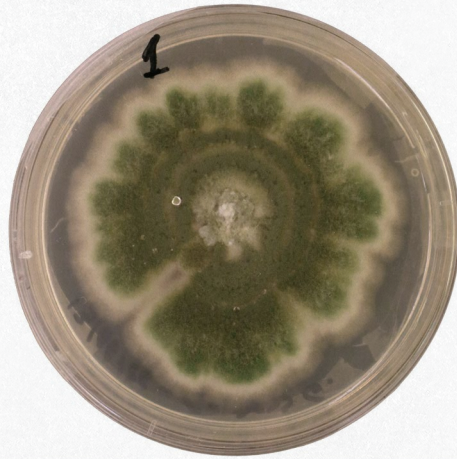


Fig. 20 - Mature Trichoderma sample (from powder), not exposed to sound. © Author.

The limited timeframe available proved insufficient for supporting the full colonisation of the medium and maturation of the colonies. When comparing the results to the mother samples on figure 9 or the sample on figure 20, it is clear that the green spores which characterise maturation were not visible yet in the exposed samples, neither was any distinct symmetry or abnormal pattern identified at this stage.

From this preliminary testing, some clear difficulties were encountered. For producing more reliable results, the experiment would benefit from being reproduced in a more controlled environment and from testing fewer samples at the same time. Keeping the control sample in a completely sound proof environment would also be helpful to increase the accuracy of the experiment. This accuracy can also be improved with more rigorous documentation, including continuous video recording and growth measurements to enable a detailed growth analysis, comparing the different samples. It might also be beneficial to tightly control the temperature of the room to avoid any temperature-related condensation, helping decrease possible causes for the accumulation of water condensation on each sample (though if the water accumulation is derived from the vibration itself, it might be difficult to avoid this at all). This condensation leads to the dissemination of spores, which results in the development of multiple colonies, jeopardising a direct comparison of growth patterns between single colonies. This issue could be addressed by exposing the mycelium to higher frequencies, including those inaudible to the human ear, which might not produce water, as shown in the sample exposed to the 800Hz frequency. Since

multiple colonies were also found on the control samples, this problem can also be addressed by using an inoculum from a younger mother sample with fewer spores, thereby facilitating a more controlled single inoculation.

Regarding the technical aspects of the system, it may also be interesting to experiment with different types of speakers, such as contact speakers, to determine whether fungi's responses to sound are solely due to direct contact vibrations or can also be elicited through sound stimulation alone. Furthermore, it seems also worthwhile to expand the research to infrasound, musical compositions, or sound recorded in urban or industrial areas in contrast with non-anthropomorphic sounds.

In light of these observations, it would also be beneficial in further research to extend the sound exposure from the minimum duration of fourteen to twenty-one days. This time frame better encompasses the full growth and maturation of mycelium, which unequivocally demonstrates how crucial it is to respect the natural development time of organisms.

Regardless of the difficulties, the results demonstrate a clear difference in growth in between samples. In the samples exposed to 20Hz, 243Hz, and 300Hz frequencies, the presence of many distinct colonies was visible, possibly caused by the accumulation of water content on the Petri dishes lids. Due to the presence of many colonies, it was difficult to understand if there were morphological changes to the fungi or if there was growth stimulation in these samples.

An unexpected inhibition of growth was observed in the sample exposed to the 100Hz frequency. This result challenges the assumption of a linear relationship between frequency values and fungal growth responses, suggesting instead that the biological impact of sound may depend on specific frequency thresholds or complex interactions between frequency and amplitude. Nonetheless, these single results are insufficient to prove such claims.

The sample exposed to the 807Hz frequency was the most similar to the control sample, however, it showed a noticeably larger central colony and fewer peripheral colonies. The central colony in the control sample measured 2.6 cm while the sample exposed to the 800Hz frequency measured 3.3 cm, as shown in figure 21. While this observation may indicate a potential stimulatory effect on growth at this specific frequency, further testing and replication are essential to validate this hypothesis and rule out incidental variables.

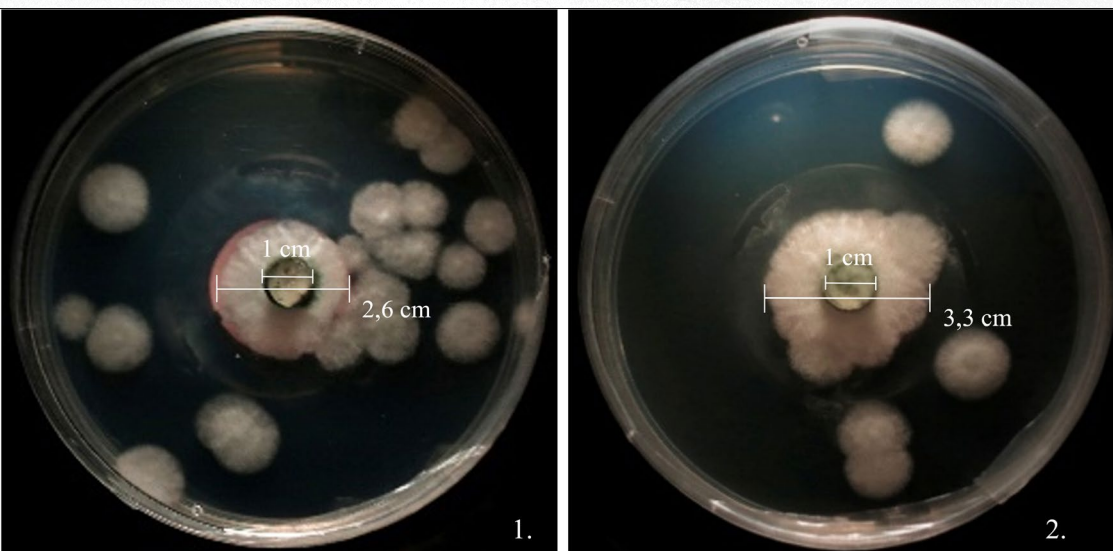


Fig. 21 - Measurements: 1. Control sample; 2. 807Hz sample. © Author.

Even though these preliminary results are not enough to confidently make claims about how sound affects the morphology of mycelium, this experience makes the intra-action between sound and fungi visually perceptible. More than serving as biological data, the different growth patterns observed across frequencies yield visual manifestations of the entanglement between sound and organisms, producing different visualisations of distinct processes of becoming.

6. CONCLUSION

6.1. EMBODYING *SYMBIOPHONE*

Symbiophone was developed through an ongoing transposition of laboratory methodologies and practices into the artwork development. Inherently, this brought into contrast the precision and rigour required to follow laboratory protocols with the intuitive and sensorial side of artistic creation. Both of these areas meet in their common striving for exploration. This transdisciplinary approach inherently redirected the focus of laboratory research from producing verifiable results towards the creation of an embodied experience. Through this artistic practice, the separation between scientific inquiry and creative exploration blurs. Rather than compartmentalising different disciplinary boundaries, interlinking distinct methods and goals produces a productive friction. When these domains are brought into dialogue, new experimental methodologies arise. Taking this transdisciplinary approach meant embracing a process of conceptual and procedural contamination between areas with, a priori, distinct objectives. When multiple areas of knowledge hybridise, they give rise to novel ways of thinking and making, contributing to more holistic understandings of complex phenomena.

A transdisciplinary approach was adopted for developing *Symbiophone*, in order to explore how invisible forces, such as sound, interact with matter and living organisms, often without our acknowledgment. In so doing, this installation

not only brings attention to this overlooked dynamic but also questions the ethical complexities surrounding collecting, isolating, and manipulating living organisms. The work becomes both a research platform and an aesthetic experience, not only to study how sound influences fungi but also to create an interspecies dialogue. Through a machine interface, mycelium's responses are rendered visible in a pictorial output observable in their growth pattern. By creating an embodied experience where the entanglement between sound and fungi becomes tangible, this project highlights the intra-actions between organisms and substances while questioning the boundaries of human agency. Observing how fungi respond to sound and exploring how this intangible medium can play a crucial role in their development brings forth an evident expression of transcorporeality, wherein fungi morphology becomes visibly entangled with the sonic environment. Through this process, it becomes clear that living organisms and substances are intimately interconnected in a continuous symbiotic process of becoming.

Looking at how symbiotic dynamics unfold and adopting symbiosis as a conceptual framework for understanding multispecies interactions entails acknowledging our permanent interconnectedness within biological communities and committing to being responsible for our conscious exchanges. This inquiry thus not only unveils latent dimensions of interspecies relationality but also contributes to nurturing an ethics of care and attentiveness within our multispecies intra-actions. By rendering visible how fungi growth is directly related to its sonic environment, the project invites reflection on how human agency is entangled with the behaviour of biological communities.

6.2. EXPANDING SYMBIOPHONE

Besides the trial described in this article at Universidade Católica Portuguesa in Porto, this installation was also exhibited at the SEMIBREVE Festival in Braga. In this context, no extensive documentation of the results of the installation was conducted due to the short term nature of the exhibition. Nonetheless, engaging with different audiences and disseminating the research proved valuable, not only to share research findings but also to test the reproducibility of the system assembly and identify weaknesses.

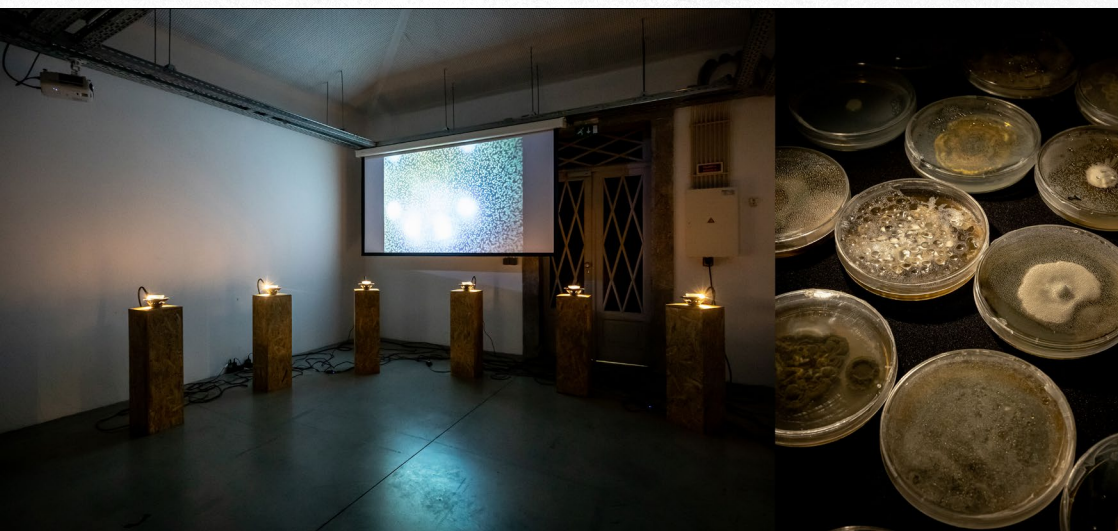


Fig. 22 - Symbiophone, photographic documentation, SEMIBREVE Festival in Braga. Photography: Courtesy of SEMIBREVE Festival.

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Moving forward, the results invite a reexamination of established methodologies and aesthetics, particularly questioning the symbology associated with the Petri dish and other tools for scientific inquiry, proposing to explore a distancing form of direct visualisation of the laboratory processes. In terms of embodiment and visitor engagement, reconfiguring the speaker layout could create a more immersive dynamic, inciting movement and deeper interaction with both the spatiality of the sound and different positions of proximity and distance to the mycelium.

Further developments may also include testing a wider range of sounds, including different compositions and infrasound, using different speakers to explore the biological responses more fully. Additionally, focusing on site-specific fungi species as well as a focus on species within the mycorrhizal network, particularly arboreal mycorrhizae and saprophytes, such as *Armillaria* species, could enhance the ecological relevance of future research.

Ultimately, these future directions point toward a more comprehensive understanding of how sound affects fungi and their symbiotic relations within the ecosystem. But importantly, this ongoing research seeks to continue fostering new forms of multispecies relationality that cultivate ethics of care and offer interesting insights into the emergence of multispecies ontologies.

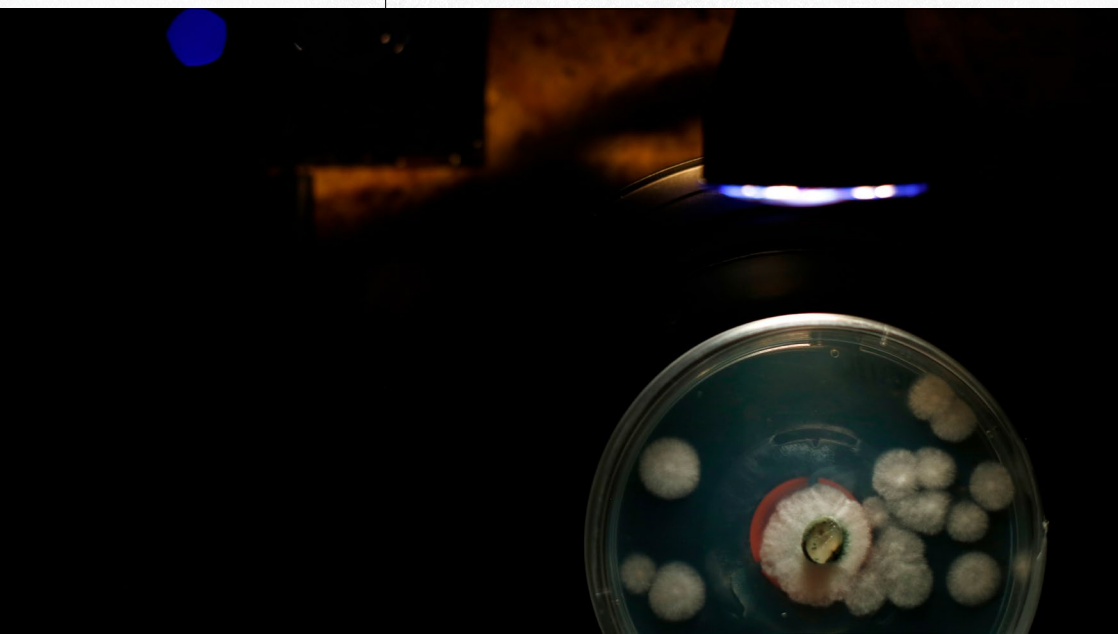


Fig. 23 - Symbiophone, photographic documentation, Universidade Católica Portuguesa, Porto.

This work was developed within the Doctoral Programme in Science and Technology of the Arts at the School of Arts – Universidade Católica, under the supervision of Prof. Dr. Cristina Sá and Prof Dr. Patrícia Moreira da Costa.

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