Growing Remediation: Mycelium, Plastic Waste, and Interdisciplinary Design

Karlena Dunn

Faculty of Design and Creative Technologies

2026

A dissertation submitted to Auckland University of Technology in partial fulfillment of the requirements for the degree of Master of Creative Technologies

Abstract

Mankind has complex interactions with plastic, characterized by our dependence on and use of it, often deceptively easy and short-lived, followed by its inconvenient longevity. The spiraling accumulation of ubiquitous waste, threatening all ecosystems and our health, poses one of the greatest challenges of our time, which many people try to ignore because of its enormity.

This problem prompted my two-stage research into remediation, remedying or reversing the environmental damage caused by plastic. Firstly, adopting a deductive approach, I undertook a scientific experiment exploring the biodegradation potential of the thin polyethylene (PE) lining on paper cups achieved by mycelium. Secondly, through inductive methods, I developed a way of communicating my findings and their wider context to the non-scientific community through a illustrated book for a general audience, to empower and encourage small-scale positive action.

Science, as commonly practiced, operates within an anthropocentric paradigm grounded in the belief that human reasoning is the primary means of understanding reality. Because science is designed by humans, it reflects human logic, values, and interests. Biodesign has emerged as an alternative epistemology, a theory of knowledge without the boundaries and limitations of the traditional scientific framework. My interdisciplinary research and design, drawing not just from science but from nature, poetry, philosophy, art, and other disciplines, worked towards emergence from small-scale intentional action contributing to broader ecological transformation. Without understanding how individual actions connect to wider collaborative systems, speculative environmental design risks remaining idealistic or utopian. Rather than focusing solely on my own work, I highlighted the relationships and connections formed throughout this study, situating them within a global community striving to develop innovative solutions to sustain life on Earth. I aimed to demonstrate how collaboration with microorganisms, particularly fungi, can help address plastic pollution. Driven by non-human, fungal intelligence, this investigation demonstrated the opportunities of looking to existing mechanisms in nature to guide our response to the ecological crisis, as well as to build resilience and adaptability, striving to reconnect people disengaged from the plastic crisis.

My laboratory skills were gained at a biodesign course (Fabricademy Brussels) and at my current workplace, Sapro-Tech, a company producing bio-polymer textile materials. PE-lined paper cup pieces on agar plates were inoculated with three fungal strains (*Trametes versicolor*, *Pleurotus ostreatus* and *Pleurotus pulmonarius*) and compared with controls. Macroscopic and scanning electron microscopy (SEM) examination revealed deterioration of the PE-lining. This allows hope for a post-anthropocene future, in which synthetic materials no longer dominate ecological systems. Interestingly, *Pleurotus pulmonarius* flaked PE as well as *Pleurotus ostreatus*, which so far had the best supportive data for biodegradation in the literature. This merits future study. Throughout my project, I observed, listened, learned, and reflected on our complex relationship with plastic, our behavioral economics and the power of storytelling. I then translated my research journey using illustrative watercolour art and non-scientific language, compiled into the tactile form of a watercoloured illustrated book for a general audience titled *A Future with Fungi*. This seeks to communicate with people disengaged from the realities of plastic via environmental storytelling, effecting positive change.

Abstract **2**
List of Tables and Figures **6**
Attestation of Authorship **8**
Acknowledgements **11**
Introduction **12**
Chapter One: Literature Review **14**
Introduction to Human Design in a Shared Ecosystem 14
Polyethylene 15
Polylactic Acid 16
Bioremediation and Mycoremediation 16
The Role of Fungi 19
A History of Collaboration with Living Organisms 20
A Future Built Environment 21
Barriers to Collaboration with Fungi 24
Mycotechnology, Humans and Nature 27
A New Roadmap for Design 30
Collaborative Survival 34
Synthesis and Research gap 35
Chapter Two: Methodology **36**
Introduction to Inductive Methodology resulting in My Two Phases of Work 36
Research Design 38
Purpose of Fabricademy 41
Procedure of Culturing Fungi 42
Limitations of Fabricademy Method 45
More Possibilities of Collaboration with Microorganisms 45
The Choice of Takeaway Coffee Cups as Research Object 47
Choice of Fungi 49
Phase One: Practical Science-Based Research 50
Procedure First Round of Experiments 50
Procedure Second Round of Experiments 53
Procedure Third Round of Experiments, at Sapro-Tech Laboratory 54
SEM Examination 63
Limitations 63
Phase Two: Creative Design Process 65
Choice of images and illustration style 67
Chapter Three: Results **68**
Introduction to Results of My Practical Science-Based Research 68
Terminology Describing Mycelial Growth 68
Results of Macroscopic Examinations during Round One of Home Experiment 71
Growth Rate 71
Appearance 72
Results of Macroscopic Examinations during Round Two of Home Experiment 74
Results of Macroscopic Mycelium Growth on Homemade Agar without Paper Cup Pieces 74
Results of Macroscopic Mycelium Growth on Homemade Agar with PE Paper Cup Pieces 75
Results Round Three of Experiments in a Professional Laboratory 75

Terminology describing Appearance Indicative of PE Degradation on SEM Images 76
Comparative Results of SEM Images 77
Moving Forward from Interim Conclusions 81
Chapter Four: Journey Towards the book *A Future with Fungi* 83
Suitability for the intended audience and reflection on impact 90
Chapter Five: Discussion and Final Conclusion 92
Research Aim 92
Interpretation of Results 92
Positioning the Findings within Existing Literature 93
Interpretation of Discolouration of Culture Plate Content 100
Reflection on the Choice of SEM Photography as Indicator of Degradation 101
Deductions after my Experimentation 103
Chapter Six 104
The Contribution of Creative Practice 104
Significance 105
Limitations of Working with Living Organisms 108
Reflection on Research Journey 108
Conclusion 109
Reference list 110
Appendix A - *A Future with Fungi* 124
Appendix B - Condensed home experiments results tables 138
Appendix C - SEM Scans 146
Appendix D - Physical workbook 151

List of Tables and Figures

Tables

Table 1 Summary of the Two Main Phases / Components of My Master's Work

Table 2 Sample Table of Observed Changes to Agar plate over time

Table 3 Results Table showing PE-lining Degradation Visible on SEM

Figures

Figure 1 SEM Images of Mycelium-induced LDPE Degradation

Figure 2 BioKnit Self-supporting Structure

Figure 3 The Proxemic Challenge of Disgust, Concern, Interest, Repulsion and Attraction

Figure 4 Mycelial Contact: calming, grounding, pleasant to hold, stimulating curiosity

Figure 5 Mycelium Skins made by Annah-Ololade Sangosanya

Figure 6 Hand-drawn Notes about the Living Systems Theory

Figure 7 Flow chart of Inductive Creative Process During Masters Work

Figure 8 Aseptic area of the Bunsen burner

Figure 9 Pouring an Agar Plate

Figure 10 Bacterial Workshop at Fabricademy Brussels

Figure 11 Consumer Answers to Questionnaire about Understanding of 'Compostable' Label

Figure 12 Home Laboratory Set-Up

Figure 13 Three Fungal Strains and Inoculated Plates with Coffee Cup Pieces.

Figure 14 Mycelia Samples on Agar Plates, Day 14: *P. pulmonarius* grew best

Figure 15 Hexagonal Laser-cut Frames to Grow Mycelium

Figure 16 Process of Creating Liquid Media Plates for Mycelium Cultivation

Figure 17 Mycelium Pellets, *P. ostreatus* (grey oyster mushroom)

Figure 18 Blending of Pellets in the Extraction Cabinet

Figure 19 Fully Cultivated Plates and Samples ready for SEM

Figure 20 Fully Grown Mycelia with and without Coffee cup Pieces

Figure 21 Hand-Drawn Diagram of Mycelial Growth Terminology

Figure 22 Three Examples of Mycelial Growths

Figure 23 Enshrouded Tomentose Growth of *P. pulmonarius* Culture

Figure 24 Healthy Tomentose Growth of *P. pulmonarius* Culture

Figure 25 Sparse Flat Sheet of *T. versicolor* Growth in Culture

Figure 26 Healthy Rhizomorphic *P. pulmonarius*, showing small Mould Contaminants

Figure 27 Even Mycelial Growth by Liquid Culture

Figure 28 SEM Image of PE Delamination on Paper Cup Piece with *P. ostreatus*

Figure 29 SEM Image of Thick Hyphal Network of *T.versicolor* Unwashed Sample

Figure 30 SEM Image of PE Delamination of Paper Cup Piece with *T. versicolor*

Figure 31 Surface and Cross-sectional SEM Images Showing Degradation of PE by *T. versicolor*

Figure 32 Double-Paged Watercolour Picture in *"A Future with Fungi"*

Figure 33 Many Pages and Aspects Inviting to be Explored in *"A Future with Fungi"*

Figure 34 Home-Use of the Book Demonstrating Fold-Out-Page

Figure 35 SEM Image of *P. ostreatus* Control Surface Unwashed on Left, versus Washed on Right

Figure 36 SEM Image of Eroding PE Layers Achieved by *T. versicolor*

Figure 37 SEM Images a: Untreated b: Treated LDPE, Showing Degradation by *Pseudomonas*

Figure 38 SEM Images: Biofragmentation of Washed Paper Cup *P. ostreatus* vs. *T. versicolor*

Figure 39 SEM Images: *T. versicolor* Effect on PE Bin Liner and Paper Cup Samples

Figure 40 SEM Images: Original Compared to Composted Samples

Figure 41 SEM Images: Biodeterioration of *P. ostreatus* and *P. pulmonarius*

Figure 42 *P. pulmonarius* growth (above) compared to *P. ostreatus*

Figure 43 Discolouration of PE by *P. pulmonarius,* Round One Experiments

Figure 44 SEM Image taken by Yuan Tao of *T.versicolor*

Figure 45 Photos Provided by François Audrézet showing Mycelial Deterioration of Paper Cups

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 Acknowledgments), 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.

Karlena Dunn

Specify the chapter number(s) in your research proposal/research component where AI was used.

Chapter number(s): 1-6

Briefly explain why the AI tool was used (e.g., idea generation, summarization, data analysis, image creation, etc.).

Purpose of AI Use: **AI was used to scan the document for missing references or faulty DOI links. In a limited case, it was asked to improve text written by the author for grammar and flow. It was not used for idea generation, or to write new pieces of text.**

Clearly state the AI tools used.

AI Tool(s) Used:
Microsoft Copilot.

Prompts or queries entered into the AI tool (only the instructive portion of the prompt is required). Include all relevant variations.

Prompts Used: **''Please compare the pasted text to the reference list attached and identify any mistakes/ accidental repeats.''**

''Please improve this section of text for grammar and flow. Do not change or add additional content.''

A summary or description of the AI-generated output. (Optional: attach output in an appendix.)

Output Received: **Analysis of references provided for example - ''what's wrong with your current version'' and the ''Corrected APA-7 version'' and ''Here is a polished version of your text''.**

Describe how the AI output was used, edited, or transformed.

The AI result was either accepted or rejected depending on personal preference and by cross
Post-AI Processing Methods: comparing the AI result with advice found on the APA 7 website or university referencing guide.

You may use this free text box to explain the intent for the use of the AI generated content. *For example, rather than stating what prompt(s) were used, you may articulate the purpose for which the prompt was used (supported by examples) here: AI was used to reduce the risk of human error regarding my references and as a grammar tool, as you would use Grammarly.*

STUDENT DECLARATION

By signing you are confirming that the AI use stated in the table(s) above are accurate and follow AUT's recommended guidelines detailed in the AI Hub and Postgraduate Handbook.

Signature:

Student Name: Karlena Dunn

Date: 25/07/2026

Acknowledgements

I feel honoured to have become connected with a global community of researchers, driven by the exploration of our material world through fungi. I give special thanks to the Fabricademy team, especially researcher Annah-Ololade Sangosanya, who showed me that Textiles and Science can exist symbiotically and taught me the microbiology skills necessary to cultivate mycelium. My supervisor, Professor Frances Joseph, whose research first inspired me to undertake a Master of Creative Technologies at AUT. The technicians, Fleur Williams, Winston Shacklock and Yuan Tao, who gave their time with unwavering generosity. Dr Keith Hudson and Dr Gayani Weeraratne at Sapro-Tech, who pushed me to continue improving my experiments, grounding them in thorough methodology. Hannah-Lee Turner, the forerunner to this work in her Master's research into degrading textiles using fungi. My good friends Sam and Ella for keeping me in good spirits and stepping up as proofreaders. Professor Huhana Smith, who mentored me throughout my undergraduate studies and taught me how to stay positive in the face of climate change. Finally, my family, who have supported me in every way possible, nurtured my connection to nature and the outdoors, and encouraged me to explore and question.

Introduction

Interdisciplinary collaboration has become vital for addressing climate change due to the scale and complexity of the issue. Climate change is a so-called “wicked problem” resistant to solution, affecting all areas of life, and deeply intertwined with socio-economic factors (Herziger, 2025). Collaboration is therefore a key theme explored in my research, not only within the human species, but also involving micro-organisms, finding opportunities for positive environmental transformation through collaboration with fungi. Newly emerging interdisciplinary design disciplines focus on facilitating future life on Earth as well as on transitioning into more sustainable ways of living, rather than aiming to design marketable products. “Speculative design” envisages future scenarios and considers, for example, emerging environmental changes and new technologies to stimulate critical thinking and discussion. “Transition design” aims to implement societal changes towards sustainability, equity, and justice using collaboration between disciplines as called for by our current complex issues. “Biodesign”, again, is interdisciplinary, combining design principles with biological sciences, engineering, and emerging biotechnologies, to solve human problems in a sustainable, regenerative, and innovative way. My primary practice is biodesign, but elements of all three have played a role in my methodology. Working within an emerging discipline has opened up possibilities beyond the constraints of established deductive research practice, enabling new forms of inquiry and experimentation. At the same time, it has required a thoughtful negotiation between scientific rigour and design-led exploration.

The project consisted of 4 stages: (1) attending Fabricademy, (2) conducting laboratory experiment (phases 1 & 2, (3) evaluation of results and creative design process, and (4) an artefact communicating the results, inviting speculation. Fabricademy was a one-week immersive introduction to biodesign research, specifically mycotechnology. It was an imperative step for approaching the research question, ‘Can fungi degrade polyethelene’ as I learnt fungi

cultivation and aseptic lab etiquette. The laboratory experiments addressed the research question from a purely scientific lense, collecting qualitative results in the form of Scanning Electron Microscopy photographs. Stage 3, evaluating the scientific results, prompted a creative exploration of the research question, and the broader role of fungi in approaching climate change. Stage 4 is the manifestation of this: my book, *A Future with Fungi.* It is the result of reflecting on my initial scientific research while also embodying the conceptual framework that shaped it. *A Future of Fungi* brings together the many strands of this research and invites the reader to speculate and explore the topic on their own.

The methods of inquiry introduced in the methodology section differentiate deductive from inductive research. The Danish philosopher Søren Kierkegaard (1843) observed that life can only be understood by looking backwards, even if it must be lived forwards. This captures the idea that while we experience life as a sequence of unfolding events, we can only fully understand their meaning through reflection.

Inductive research allows action on this reflection; it is open-ended and adaptable, while deduction focuses on confirming or rejecting a hypothesis. Taking an inductive approach facilitated my transition from a scientific experiment to a creative output. This required interim conclusions and discussion within the methodology and results sections, as my project's practical aspect—and even direction constantly evolved in response to learning and influences along the way. This differs from the rigid separation of these sections customary when reporting on deductive research.

Chapter One: Literature Review

Introduction to Human Design in a Shared Ecosystem

Microplastics have a ubiquitous presence in all ecosystems (Cox, 2019). The scale of impact the invention of plastic has had on the global ecosystem illustrates the extent of the impact afforded by the ability to design and produce. However, statistics documenting the widespread environmental impacts of plastics also highlight the scale of positive change that could be achieved through a transition to less harmful materials. The greater the difficulty, the greater the glory in surmounting it (a concept associated with Epicurus, 341 BC - 271 BC).

Twelve point seven million metric tonnes of plastic waste are reported to be entering the ocean annually (Jambeck et al. 2015). Filho et al. (2020) and Stanley et al. (2025**)** warn that the effects of plastic pollution extend beyond wildlife and into human health, particularly through microplastics found in food, drinking water, and human tissues, raising significant concerns about their toxicity.

The first plastics (Greek: plaskitos, "able to be molded") were naturally occurring polymers such as shellac and rubber. These were forerunners to the first synthetic plastic: "Parkesine", developed by Alexander Parkes in 1862 (Stanley et al., 2025). This was followed by "Bakelite", a polymer made from phenol and formaldehyde with impressive heat-resistant and non-conductive properties, which made it valuable for the growing car and electrical industry. Synthetic materials have continued to replace natural materials ever since; for example, glass, wood, metal, wool, cotton and silk, especially during times when trade was restricted by political instability. World War II is an example of an era when natural resources were scarce, causing the need for cheap, readily available alternatives (Dennis, 2024). Stanley et al. (2025) describe further production inflation post-war, caused by a spike in consumerism, which saw plastics becoming established as a material for packaging, bottles, straws and everyday household items by the 1950s. Plastics offer great benefits: they are low-cost, durable, extremely versatile and

perform incredibly well. Therefore, it has taken time to realise their main drawback: most plastics do not decompose.

Waste management systems are limited and unable to keep up with the rate of plastic production. According to Filho et al. (2020), the production of plastics has increased from one point five million metric tons in 1950 to 359 million metric tons in 2018. Few other materials have so quickly dominated all areas of human activity. The first reports of plastics in the ocean appeared in the 1970s (Jambeck et al. 2015), but awareness of their devastating ecological impact only developed during the subsequent decades. Jambeck, in an interview with Parker for *National Geographic* (2018), stated that leakage from global waste systems into the oceans was inevitable with this scale of increase in plastics use by mankind.

Plastics are a family of materials rather than a singular one (Dennis, 2024). The number of materials within this family satisfies the demand for almost every property, texture, strength, or stiffness. Plastics are constantly evolving, with material scientists working on new formulas, combinations of materials, and new "feedstocks" (raw materials to supply or fuel a machine or industrial process) to overcome issues of permanence and waste accumulation. Some plastics are only partially synthetic and therefore often less permanent, more biodegradable, and developed with waste management in mind, which can include utilisation of microorganisms for mycodegradation (Olonisakin K).

Polyethylene

Polyethylene (PE) constitutes 26 percent of the total plastic production and can, for example, be found in the lining of paper cups. PE is the most abundantly used plastic of all types (Jeremic, 2014) and presents a significant environmental challenge. Apart from production from limited fossil fuel resources, its chemical stability and resistance to biodegradation leads to long-term persistence in ecosystems. Its extensive global use continues to drive accumulation in the environment (Singh & Argarwal, 2024). Recent industry and sustainability reports indicate that around 99% of disposable paper cups are lined with PE (Closed Loop Partners, 2023) and that approximately 97% of cups produced end up in landfill due to recycling limitations (Cho,

2025). GreenMatch calculated that about 16 billion disposable PE-coated paper cups are used per year. (GreenMatch, 2023).

PE is a polyolefin plastic (a versatile class of petroleum-based synthetic polymers derived from simple olefins/alkenes), consisting of long methylene group (CH_2) chains, hydrocarbons containing a carbon-carbon double bond. These organised repeating components often exceed those found in nature (Odigbo et al., 2023). In the polymerisation reaction to form PE, ethylene opens up under high temperatures, forming covalent bonds. These are subsequently very hard to break, therefore, PE is difficult to degrade (El-Sherif et al., 2022). Reconstructing polymers during PE-recycling to synthesise new plastics also requires artificial temperatures and pressure, which again has adverse environmental impacts. Carole Colett, Professor in Design for Sustainable Futures, emphasises that we must design under life-friendly conditions in order to be truly sustainable in our practices, as well as shifting our material choices by not exceeding conditions found in nature in their production (2025). Transitioning to more economical and eco-friendly methods of production and waste management is imperative (Srivastava et al., 2026).

Polylactic Acid

Polylactic acid (PLA) is used to line a small proportion of paper cups that are not coated with PE. PLA is more sustainable as it is made from renewable sources such as sugarcane or corn starch; however, it has a limited shelf life, less heat resistance, and is still only degradable under complex conditions that are not easily achieved through hydrolysis, enzymatic action, microbial assimilation, ultraviolet light irradiation, and thermal processes.

Bioremediation and Mycoremediation

New technologies for the biological degradation of PE need to be developed. Possibilities for converting the degraded product into valuable materials for onward use should be explored. Current waste management processes often require energy-intensive physical and chemical degradation methods and lead to the release of toxic byproducts.

Bioremediation is the process of using organisms, or derivatives from organisms, to degrade pollutants (Van Dillewijn et al., 2009). Microorganisms are essential for detoxifying

ecosystems without further pollution (Pattani et al., 2026). This can sometimes offer a permanent solution, transforming the pollutant to its molecular constituents, such as carbon dioxide and water, rather than a remediation method that transfers waste from one phase to another.

By 2020, nearly 436 species had been reported to degrade PE (Gambarini, 2021, as cited in Perera et al., 2023), with a ubiquitous presence due to microbial diversity and adaptability (Zhang et al., 2022). Species include a wide variety of fungal strains capable of a form of bioremediation called mycoremediation.

Interdisciplinary collaboration for addressing climate change is a key theme explored in my research, not only within the human species, but also involving micro-organisms, finding opportunities for positive environmental transformation through collaboration with fungi. One example is their ability to transform pollutants into their non-toxic molecular constituents, such as carbon dioxide and water, in a process known as Mycoremediation. This short introduction to mycoremediation, and mycotechnology is an invitation to imagine an alternative future in which humans and nature exist in a truly symbiotic relationship.

Depolymerisation is the process of breaking up the polymer chains in PE, which enables degradation. The mycelia of some fungi release enzymes which cause depolymerisation,. A particularly important enzyme is laccase, a type of multicopper oxidase enzyme catalysing the oxidation of various phenolic substrates. Wadhwa et al. (2023) describe laccases as enzymes that are typically excreted by filamentous fungi as part of their secondary metabolism. One function of fungi in forests is that of decomposers, “eating” or digesting dead organic matter. This mechanism can be harnessed to help humans in their waste management. The laccase enzymes serve different, even opposing, functions in different organisms. In plants, they are involved in lignification (building lignin). In fungi, they are linked to delignification, meaning laccases help to construct organic matter in plants and to deconstruct it in fungi (Wadhwa et al., 2023). Laccases have utility in the textile, food, paper, and pulp industry, as well as in soil remediation and biodegradation of environmental pollutants. Further applications include the breakdown of pesticides and insecticides, transformation of toxic textile dyes, and waste detoxification.

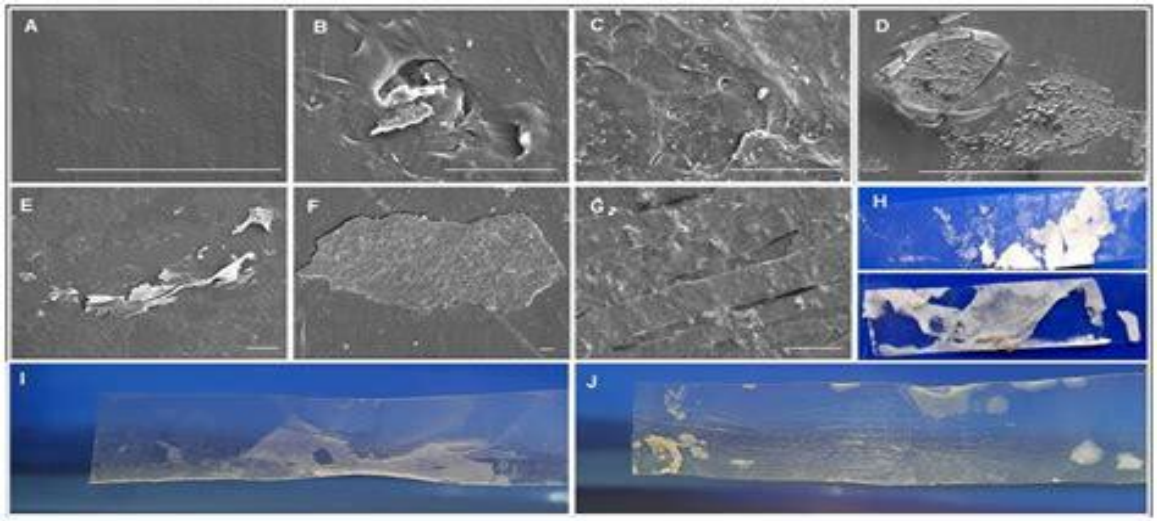
Although many fungal species make extracellular laccase, not all produce sufficient quantities for bioremediation (Thakkar & Bhatt, 2020).

Ratuchne et al. (2019) state that species *Pleurotus (P.) ostreatus and P. cystidiosus* can absorb nutrients from plastic polymers. The ability of these fungi to extract energy from synthetic materials such as plastics, suggests greater resistance and resilience of some lifeforms to the ecological impact of humans than is often recognised. It also illustrates the Earth's potential for recovery. In studies led by Perera et al. (2023), the degradation of low-density PE (LDPE) using wood decay fungi was explored. Fifty fungal samples were harvested from decaying Sri-Lankan hardwoods and assessed for their wood degradation properties as well as depolymerisation enzyme activitiy. Twenty-two of the fifty fungal samples were incubated with LDPE sheets, with and without wood as a carbon source. A strength of this study was the number of measures, both qualititatve and quantitative, including sample weight, tensile strength, infra-red spectroscopy and Scanning Electron Microscope (SEM). *Phlebiopsnis flavidoalba cultures* demonstrated the most reduction in sample weight and tensile strength as well as the extent of scanning electron microscopy (SEM) change. (Figure 1). LDPE layers were peeling off, showing surface degradation. LDPE layers were peeling off, showing surface degradation. Fungal-treated LDPE sheets became rough, showing cracks, holes, and focal peeling-off, whereas the untreated sheets retained a smooth appearance. The qualitative SEM results are limited in scope, as best suited to showing surface deterioration, yet are congruent with the other measures of degradation chosen. As the most effective culture, *Phlebiopsnis flavidooalba* cultures were also selected for a formal test of biodegradation (based on CO2 production) and again performed well, confirming mineralisation (the end stage of biodegradation where CO2 is released). The results in this paper consistently showed more effective LDPE degradation if no wood was present in the culture to degrade, which is an interesting finding (and the opposite of the Authors' hypothesis that wood would enhance the process), reflecting the flexibility of Fungi in choice of carbon source. The transferability of these findings to the degradation of PE-lined

cups remains unclear, as the experiments employed highly specific fungal cultures from Sri Lankan forests and excluded other carbon sources.

Figure 1

SEM Images of Mycelium-induced LDPE Degradation (Perera et al., 2023)



Note. Image reproduced from Perera, P., Herath, H., Paranagama, P. A., Wijesinghe, P., & Attanayake, R. N. (2023). Wood decay fungi show enhanced biodeterioration of low-density polyethylene in the absence of wood in culture media. *PLOS ONE, 18(7),* e0288133. https://doi.org/10.1371/journal.pone.0288133. Licensed under CC BY 4.0.

The Role of Fungi

Brown-rot and white-rot fungi are saprotrophs, organisms that break down dead organic matter through extracellular digestion. They release enzymes through their cell walls to decompose complex molecules. Brown-rot fungi primarily degrade cellulose and hemicellulose, leaving wood brown and crumbly. In contrast, white-rot fungi can break down all components of wood, including lignin, resulting in a pale, fibrously textured residue. Key enzymes involved in this process include lignin peroxidases, manganese-dependent peroxidases and laccases, all of which dismantle large carbon-based structures. This releases nutrients, which are then reabsorbed and cycled back into the forest's ecosystem (Kirk & Cullen, 1998).

This remarkable ability to decompose tough organic material extends beyond the forest system. Saprotrophic fungi have been shown to degrade some of the most persistent pollutants, including pesticides, industrial dyes, hydrocarbons, and even components of nuclear waste

(Dadachova et al., 2007). They can be employed to clean oil spills and remediate contaminated soils (Stamets, 2005). Many pollutants share structural similarities with lignin, such as long hydrocarbon chains, and are therefore amenable to the same enzymatic breakdown by fungi. This process is called mycoremediation.

White-rot fungi, in particular, are recognised for their exceptional ability to degrade a wide range of environmental pollutants, including plastics (Singh et al., 2026). Their natural role in composting dead wood makes them powerful agents for myco-remediation. This potential has inspired contemporary research into fungi-led recycling. For example, Hannah-Lee Turner (2024) demonstrated that *P. ostreatus* (grey oyster mushroom) can grow on textile waste and accelerate its degradation, a finding echoed by ongoing research from the University of Leeds, UK (Fletcher, 2025). There is also supportive literature for the ability of *P. ostreatus* to degrade plastics (da Luz et al., 2013). Despite the body of research exploring the ability of various Fungi to degrade LDPE, I identified a research gap when looking for the studies of the ability of Fungi to degrade LDPE coated paper, or LDPE tightly bonded onto paper cups. There has been a single publication (Gotvajn et al., 2018) demonstrating delamination of plastic-coated waste paper by the white rot fungus **D. Squalens.,* but a complete research gap regarding the efficacy of fungal cultures in degrading LDPE within paper cups. The reasons behind this are unclear, but may relate to publication bias if attempts to degrade the LDPE in paper cups have been unsuccessful. I spoke to one researcher, François Audredéz whose pilot study tackling this question ran into technical difficulties.

A History of Collaboration with Living Organisms

Fungi have played a fundamental role in shaping life on Earth and still underpin many human processes, although their contributions often are unappreciated. In *Entangled Lifeh*, Merlin Sheldrake explains how four hundred million years ago, “fungal allies” helped plants from freshwater habitats to move onto land. Fungi were therefore foundational to the rise of plant life and, ultimately, the evolution of human life on Earth (Sheldrake, 2020; Strullu-Derrien

et al., 2018). Continuing this collaboration, many deeply embedded human practices rely on fungal activity, such as beer brewing, and making bread, cheese, or penicillin.

This long-standing entanglement between humans and fungi provides an important foundation for contemporary biodesign practices, where collaboration with living organisms becomes both a conceptual and material strategy. *Mending Cracks* by Christina Stadlbauer is a project exploring the transformative potential of mycelium in repairing discarded human artefacts. Drawing inspiration from the traditional Japanese technique of Kintsugi, in which broken ceramics are repaired with gold, Stadlbauer's process, known as BactoHealing, aims to mend cracks by using microorganisms. In this process, bacteria and fungi grow a bond, rather like "scar tissue" over fractures (Stadlbauer, 2025). The timeline of this process is biological and therefore beyond human control, encouraging mindfulness and humility in the face of natural cycles. Stadlbauer's work has shaped my understanding of the autonomy of living organisms within the collaborative practices promoted by biodesign. As a creative precedent, BactoHealing opens up conversations about the agency of non-human life-forms, the foundations of care ethics, and what it means to work with living entities. While the project does not provide empirical evidence regarding these concepts, it demonstrates how biodesign can be used to provoke reflection on human relationships with living organisms. It also raises important questions about where co-working with living organisms sits on the spectrum between exploitation and collaboration.

A Future Built Environment

Alongside co-designing with living organisms, designing in a way which facilitates more integration between nature and humans is becoming increasingly relevant. In Dezeen Architecture and Design Magazine, Alyn Griffiths writes about a project "Led by Living" in which a pavilion made from materials with microbial properties was created to explore how architecture can help to build healthier environments for humans (Griffiths, 2021). Projects such as Led by Living demonstrate growing interest in integrating biological systems into architectural design. While these projects do not provide evidence that such approaches will

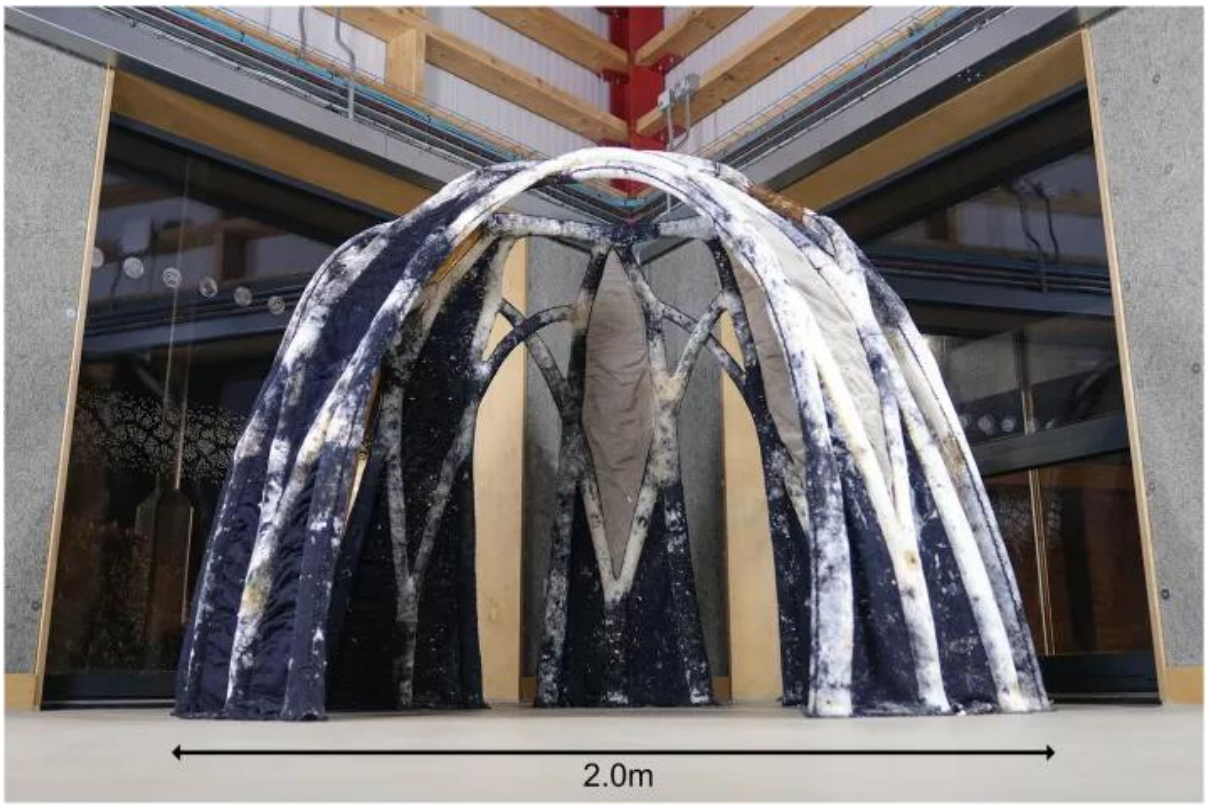
become widespread, they illustrate emerging design directions within bio-integrated architecture and prompt speculation as to what co-designing with living organisms may look like in the future.

There is no doubt that addressing the environmental impact of construction will become critical in the future, as it remains one of the most significant polluting industries. According to Yu et al. (2024), construction activities account for for 40 % of global energy consumption and 36 % of carbon emissions.

BioKnit by Kaiser et al. (2023) addresses this problem with a biocomposite called mycocrete. A mycelium-containing paste was injected into a tubular textile framework acting as an exoskeleton. Over time, the mycelium grew through the substrate into the form pictured below (Figure 2). Mycocrete could be created at the scale necessary for construction in a low-energy and carbon-neutral process, but growth time remained a limitation and was difficult to influence. Mycocrete provides a speculative example of how mycelium-based construction systems might be applied within future built environments.

Figure 2

BioKnit Self-supporting Structure



Note. Adapted from Kaiser R, Bridgens B, Elsacker E and Scott J (2023) BioKnit: development of mycelium paste for use with permanent textile formwork. *Front. Bioeng. Biotechnol. 11:1229693*. doi: 10.3389/fbioe.2023.1229693 Copyright 2023 by the authors. Licensed under CC BY 4.0

Urban mycelial structures are not solely a utopian future. Kaiser et al. (2023) observe that research into biomaterials, particularly mycelium-based composite materials for construction, has expanded substantially over the past decade. However, the potential adoption of these materials depends not only on their technical performance but also on public understanding and acceptance. As the preceding discussion suggests, unfamiliarity with fungal materials may create emotional and perceptual barriers to their use within the built environment. This challenge informed the decision to explore communication through a book format. By combining scientific information with

creative storytelling and visual imagery, the book aims to foster familiarity with fungi and communicate their potential role in sustainable futures, thereby addressing some of the barriers associated with material acceptance.

Barriers to Collaboration with Fungi

Walker (2022) examines barriers to adopting mycelium-based materials in *A Mycelium Connection*, focusing particularly on sensory responses and the emotion of disgust (Figure 3). She identifies a significant research gap surrounding mycelium biocomposites, noting that existing studies have largely prioritised production processes and technical performance over users' sensory experiences. To address this gap, Walker presents a "material experience study" that uses surveys and video observation to examine early adopters' responses to mycelium materials. She characterises disgust as a "pseudo-threat", a response that signals perceived risk despite the absence of actual danger. Her findings reveal the complex role that sensory perception plays in shaping public attitudes towards mycomaterials.

This insight is particularly relevant to my project, as it highlights the importance of sensory and emotional experiences in the acceptance of emerging materials. If negative sensory responses can inhibit acceptance, positive experiences may help to foster familiarity, trust, and engagement. This understanding contributed to the decision to develop an interactive illustrated book that communicates fungal concepts through creative storytelling and visual engagement.

Walker also acknowledges the diversity of responses to mycomaterials, noting that curiosity may coexist alongside feelings of disgust. This tension between attraction and aversion warrants further investigation and points to a potential limitation of the study: the inherently subjective and unpredictable nature of emotional responses.

Figure 3

The Proxemic Challenge of Disgust, Concern, Interest, Repulsion and Attraction (Walker, 2022)



Note. Reproduced from *A Mycelium Connection: A study of the influence of mycelium bio-composites' senso-aesthetics on disgust and other barriers to uptake in architecture*, by M. Walker (2022), Master's thesis, Victoria University of Wellington. https://www.researchgate.net/publication/363665844. Copyright 2022 by the author. Reproduced with permission.

Walker (2022) continues to dissect negative emotional responses toward fungi, recognising that many people experience an innate feeling of disgust:

> "Our minds tend to function by identifying what is and what is not. We find comfort in polarities, life and death, waste and commodity, human and non-human; when these polarities are challenged, it provokes existential anxieties. Mycelium represents life and death, and are neither plant nor animal; this inability to make sense of them can evoke fear and mistrust, compounded through the awareness of the health risks of poisonous fungi and moulds." (Walker, 2022, p.116).

Figure 4

Mycelial Contact: calming, grounding, pleasant to hold, stimulating curiosity (Walker, 2022)



Note. Reproduced from *A mycelium connection: A study of the influence of mycelium bio-composites' senso-aesthetics on disgust and other barriers to uptake in architecture*, by M. Walker (2022), Master's thesis, Victoria University of Wellington. https://www.researchgate.net/publication/363665844. Copyright 2022 by the author. Reproduced with permission.

Participants of her study described material responses to mycelium composites such as "calming", "grounding", "pleasant to hold", as well as "stimulating curiosity" (Figure 4). Furthermore, mycelium-based composites can contribute to healthier indoor environments as they are bio-based. Completely organic materials, grown from fungal mycelia and lignocellulosic substrates, are low-toxicity materials with minimal chemical emissions (Elsacker et al., 2020). Elsacker and Jones express the need for research that focuses on issues of awareness and trust towards bio-composites (as cited in Walker, 2022, p.5). Walker (2022) discusses the psychophysiological benefits of indoor architectural nature exposure, for example by integrating mycelium into our built environment.

Mycotechnology, Humans and Nature

To understand the landscape that humans have built on Earth, we should understand what has shaped our cultural perception of nature and what drives our interactions with the environment. We are dependent on nature functioning well. Collet (2021, p.1): "Simply by looking at the history of food, we can witness a long-established relationship with microbial invisible organisms". However, some Western science and cultural traditions center on an "anthropocentric" belief that we are separate from nature and the microbial world.

Cartesian dualism (Plumwood, 1993; Haraway, 2008), formulated by 17th-century French philosopher René Descartes, is the idea that everything that exists falls under two categories. Both of these categories are required to give a true description of reality. Humans are differentiated and separated into mind and body. He argued that non-human animals are autonomous machines without a mind, soul, or body. More recently, Anna Tsing (2015) described Western philosophers as identifying a nature that is grand and universal but also passive and mechanical, shaping our understanding of science and our place in the world. Haraway (2008) and Plumwood (1993) both argue that Western science is deeply shaped by Cartesian dualism, particularly through its enduring separation of mind and body, culture and nature, the observer and the observed. Western science discourages a holistic understanding of humans as an integrated life form within ecosystems. Taxonomy and classification of life-forms have created a hierarchy in which we feel superior to the bacteria and fungi with whom we cohabit our bodies, who were there long before us and who have granted us a space to evolve into. Cartesian dualism, as a philosophy encouraging separation between humans and other life-forms, is still carried in societal behaviours today and partially accounts for the environmental exploitation. The Western anthropocentric worldview sees nature's resources as a tool for furthering the self and rapid economic growth (Collet, 2021). Mylius (2018) extends this critique through the concept of normative anthropocentrism, arguing that scientific inquiry is often shaped by assumptions of human superiority and centrality. Such assumptions can limit how humans understand and engage with the more-than-human world.

Biodesign has emerged as an alternative approach that challenges these assumptions by positioning nature not simply as a resource to be extracted, but as a source of knowledge, intelligence and collaboration. Rather than focusing solely on human needs, biodesign explores reciprocal relationships between humans and other living systems, seeking design solutions that support broader ecological wellbeing.

Several theorists have shaped contemporary biodesign discourse, including Donna Haraway, Janine Benyus and Carole Collet. Of particular relevance to this research is Collet's (2021) framework for designing with living systems. Collet proposes three approaches: nature as a model, nature as a co-worker, and nature as a hackable system. Together, these approaches provide a framework for understanding how designers might learn from, collaborate with and actively engage biological systems within design practice.

The concept of nature as a co-worker is particularly relevant to mycotechnology. Collet argues that meaningful collaboration with living organisms requires designers to create conditions that support growth and agency, allowing organisms to contribute materials or perform specific functions. Within this research, fungi are considered collaborators rather than passive resources, with their biological processes explored for their potential role in the degradation of synthetic materials and the development of alternative material futures.

The human-nature separation described above is not a value shared across all cultures. Mātauranga Māori acknowledges a spiritual and genealogical connection between people and the environment (Wehi, 2019). This perspective promotes environmental guardianship and reflects knowledge systems that are deeply rooted in relationships with the natural world. Wehi reflects that ‘Working with interdisciplinary knowledge including Mātauranga will be critical to halt further biodiversity loss and improve outcomes for the environment and people, in New Zealand and worldwide’. Wehi's (2019) recognition of the value of interdisciplinary knowledge, including Mātauranga Māori, is particularly relevant to this project. The research similarly draws upon multiple ways of knowing, combining scientific literature, design practice, and creative communication to explore human relationships with fungi and the environment.

Some innovations widely regarded as novel within Western design and biotechnology such as mycelial leathers (Figure 5), have precedents in Indigenous material practices. Blanchette et al.(2021) documented Tlingit wall pockets constructed from fungal mycelial mats, demonstrating the historical use of fungal-derived textiles by Indigenous communities in North America.

Figure 5

Mycelium Skins made by Annah-Ololade Sangosanya, Brussels, Photo by Author, 22/05/2025

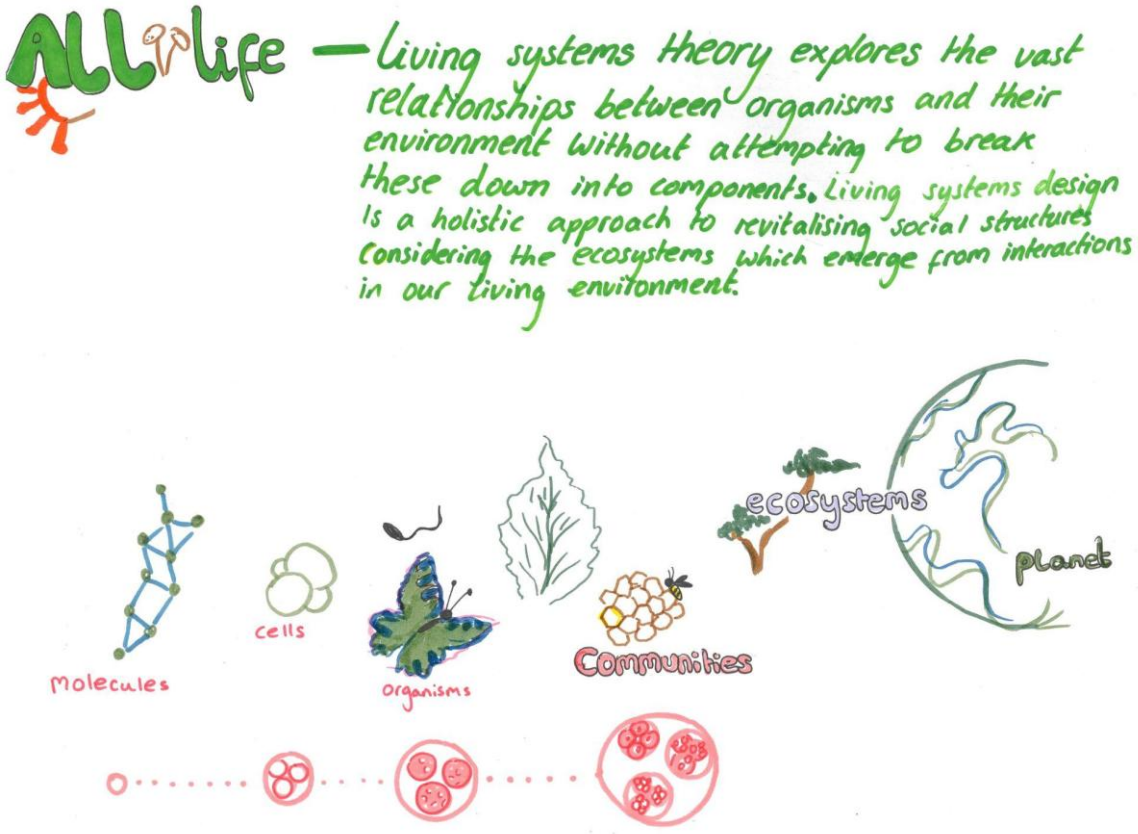


A New Roadmap for Design

Biomimicry, dubbed by Janine Benyus, is an integration of multiple disciplines including biology, design, engineering, and ecology. From the Latin “bios” - life and “mimesis” - the act of representation or imitation (Benyus, 1997, p.7), biomimicry involves using mechanisms found in nature to help solve human problems. Benyus (1997) speaks of Indigenous and traditional communities who have lived in symbiosis with a deep-rooted connection to nature for millennia. She adds that this way of being and seeing the world comes intuitively. It means returning to ancient practices of a time in which human behaviour was in synchronicity with the Earth's cycles. Benyus (1997) states that “wisdom” comes with time on the planet, and is to be found in Indigenous communities and species that have lived on Earth far longer than humanity. Flaws in Western science can arise from studying our world in separation, rather than as a whole (Benyus, 1997).

Figure 6

Hand-drawn Notes about the Living Systems Theory, by the Author, 17/05/2024, Wellington



"Living systems design" and "holism" are alternative intertwined worldviews, understanding interdependence and connection across life-forms (Figure 6). The relationships organisms have to one another and their environment are studied and prioritised. In *Emergent Strategy,* Brown (2017) describes a paradox: Humans align themselves to animals who rule the food chain, for example lions and tigers. Yet these very animals are isolated in their power and risk becoming extinct. Instead, small, collaborative species including insects, fungi, bacteria and viruses have adapted well and are coping better with the pressures of our rapidly changing environment. Some of these species have already survived multiple mass extinctions. Removing the sense of hierarchy is required, collaboration with other species offers an evolutionary benefit.

We are not better off without our cohabiting "lesser" species, such as bacteria and fungi. Humility may allow us to be led and taught by these species.

Symbiosis, interdependence and self-organisation are all terms covered under the umbrella of the living systems theory. Terry Irwin (2020), the head of school at Carnegie Mellon, states that these act as leverage points for change within complex systems. Climate change and other wicked problems are tied into systems of incredible complexity. Frameworks may be valuable tools. Holism emerged in an attempt to address the loss of biodiversity and its impacts, caused by human decision-making (Khajuria & Kumar 2017), and provides a framework to consider all affected individuals:

1) The individuals in charge of managing the whole - these are the decision-makers.

2) The resource base - this entails all of the resources available, such as land, machinery, and skills.

3) The individuals who influence or are influenced by the decision-makers.

Though simple, this tool encompasses the decision process from start to finish: manufacturers are the decision-makers in the scenario "PE-lining of paper cups". The current resource base for PE-lined paper cups relies heavily on petrochemical feedstock and associated industrial infrastructure. The "individuals who influence" are biotechnologists and designers working on alternatives. The "individuals being influenced" are both consumers and the environment, which suffer consequences of the initial decision.

Decisions have primarily been human-centred for a long time (Wakkary, 2021). This individualistic way of seeing the world may have emerged out of industrialisation. Carole Collet discusses how design as a profession emerged out of the Industrial Revolution, a time in which the seemingly limitless abundance of the Earth's resources presented "a means to pursue rapid economic growth and wealth" (Collet, 2021). The financial progression of the individual has been misconstrued to equate to a person's place and value in the world, which has founded the motivation to further the self at any cost. The predominant human-centred approach to management has contributed to stretched resources, a strained planetary ecosystem, widespread

inequality and poverty. Pollution is a wicked problem, interlaced with social issues. Viewing climate change in isolation fails to acknowledge its entanglement with related socioeconomic problems (Islam & Winkel, 2017). Disadvantaged societies and groups will suffer disproportionately from the adverse effects of climate change, resulting in greater subsequent inequality, which is reinforcing feedback in a vicious cycle. A "tower of consumerism" driven by the Western world has seen a rapid surge of industrial development in countries such as India, putting strain on a system that has not been built to deal with this rate of extrapolation (Singh et al., 2023) and an ecosystem that has to pay the price.

Systems thinking is required to understand the plethora of factors influencing climate change to help identify possible leverage points for change and areas of weakness within the system. Another form of thinking directly adjacent to systems thinking is "Emergence". Emergence notes how small actions and connections inform the development of ecosystems and societies (Brown, 2017). One aspect is the opportunity for a shift in human behavioural patterns. Doom is predicted and presented by every headline, making it difficult to see less sinister trajectories for the human race. But Emergence, explored by Adrienne Maree Brown in *Emergent Strategy*, speaks of hope, of awareness for how little changes across an interconnected system can create space for the worlds we aspire to. She describes her book as a thought cluster for those who seek to turn our legacy from crisis towards harmony. As a designer, I require this optimism and larger picture to prevent my efforts in biodesign from being swallowed by the mainstream lack of consideration for the environment prevalent in the design industry at large.

Collaborative Survival

Anthropologist Anna Tsing introduces the idea of collaborative survival: “To recognise processes where multiple species rely on each other to survive within damaged landscapes” (qtd in Liu et al., 2018, p.2). She emphasises that this is not a narrative in which humans are framed as the protectors of the planet, but rather a focus on building collaborative relationships with other species. Existing interactions in nature can inspire us to move towards benefiting all life. In *The Mushroom at the End of the World*, the matsutake mushroom is an example of a lifeform that resisted prolonged damage from humans. Matsutake mushrooms appeared during devastation: “When Hiroshima was destroyed by an atomic bomb in 1945, it is said, the first living thing to emerge from the blasted landscape was a matsutake mushroom” (Tsing, 2015, p.3). Life's ability to persist in the most hostile conditions provides hope for the future and changes the question from: “Will there be life on Earth?” to “What will life look like, and which species will adapt to thrive in the Earth's rapidly changing climate?”

In *Two Natures,* the “first nature” means nature as it was before human intervention (Cronon, 1995). The “second nature” then encompasses changes made by humans to increase productivity for capitalistic exploitation. The “third nature”, as added by Tsing (2015), describes life-forms managing to thrive despite human capitalism. This third category is uncertain, open to change, and full of possibilities. “Post-capitalist” or "post-anthropocentric" design are associated disciplines, alternative to the design that has historically been human-focused innovation to improve human lives. Post-anthropocentric design acknowledges that neither capitalism nor humans will exist in the future, but the effects of our design choices will last. This reframes design from something centred on human needs to something oriented towards other life-forms and future ecologies.

Synthesis and Research gap

The scientific literature reviewed in this section highlights the need for continued research and innovation to address the plastic crisis. It also provides substantial evidence that fungi can degrade polyethylene (PE). While evidence exists, few studies fully examine how fungi interact with PE that is tightly bonded to paper. Furthermore, none compare the efficiency of different fungal strains for this application.

Precedents from creative industries such as Architecture, textiles, and biotechnology added a new angle to my research: human response to fungi and foreign materials, the distinct barriers to acceptance, and the historical evolution of this relationship. This prompted me to explore an illustrated book to connect people with the subject and spark curiosity.

Chapter Two: Methodology

Introduction to Inductive Methodology resulting in My Two Phases of Work

This project combined experimental biomaterial research with creative practice-based design research. The research developed through an iterative process in which laboratory experimentation, reflection, literature review, and design exploration informed one another. The project consisted of two interconnected phases. Phase One investigated the potential of selected fungal species to biodegrade polyethylene (PE)-lined paper coffee cups through a series of laboratory experiments. Phase Two translated insights gained from this experimental work into a speculative design outcome, an illustrated book titled *A Future with Fungi*, intended to communicate the potential of fungal collaborations to a broader public audience. Rather than following a strictly deductive or inductive research pathway, the project moved iteratively between observation, experimentation, interpretation, and creative development, allowing findings from each phase to inform subsequent decisions.

Haque (2022) defines the inductive process as starting with observation and then progressing to exploration and discovery. He contrasts the deductive method as starting with theories or hypotheses which then lead to secondary observations. Induction is open-ended and adaptable, while deduction focuses on confirming or rejecting a hypothesis. My research journey oscillated between deductive and inductive processes. Further observations led to interdisciplinary work between design, science, art and others, as befitting a complex problem.

The project evolved through practice-based and experimental research. I learned the specific skills I needed by attending Fabricademy Brussels, a course for interdisciplinary designers that shares emerging technologies and practice techniques. The programme provided foundational knowledge and technical skills that supported the research, particularly in laboratory protocols and aseptic working techniques. These skills, taught by Biologist & Textile Designer Anna Ololade were essential for cultivating fungi under controlled conditions and minimising contamination from competing microorganisms during the experimental work. I

refined my laboratory practice at Sapro-Tech under the supervision of Chemist Gayani Weeratne.

Phase one consisted of multiple rounds of laboratory experiments that continually improved as facilities became available, along with critical reflection and iteration. The second phase was complex, starting with an exploration of the potential meaning of the scientific results, using speculative thinking about future applications of fungi and their role in tackling climate change and sustaining life on Earth. I then considered different design-based communication methods for making this information accessible. This phase addressed how to overcome barriers for collaboration with nature and how to raise greater awareness of the opportunity for environmental restoration through collaboration with mycelium as a lever to greater engagement with nature overall. I used speculative design to envisage future collaborations with fungi. I present this in *A Future with Fungi.* Beyond people concerned about climate change and interested in positive, solution-oriented innovations, the target audience includes individuals who might not engage with environmentalism, in the hope that the book's illustrations and interactive nature awaken their interest. The intention is to encourage reflection on the presence of plastics and other forms of pollution; however, rather than experiencing climate doom, the interaction might result in small positive actions that gather momentum toward a healthier collaboration with nature.

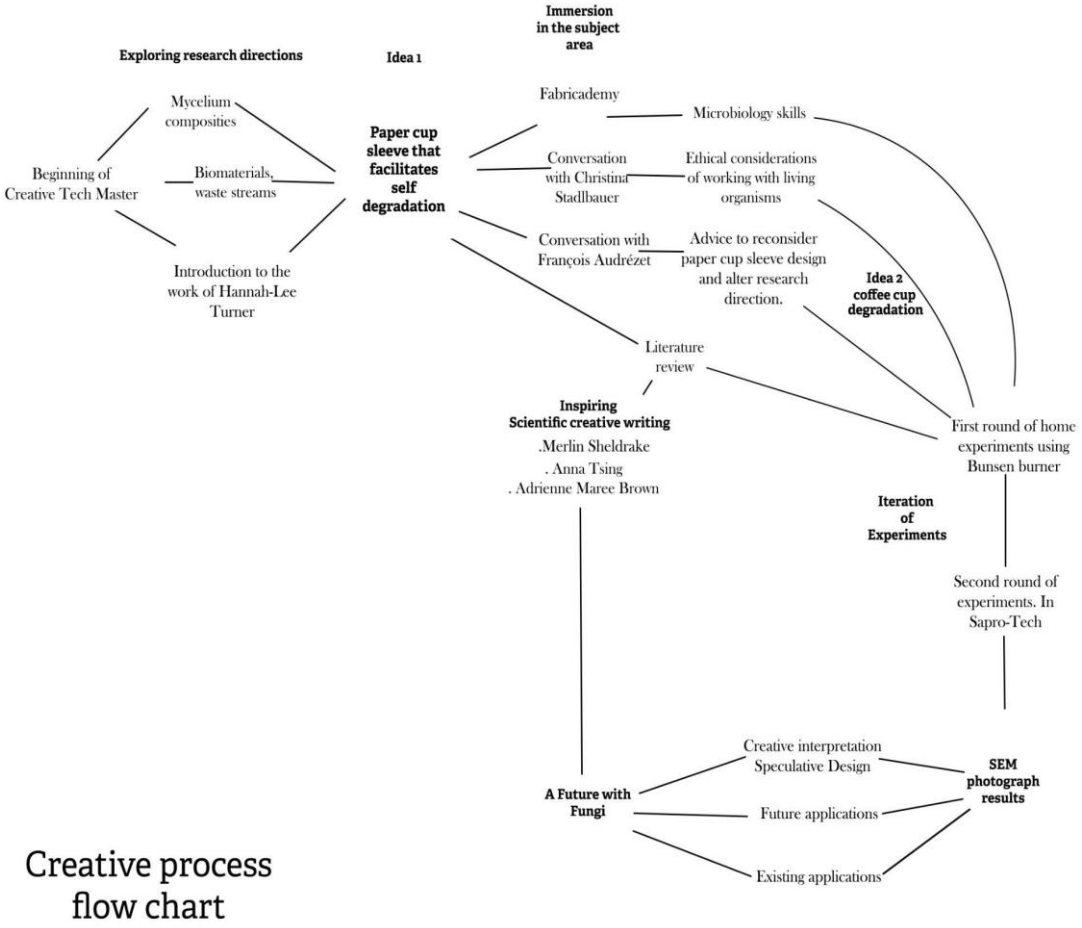
As biodesign is an emerging discipline, there is no set framework for approaching research, which opens the opportunity to create one's own pathway. My project pathway started from observing a problem (littering with PE-lined paper coffee cups), considering nature as a model of life-cycling waste, scientific investigation of mycoremediation (working with nature), towards consideration of the wider context and exploration of how to translate these findings into change (fungal networking and interspecies collaboration as a hackable system of nature).

Research Design

My research journey is depicted in the flowchart in Figure 7, and shows key practitioners whose work influenced my research lenses as well as my writing style in *A Future with Fungi.* Merlin Sheldrake (Science), Anna Tsing (Anthropology) and Adrienne Maree Brown (Activism) all work in interdisciplinary spaces. Merlin Sheldrake's book *Entangled Life* (2020) exposed me to creative scientific writing and the importance of storytelling in connecting the public with nature. Anna Tsing's research methodology complements this project's inductive approach. In *The Mushroom at the End of the World* (2015), Tsing describes the process of allowing research goals to emerge over time, rather than being predetermined as in big science. I allowed observations of, and collaboration with, mycelium to shape and inform the direction of my research.

Figure 7

Flow chart of Inductive Creative Process During Masters Work. By the author, 18 June 2026



My scientific and creative pathway illustrated in figure 7 led towards the two project outcomes: SEM photographs showing fungal impact on PE, and the book *A Future with Fungi.* I began with rapid idea generation, which led to iteration one, a self-degrading, therefore truly biodegradable, coffee cup. After seeking the advice of the wide range of practitioners listed in the diagram above, this idea was deemed unsuitable due to its complexity.

Table 1

Summary of the Two Main Phases / Components of My Master's Work

Approaches	Methods	Theoretical Influences	Outputs
1. Test the ability of three strains of fungi to degrade PE	Practice based research: Scientific experiments into biodegradation. Inductive research reflection, Advice from subject specialists	Literature review Secondary research Learning/sharing ideas at Fabricadamy and Sapro-Tech, Secondary research	Qualitative SEM photography results. Reflection on limitations. New idea formulation detirmining
2. Create a means to communicate scientific content in order to achieve a culture change in our relationship with plastics and nature	Reach out to many people, including non-scientists. Aim to publish to broaden reach after completion of Masters	Literature review Observation Intuition Reflective practice Formation of a mycelium-like network of people and ideas Storytelling Watercolour art	Storytelling Watercolour art Create an illustrated book for readers outside of readers outside of environmental and scientific communities

Table 1 summarises the two primary phases of this research, along with their aims, methods, theoretical influences, and outputs. The experimental phase generated insights through laboratory observation and testing, while the creative phase translated these findings into accessible public communication.

Several limitations influenced the experimental work. Access to laboratory facilities was initially restricted, and although collaboration with Sapro-Tech improved resources, the research remained limited to low-risk fungal strains. I could not perform regular scanning electron microscopy (SEM) analysis of samples, so relied on laboratory staff for imaging. Furthermore, while visual assessment showed biodeterioration, additional chemical analysis of degradation products would have strengthened the scientific evidence for biodegradation.

Reflecting on these limitations highlighted that scientific findings alone are unlikely to drive change unless they are communicated effectively beyond academic and technical audiences. This insight informed the transition from the experimental phase to the creative phase

of the project. Laboratory observations, combined with insights from the literature, shaped the development of *A Future with Fungi*, an illustrated book designed to engage non-specialist audiences, particularly readers who may not typically engage with environmental or sustainability-related content.

The two phases are complementary. The experimental research contributed to knowledge regarding fungal interactions with PE-lined paper cups, while the book sought to communicate broader possibilities for human-fungal collaboration and environmental restoration. The creative development of the book was guided by narrative inquiry, which proposes that people make sense of complex ideas through stories and that narrative and imagery can influence understanding, meaning-making, and cultural attitudes (Clandinin & Connelly, 2000).

Purpose of Fabricademy

Attending Fabricademy Brussels, hosted by Celia Raspanti (Textiles), contributed as preparation and skills development for the experimental work. Though the topics covered spanned across a range of emerging technologies, mycelium and biomaterials were the key focus of the program. The opportunity to connect with those already practising in this space has been invaluable for my project, for sharing stories and ideas, observations and reflections, for becoming part of a network. In April 2025, Annah-Ololade Sangosanya presented her project *"Fungal Skins: Macro"* at Milan Fashion Week. In a process developed at the microbiology department of the Vrije Universiteit Brussel (VUB), Annah-Ololade fed textile waste to fungi, which grew into new materials (Treciokaite, 2025). At Fabricademy, she introduced me to the microbiology skills necessary to inoculate mycelium for growing cultures and materials, which I subsequently reproduced in a home setting. At a factory visit to underground fungi farm I explored scaling up bench-top research with modern farming techniques, and learnt current research into textiles and plastics waste at the Centexbel Research Centre.

Procedure of Culturing Fungi

Figures 8 and 9 demonstrate how to create an aseptic working area using a Bunsen burner and the pouring of agar plates, both of which are common procedures in fungal cultivation and inoculation. Traditionally, microbiology practitioners have used a Bunsen burner to generate an upward air current that may help reduce the deposition of airborne contaminants in the immediate workspace. To support aseptic technique, the work surface was cleaned with either isopropyl alcohol or ethanol before procedures were undertaken. However, the use of flammable solvents near an open flame presents potential fire and burn hazards and therefore requires appropriate laboratory safety precautions, training, and supervision.

During inoculation, small sections of mycelium can be transferred from a colonised culture plate to a fresh agar plate under aseptic conditions to minimise the risk of bacterial or mould contamination. Once established, vigorous mycelial growth may be better able to compete with some contaminants. The same working area can be used when pouring fresh agar plates. In this process, laboratory bottles containing molten agar medium, typically maintained at approximately 40 to 50°C, are briefly exposed to the flame to reduce contamination at the bottle opening before the medium is poured into **disinfected** Petri dishes and sealed with laboratory tape.

I was instructed to hold the Petri dish slightly ajar while pouring the agar in order to minimise airflow into the dish and thereby reduce opportunities for contamination. Although the use of a Bunsen burner remains a widely taught component of aseptic practice, recent experimental research has found that Bunsen burners do not consistently reduce airborne microbial contamination and that their effectiveness appears to be highly dependent on environmental conditions (DeVincent et al., 2026). Their findings suggest that the technique should be applied cautiously and as part of a broader aseptic protocol rather than relied upon as a guaranteed means of creating a sterile working zone. This, in combination with the potential associated hazards of the method led to revision of the chosen methodology for the second round of experiments, conducted in the Sapro-Tech laboratory.

Figure 8

Aseptic area of the Bunsen burner. Diagram provided by Fabricademy, 19/05/2025

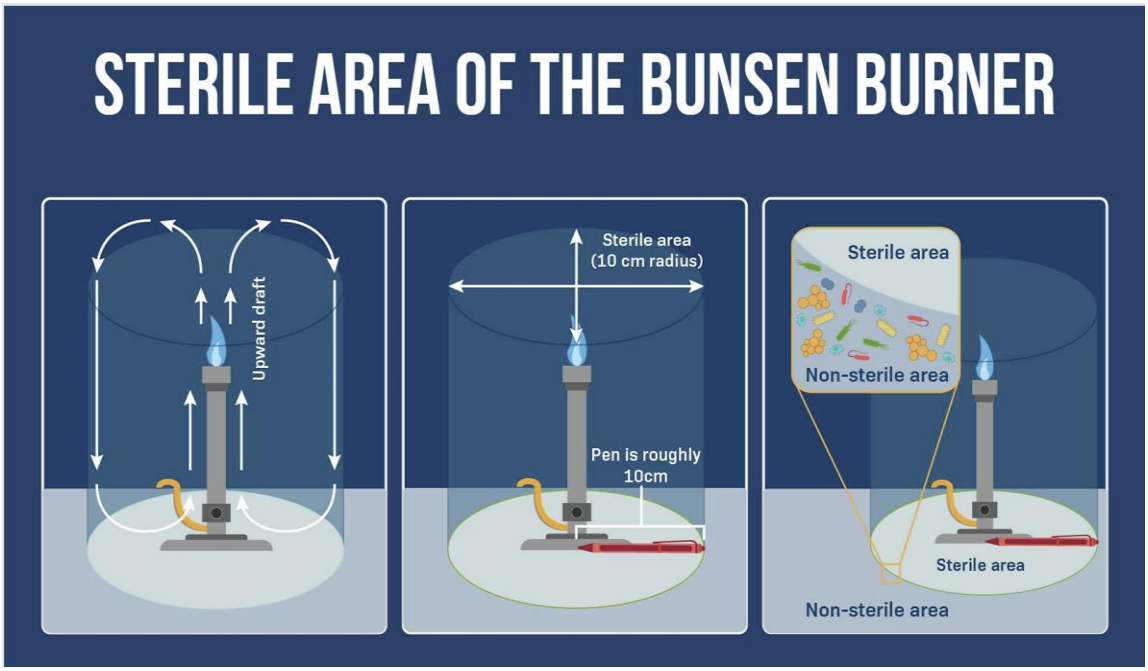
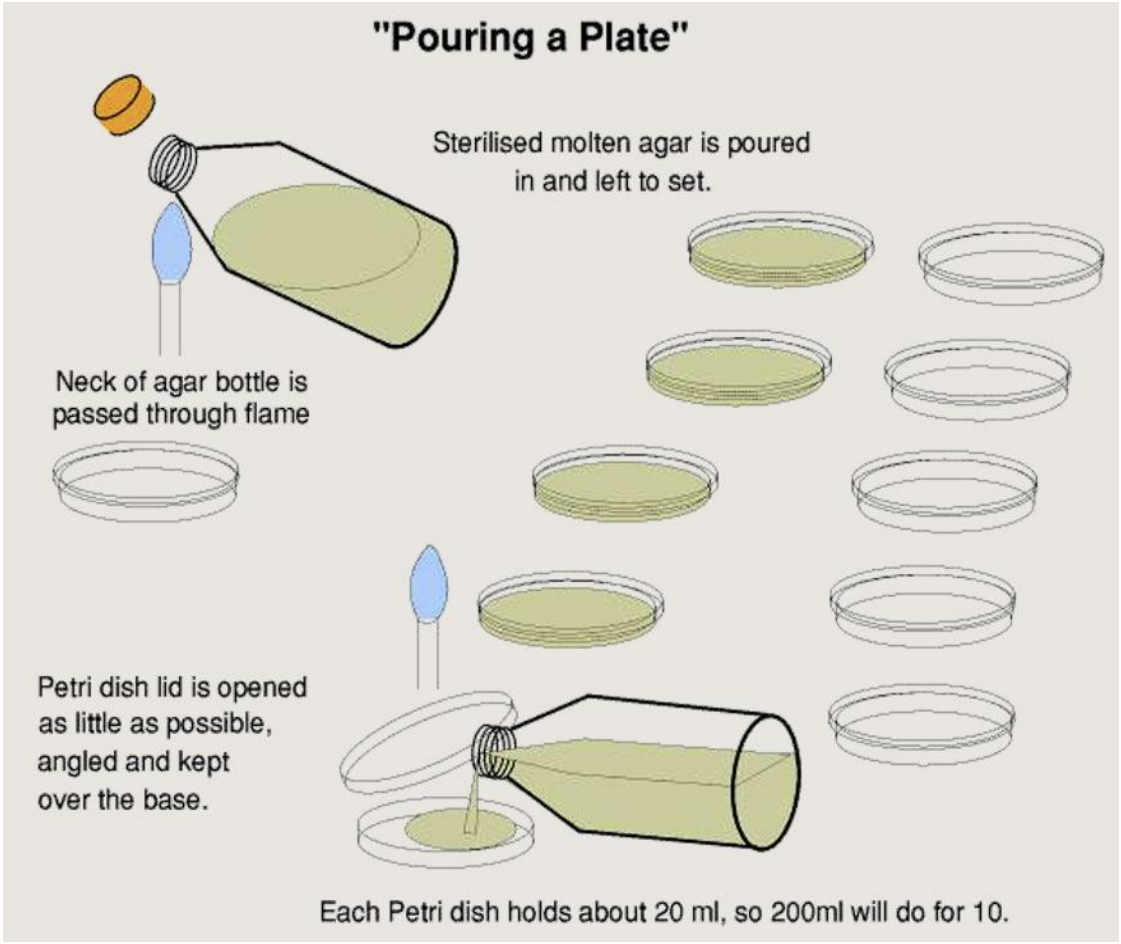


Figure 9

Pouring an Agar Plate. Diagram provided by Fabricademy, 19/05/2025



Limitations of Fabricademy Method

The methods taught at Fabricademy are not necessarily practised in laboratories due to challenges with heat-based sterilisation and hazards associated with open flames. A risk of using a Bunsen burner to sterilise tools for mycelium inoculation is the potential to damage the mycelium if the tool is not cool enough. This method also cannot be up-scaled, as would be required for real-world applications in tackling plastic waste. Nevertheless, the Bunsen burner method is appropriate for home setups if a research laboratory is not available.

More Possibilities of Collaboration with Microorganisms

Another skill in collaborating with micro-organisms I learnt at Fabricademy was bacterial dyeing using antibiotic bacteria known as *Streptomyces*. This technology is being developed as a chemical-free alternative to traditional dyeing methods. We transferred a small amount from a *Streptomyces spp.* culture, which had already begun producing purple colour onto new agar plates (Figure 10). *Streptomyces* is a genus of *actinomycetes*, gram-positive bacteria known for their filamentous structure, resembling fungal hyphae growing in different colours; in this subspecies purple, creating stunning eco-friendly fabric dyes.

Figure 10

Bacterial Workshop at Fabricademy Brussels, 20/05/2025



The Choice of Takeaway Coffee Cups as Research Object

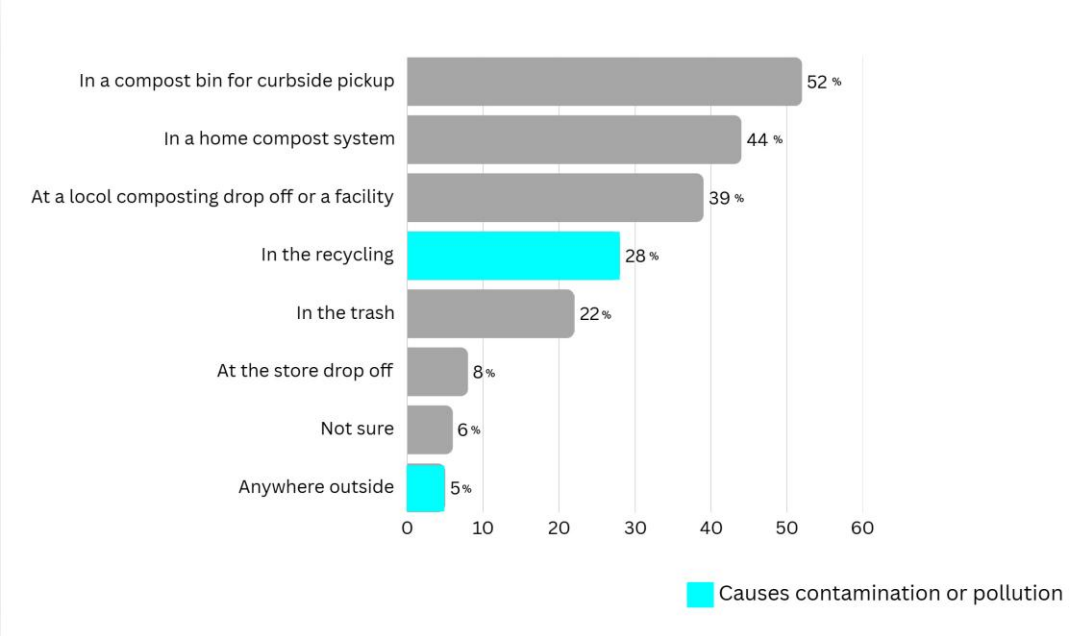
Paper cups made a good choice as research objects for several reasons. Misconceptions concerning their sustainability, a lack of transparency, and, most importantly, insufficient waste management systems to handle the rate at which they are produced result in a sizable problem. Most "paper cups" are only about 95% paper and 5% tightly bound plastic (Zangmeister, 2022). Starbucks Coffee Company, one of the top consumers of paper cups, estimated they were distributing six billion disposable cups annually and using more than 8,000 plastic cups every minute (Gregory, 2021). This places Starbucks as one of the key polluters in the coffee industry and drove my choice to research the degradation of their disposable cup plastic lining. Alongside easy availability of their cups for my research, I thought it important to choose a brand people recognise, highlighting it as a problem of immediate relevance.

The increasing consumer demand for environmentally friendly products has also increased the amount of "greenwashing" in the packaging industry, misleading consumers into believing a company or product is more environmentally friendly than it actually is. This can come in the form of adding natural elements to the design, such as leaves, the colour green, or deceptive labels on the cups, such as "eco-friendly" or "biodegradable" (Somany, 2023). Studies carried out by the Biodegradable Products Institute, North America, confirmed that most people do not understand what different composting labels mean. A survey of 2700 participants showed that 49% could not distinguish between "biodegradable" and "compostable" (Pyzyk, 2023). Paula Luu, senior project director at the Centre for the Circular Economy at Closed Loop, New York City, explains that the improper disposal of paper cups plays a critical role in the contamination and pollution surrounding takeaway cups (Luu, 2021). Figure 11 offers an insight into how much confusion there is about how to best dispose of waste. In Aotearoa New Zealand, the term "commercially compostable" is misleading, resulting in many cups ending up in landfill. Clearer labelling and transparency are required, as well as greater public education. "Biodegradable" means spontaneous degradation over time, whereas "compostable" requires

specific conditions. “Commercially compostable” requires constant higher temperatures over longer time than usually achieved in “home compostable” settings.

Figure 11

Consumer Answers to Questionnaire about Understanding of “Compostable” Label (Pzyk 2023)



Note. Adapted from “*Unpacking Labeling and Design: U.S. Consumer Perception of Compostable Packaging”* by Closed Loop Partners and Biodegradable Products Institute. As cited by Pzyk K. 2023. *Consumers don’t understand ‘compostable’ messaging on packaging, survey finds*. (Consumers don’t understand ‘compostable’ messaging on packaging, survey finds | Packaging Dive). 2023

The specific barrier inhibiting the recycling of paper cups is their PE lining, which constitutes five percent of the cup (Ma, 2018). Researching possible solutions for this specific issue is a feasible approach to addressing the large-scale problem of all plastic pollution. Rather than being recycled, 77.1% of cups are incinerated, and 22.9% end up in landfill (Eurostat 2023, qtd in Anand et al., 2023). The incineration process results in a high risk of microplastic release due to incomplete thermal degradation and heat-driven fragmentation. Paper cups have been shown to release plastics at 4°C, 50°C and 80°C at 126 to 1420 particles per litre, depending on temperature (Akbulut et al., 2024). Incineration risks aside, this also means that consumers are drinking microplastics as part of their takeaway coffee.

The risk of pollution is not limited to the material constitution of the cups; the fleeting nature of single-use takeaway products increases the likelihood of littering. This highlights the social issue tied to consumer- or consumption-culture (referring to societal norms, values, and practices surrounding the acquisition, use, and disposal of goods and services, shaping both individual identity and social structures), and presents another angle from which the plastic crisis needs to be addressed (Liboiron, 2021). Choosing to focus on paper cups also evolved out of noticing them in my daily life, every day in the classroom and on my way home, discarded at the side of the road.

Once I started looking for them, I saw the scale of the problem and was alarmed by how desensitized we are to littering and pollution in our daily lives. Big companies like Starbucks rely heavily on marketing via their logo, in this case, on their cups. The more prevalent their cups are, the stronger the marketing. The view that "no publicity is bad publicity" may further disincentivize the company from reducing the litter problem they cause, which can only be tackled through a broader shift in public opinion and resulting consumer pressure. The difficulties PE-lined paper cups pose for conventional waste management make them ideal candidates for mycoremediation research. I could find no published literature on paper cup mycodegradation.

Choice of Fungi

Following my literature review, I decided to work with *P. ostreatus, P. pulmonarius* (phoenix mushroom), and *Trametes (T.) versicolor* (turkey tail mushroom), supplied by SporeShift Mushrooms NZ, as these species are well-documented for their enzymatic versatility, with enzymes capable of breaking down tough, recalcitrant plant polymers (Reyes, 2021; Yang, 2024) and supported by research in plastic mycoremediation. Furthermore, they are non-pathogenic to humans and non-invasive, therefore readily available through online suppliers without requiring specific laboratory authorisation. Whereas Seenivasagan R. et al. (2022) identified different fungi (*Rhizopus species (spp.)* and *Aspergillus spp.*) from a plastic disposal site and used them to degrade LDPE on disposable paper cups, in a study by Marquez et al.

(2024) *P. ostreatus* was used to degrade low-density PE films in liquid fermentation solutions. One issue with paper cups is the tight bond between the paper and the PE, which makes up about five percent of so-called "paper cups". Žgajnar Gotvajn A. et al. (2018) used another white-rot fungus, *Dichomitus squalens*, to delaminate plastic-coated waste paper. I found no previous study testing the performance of *P. ostreatus*, *P. pulmonarius* and *T. versicolor* on PE-coated paper cups and therefore felt that my experiments could potentially add to the scientific literature.

Phase One: Practical Science-Based Research

Three rounds of experiments were conducted, each to varying degrees of scientific precision. Each round of experiments was not just an iteration of the last, but an improvement through new resources and facilities becoming available. I cut Starbucks coffee cup pieces and placed them in a star shape onto the agar plates, then inoculated the plates centrally with the three fungal strains.

I used an observational approach, monitoring, measuring, and photographing mycelial growth in these Petri dishes daily. Observations also included any signs of PE degradation or culture contamination. I planned to compare samples for vigour of growth and indications of PE deterioration, aiming to identify which strain was the most effective.

Procedure First Round of Experiments

The first took place at home (Figure 12) using the Bunsen burner method explained in Figure 8 and agar plates obtained from SporeShift Mushrooms. Within the aseptic bubble this method created, three segments of mycelium, one from each strain, were transferred centrally into individual agar plates containing 6 pieces of Starbucks coffee cup and nutrient agar (agar containing a sugar food source). They were then left to grow for up to 2 weeks. Observations were stopped earlier if the entire plate had been colonised, or detrimental contaminant growth became apparent. At this point, each plate was fully dehydrated and a small piece taken for SEM analysis.

Figure 12

Home Laboratory Set-Up. Photos taken by Author, 30/08/2025

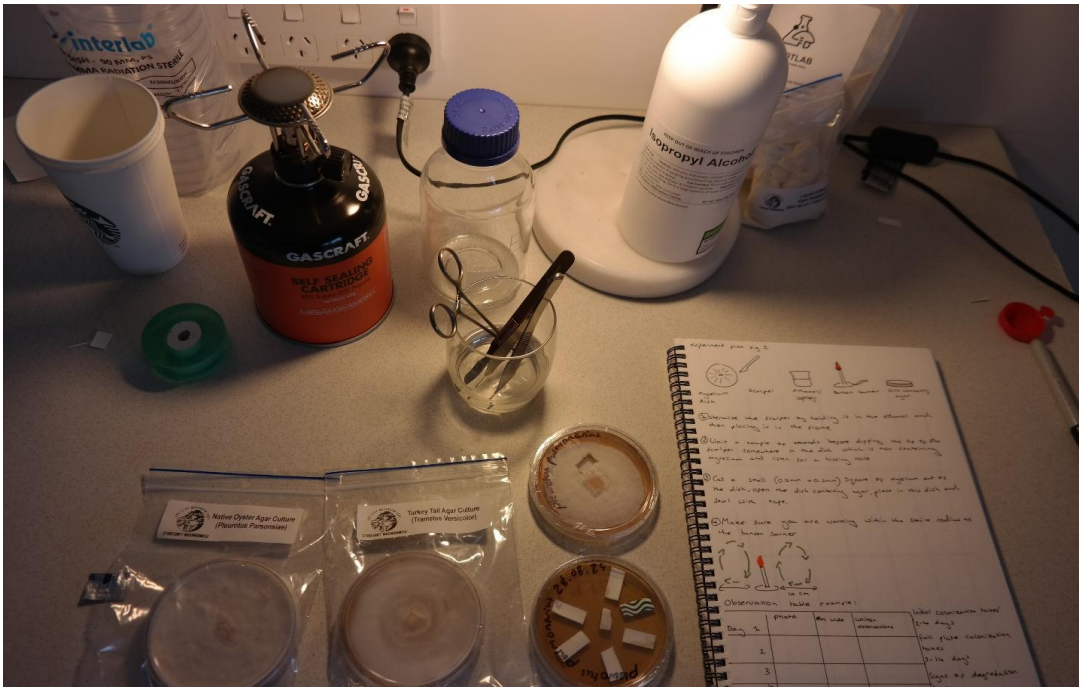
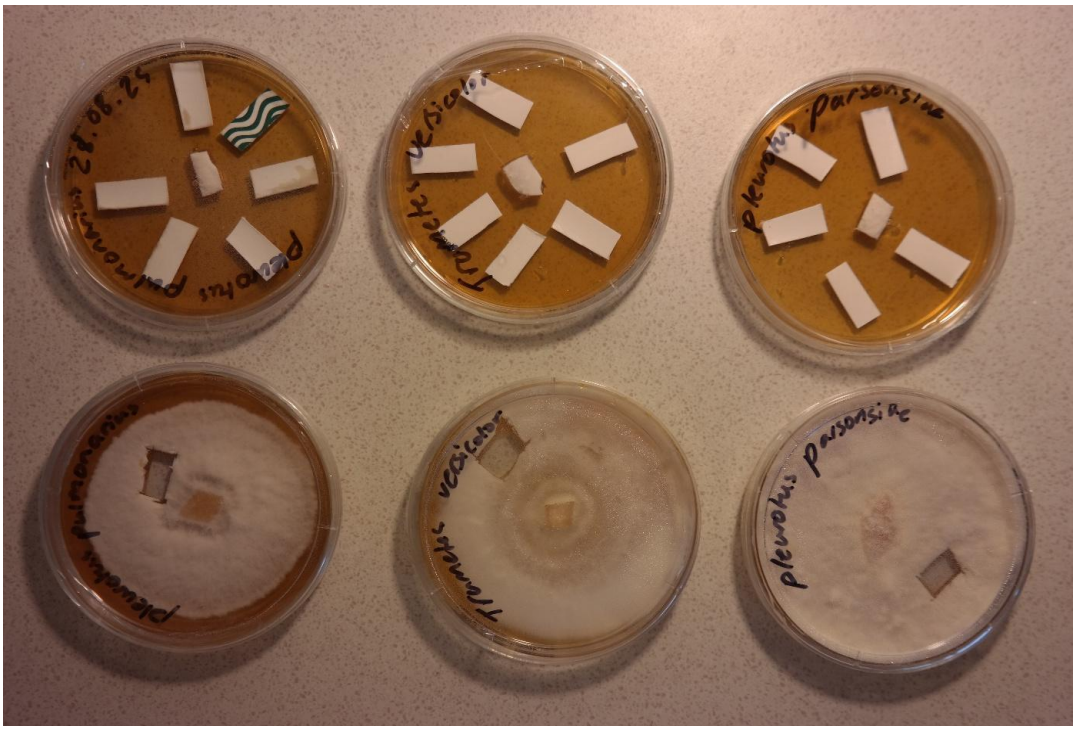


Figure 13

Three Fungal Strains and Inoculated Plates with Coffee Cup Pieces. Photo by Author, 28/08/2025



Over the following 14 days, data collection methods involved recording daily changes in size and any additional observations (Figure 13, Figure 14) by measuring size differences and taking photographs. Data was recorded in the results table formatted as seen in Table 3, for example - refer to the appendix for full results.

Figure 14

Mycelia Samples on Agar Plates, Day 14.: P. pulmonarius grew best. Photo by Author, 11/09/2025

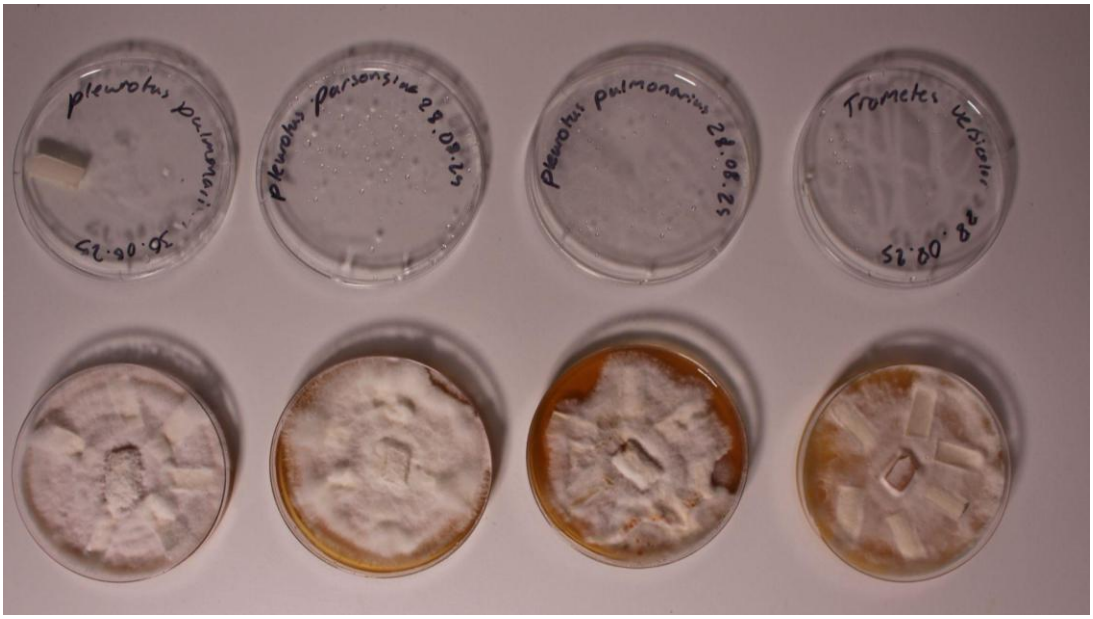


Table 3

Sample Table of Observed Changes to Agar Plate over Time, by Author 2025

Day	Species name: *P. pulmonarius*	Size (cm in diameter)	Observations	Mould contamination
1		0.8		No
2		0.9		No
3		1.1	Has grown all around the agar wedge, including underneath	No
4		1.6	Largest size increase so far	No

Procedure Second Round of Experiments

For the second round of home experiments, I made the agar plates myself because I wanted to control the amount of sugar available to the mycelium. I added four grams of malt extract per 100 grams of agar to create a low-strength medium so that the fungal strains would be more inclined to use the paper cup as a food source. At a one-to-one ratio, distilled water was combined with the agar-nutrient mix in a laboratory bottle and placed in the pressure cooker for 20 minutes with the lid slightly loosened. The agar was poured into Petri dishes (Figure 9) within the aseptic zone of the Bunsen burner flame and left to cool slightly before being sealed with Petri dish tape. Before cultivating three strains in plates containing paper pieces, I also created control groups containing only mycelium.

In this round of home experiments, the deeper paper layer of the cup was removed to isolate the superficial plastic layer. The intention was to make the decomposition of the material more visible by separating layers. Following the same arrangement shown in Figure 13, I positioned the plastic pieces around the dishes inoculated with mycelium. Growth was then recorded using the same results table.

After 14 days of recorded growth, some samples were opened inside the small laminar flow hood to take photos. Next, they were dehydrated for four hours in preparation for SEM, taking photos of the surface morphology as well as a cross-section. Following this, all samples had to be disposed of in a biohazard bin in keeping with standard laboratory operating procedures. I ensured there was a control group for each strain of mycelium, which contained no paper pieces and only nutrient agar. This allowed me to compare growth on the plastic with a competing food source to growth on the plastic without. Experiments conducted in the Biolab facilities at AUT utilised a miniature laminar flow and a regular cooking pot to replace the pressure cooker. The flow hood consisted of an air filter which sucked in air and blew sterile air out, creating a 20 cm by 10 cm section of sterile air in front of the air filter. Samples contained in this area should not have been at risk of contamination. I did not inoculate any new samples containing pieces of paper cups, but created more control plates in case I wanted to use them to cultivate new plates in another round of experiments.

Procedure Third Round of Experiments, at Sapro-Tech Laboratory

My third round of experiments was carried out at the Sapro-Tech Biotech lab in Parnell, Auckland (biopolymer-based textiles company, https://www.sapro-tech.com/). It was clear that further iteration of the home experiments was required due to the large range of growth morphologies observed. Especially if scientifically viable results were to be obtained, in which strains could be compared to each other. Experiment methods were altered to improve consistency and create a more stable environment, under the supervision of Dr. Gayani Weeraratne. Instead of taking a segment from a cultivated plate and inoculating a fresh agar plate, this method involved growing mycelium pellets in liquid media, blending them, and then

pouring the mixture onto an agar plate containing solid media. This approach encouraged even growth of already partially established colonies across the entire dish, rather than mycelium spreading outward from a single central inoculation point.

Another difference in this experiment was the shape and size of the paper cup pieces, as well as the addition of a new test group examining mycelium growth on black PE bin liner material. All paper cup samples had six holes punched into them to make it easier to observe growth within the cross-section rather than only on the surface. This adjustment was made in response to concerns raised by Dr. Keith Hudson (Scientist and founder of Sapro-Tech) regarding limitations of my previous results.

Findings from phase one informed methodological refinements in phase two, particularly in relation to gaining access to the surface of interaction between the mycelium and PE without damaging the mycelium. The response to this risk was to take cross-sectional scans and photograph both “unwashed” and “washed” samples, where the top layer of mycelium had been carefully removed. The experimental plan below was inspired by a similar study previously conducted by Sapro-Tech. The laser-cutting of the material was intended to increase the observable surface area and provide clearer insight into what was happening within the cross-section.

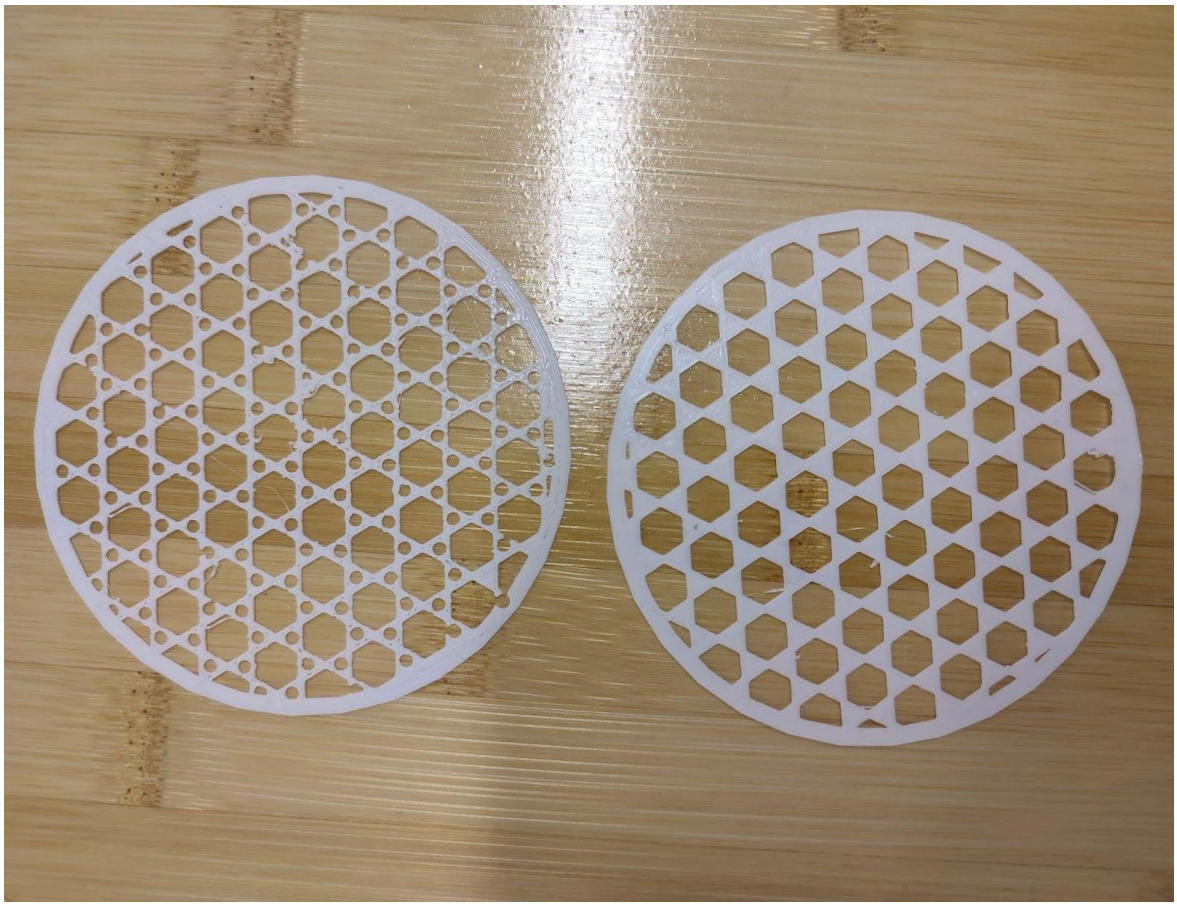
Summary of Third Round of Experiments at Sapro-Tech

1) Laser-cut hexagonal holes into a flat surface of paper removed from a coffee cup, similar to the image below (Figure 15)
2) Create media for culture to grow in using ratios provided by Sapro-Tech
3) Use the wider end of the pipette to take small segments from a freshly cultivated plate
4) Place the scaffolds in the autoclave
5) Add 10 µg/ml tetracycline antibacterial solution to the fungal media to suppress bacterial contamination
6) Inoculate liquid culture (10%) into the fungal media
7) Gently mix

8) Pipette 20 ml into 90 cm Petri dishes and add paper scaffold on top of the media, slightly submerge
9) Make 6 control plates (3 of each media)
10) Grow and monitor for 7 days

Figure 15

Hexagonal Laser-cut Frames to Grow Mycelium, Sapro-Tech, 2024



Equipment

. Tweezers (x 5)

. Conical flask (x 3)

. Laboratory bottle

. Mixing plate

. Laboratory scales

. Autoclave

. Laminar flow hood

. Hole punch

. Refrigerator

. Sterile Petri dishes

. Cultivated plates of chosen mycelium strains (x 3)

Using laboratory scales, I measured the following quantities to create liquid and solid growth media:

- Liquid media in a conical flask:

Rye 2 g

Dextrose 10 g

Yeast extract 5 g

- Solid media in a laboratory bottle:

Potato starch 2 g

Dextrose 10 g

Yeast extract 5 g

Agar powder 5 g

The dilution formula used to calculate the concentrations for both the liquid and solid media was C1V1 = C2V2, where C1 is the concentration of the initial solution and V1 the volume of the initial solution to be diluted. C2 is the concentration of the final diluted solution and V2 the final volume of the diluted solution. I began by preparing two solutions: one for solid media and one for liquid media. The solid media recipe included agar powder for producing Petri dishes. I measured just under 500 mL of distilled water to account for the increase in volume once the agar was added. A visual guide to this process is shown in Figure 16.

Figure 16

Process of Creating Liquid Media Plates for Mycelium Cultivation, Sapro- Tech, 2024



Accurately measure the following amounts for liquid and solid growth media

Liquid media-

2 grams of rye
10 grams of dextrose
5 grams of yeast extract

Solid media -
2 grams of potato starch
10 grams of dextrose
5 grams of yeast extract
5 grams of agar powder

Mix on mixing plate, refrigerate both



Wrap at least 5 tweezers in tinfoil and create bungs using wool. Then cover with autoclave tape

Wipe down the extraction cabinet using isopropyl alcohol. Set up a stack of sterile petri dishes on the left hand side of the cabinet as well as pipette tips.

Start by opening the petri plates with one hand and carefully pour th solid media into the plates allowing them to cool with the lid slightly ajar. once hard place in fridge



Take your hardened agar plates and using the larger end of the pippette tip punch 3 circles into the cultivated plate.

Place these into the agar plate and seal using tape.

Following the same method place 3 circles into the liquid media and place the shaker incubator for 3 days. After 3 days the above pellets will have grown.

Blend these inside the sterile cabinet



Fill a 500 ml pipette with the blended media and pour into the petri plates. Using tweezers place paper discs in the centre of the dish and seal.

Punch six holes in the paper cup discs before placing in the dish.

Place in oven to grow









Both solutions were stored in the fridge overnight and then autoclaved for four hours, with utensils wrapped in tinfoil and placed alongside them in water. After cooling to approximately 45°C, all utensils and media were removed, and the extraction cabinet was sterilised with isopropyl alcohol before placing the items inside. I was taught to divide the cabinet into two sections: one for used or potentially contaminated items, and the other for unopened sterile materials. To prevent the agar from cooling and solidifying in the bottle, I began by pouring it into Petri dishes, taking care not to position my hands directly over the open plates to avoid contamination. The dishes were left to dry with their lids slightly ajar, then sealed and stored in the fridge once cooled. The next step involved inoculating the liquid media with samples taken from the fully cultivated plates ordered from SporeShift Mushrooms. Using the wider end of a pipette, three small plugs were punched from each cultivated plate and transferred into the liquid media using sterile tweezers. This process was repeated for all three fungal strains, after which the conical flasks were placed in an environmental shaker. The shaking motion promoted interaction between the fungi and the nutrient medium.

After three days in the incubator, mycelium pellets formed in each of the conical flasks (Figure 17). Before transferring these onto solid media, the pellets were homogenised inside the Extraction cabinet (Figure 18). Once all pellets had been broken up, a thin layer of the solution was pipetted onto each Petri dish. Next, I had to add the paper cup. Using a hole punch to create openings in the paper cup, I transferred one disc into each agar plate, ensuring that each fungal strain had three replicate plates. I also cut small discs of black PE bin liner plastic to determine whether degradation would be easier to observe without the paper layer and remove this competing food source. All samples were then labeled, dated, and sealed (18 November 2025). I monitored all samples over a period of 14 days for signs of degradation and recorded my observations in the digital workbook presented in the appendix.

Figure 17

Mycelium Pellets, P. ostreatus (grey oyster mushroom). Photos by Author, Sapro-Tech 18/11/2025



Figure 18

Blending of Pellets in the Extraction Cabinet. Photo by Author, Sapro-Tech, 18/112025



As there were three groups of fungal strains and plastic, it was possible to open the plates at various stages of growth. One group was opened after three weeks to make observations focused on indicators of material degradation, including layer separation and surface morphology growth. Although daily changes were not recorded, regular checks for contamination were conducted. On 1 December 2025, the experiment was concluded, and all Petri dishes were opened and photographed (Figure 19). Next, they were dehydrated, in preparation to be scanned in February 2026. As with previous experiments, photographs of both the cross sections and surface morphology were taken to assess degradation.

Figure 19

Fully Cultivated Plates (top) and Samples ready for SEM. Photo by Author, Sapro-Tech, 01/12/2026



SEM Examination

After two weeks of mycelial growth, each culture plate was fully dehydrated before a small sample was taken to the AUT lab for SEM analysis by the lab technician Yuan Tao, who provided me with images. I analysed these to gain insight into changes in surface morphology, which were then classified and recorded.

Limitations

A limitation of the first round of my experimentation was the lack of access to the laboratory equipment required to cultivate mycelium in liquid culture. The Auckland University of Technology (AUT) photo studio facilitated higher-quality photographs (Figure 20); however, this also increased the risk of contamination. To reduce the risk, Petri dishes were opened in a mini laminar flow hood. This was a 20 cm by 10 cm 3D-printed setup that filtered a small section of air in front of the largest panels. I did not have the opportunity to acquire SEM skills myself and had to rely on the AUT lab technician to do the SEM examination and provide photographs, which limited the number of images I had available for examination. My assessment options were macroscopic culture plate examination and SEM, which are both different ways of looking at the samples. I had no access to analysis of chemical PE degradation, and could therefore only report on biodeterioration.

Figure 20

Fully Grown Mycelia with and without Coffee Cup Pieces. AUT, Photos by Author, 2025



Phase Two: Creative Design Process

While the experimental component of this project yielded clear quantitative results, it offered limited opportunity to communicate the broader body of research and design thinking that informed the work. To address this, I developed a book titled *A Future with Fungi*, intended as an accessible introduction to the relationships between biology, design, and sustainability how collaborating with mycelium may help to regenerate and sustain life on Earth

I designed the book for an audience with limited familiarity with mycology, design research, or environmental science. Rather than using an academic format, the book communicates information through concise text, diagrams, photographs, and visual storytelling. This approach was intended to make complex concepts more approachable and engaging for non-specialist readers and is supported by a substantial body of academic literature.

In what is called the screen inferiority effect Khan (2024) explains how brains respond differently to knowledge attained from screens versus books. Storytelling and hand painted images reach people better by integrating a relatable human element, thereby building trust. Narratives have a significant impact on public perception shaping cultural beliefs and societal norms (Henry, 2024). Shifting the cultural narrative surrounding fungi and their association with disease is important for accepting and advancing mycelium technologies.

The book draws on literature gathered throughout the research process, including sources reviewed during the literature review phase and additional case studies identified after the experimental work whilst searching for comparable projects to situate my own work within a broader landscape of creative practice. Rather than focusing solely on mycelium's potential role in addressing plastic pollution, the book situates this application within a broader context of human-fungal relationships. Topics include architecture, medicine, fashion, ecology, and examples of design practices that collaborate with living systems. These themes were included to show the diversity of fungal applications and encourage readers to see fungi as active participants in ecological and social systems.

Pieces of literature covered in my book include *Design for Collaborative Survival* by Liu et al. (2018), which acts as an introduction to the subdiscipline of post-anthropocentric design, co-design in architecture, and my own speculative designs inspired by mycelium. The writing style is influenced by texts such as Anna Tsing's *The Mushroom at the End of the World,* Merlin Sheldrake's *Entangled Life,* and Adrienne Maree Brown's *Emergent Strategy*. These works share a common thread: they acknowledge the planet's current state of crisis whilst offering constructive, hopeful pathways to navigate and transform our "broken world". Doom-laden climate-related news reduces public motivation and the likelihood of environmental engagement, and therefore worsens the problem. Researchers at Charles Darwin University have introduced "positive environmental journalism" as a response to this. Recent research shows a growing audience preference for hopeful, solution-based content that reconnects humanity with nature and fosters ecocultural identification and affiliation (Etaywe & Pinkerton, 2025).

Science relies on creative storytelling and language to evoke interest and care. Etaywe and Pinkerton (2025) emphasise that language is central in scholarly, journalistic and policy responses to environmental crises and that it is a means to align values, emotional commitments and behaviours. For this reason, *A Future with Fungi* was intentionally written in an optimistic and exploratory tone.

The book concludes with Brown's concept of emergence (Brown, 2017), the process by which small, simple interactions give rise to large-scale patterns, behaviours, or systems that are more complex than the sum of their parts. In *A Future with Fungi,* I chose to leave the reader with the idea of emergence to encourage their own mindful exploration of the topic and to suggest a way of thinking that supports a positive approach to addressing climate change. Climate grief has become an increasingly recognised emotional response to ecological loss, yet there remain very few structured tools or institutional frameworks to help people process it (Cunsolo & Ellis, 2018). The concept of emergence encourages readers to see environmental action not as an overwhelming challenge, but as a gradual, collective process of transformation.

Choice of images and illustration style

Images were selected according to their ability to communicate concepts that would be difficult to convey through text alone. For example, the first fold-out spread depicting a branching mycelial structure was designed to communicate the vast scale of the *Armillaria ostoyae* network described by Bone (2013). Visual references were gathered throughout the research process from books, articles, documentaries, and design projects. From these references, I developed sketches and layouts that translated key concepts into simplified visual narratives. I prioritised imagery that could evoke curiosity and wonder while remaining scientifically grounded. Diagrams were used to explain biological processes and relationships, while illustrations allowed abstract ideas and future possibilities to be communicated more intuitively.

The narrative structure of the book was developed iteratively through a process of organising and rearranging research themes. Early drafts grouped information according to discipline; however, this approach felt fragmented and overly academic. Through successive revisions, the content was reorganised into a more accessible narrative that moves from introducing fungi and their ecological significance to examples of contemporary design practice and finally to speculative futures. This progression was intended to gradually build readers' understanding while maintaining engagement through a balance of scientific information, case studies, and visual material.

The book underwent multiple rounds of revision throughout its development. Friends and family reviewed drafts alongside the evolving dissertation, ensuring consistency between the scientific research and the public-facing publication. During this process, technical language was simplified, sections were shortened or expanded, and the balance between text and imagery was adjusted to improve clarity and accessibility for a general audience, based on their feedback.

Chapter Three: Results

Introduction to Results of My Practical Science-Based Research

This section summarises observations and quantitative data obtained over the course of three experimental rounds as outlined above, investigating what happened to PE bound onto Starbucks paper cups under the influence of *P. pulmonarius, P. ostreatus* and *T. versicolor* mycelium. For complete comparative results, refer to the workbook in the appendix.

Terminology Describing Mycelial Growth

To accurately describe the range of fungal activity observed, I researched the terminology used to characterise different forms of mycelial growth and what each form may indicate. This nomenclature was incorporated throughout both the results section and the following discussion (Figure 21).

Delaney (2025) explains that "rhizomorphic" mycelial growth consists of thick, cord-like strands expanding outwards in a relatively uniform manner. This form of growth is generally considered an indicator of good fungal health and is associated with efficient nutrient absorption. "Cord mycelium" is a form of rhizomorphic mycelium, distinguished by circular, ring-like growth patterns commonly referred to as "fairy rings".

"Tomentose" mycelium appears as fluffy, cloud-like formations and is often associated with higher humidity and lower oxygen availability.

"Satellite colonies" are secondary growths that emerge distant from the primary mycelial body. These do not inherently indicate contamination. When they develop slowly and share the same colour and morphology as the main colony, they are typically of the same fungus and benign. However, satellite colonies that appear rapidly or differ in colour or texture from the main colony indicate contamination. Images displayed in Figure 22 show examples of three of these growth patterns. *P. pulmonarius* shows healthy, even, rhizomorphic growth on the far left. In the middle, *P. ostreatus* demonstrates satellite colonies, which later became obvious as contaminants, and on the far right, a fluffy tomentose growth of *P. pulmonarius.*

"Enshrouded mycelium" describes a condition in which the mycelium becomes surrounded by unfavourable environmental conditions, resulting in obscured or inhibited growth (Planet Spores, n.d.). A shroud is a covering for burial. To shroud means to obscure, conceal, or disguise. Figure 22 illustrates this appearance on a culture plate with *P. pulmonarius,* which initially grew in a healthy tomentose pattern, but then stalled and became withered.

Figure 21

Hand-Drawn Diagram of Mycelial Growth Terminology, Author, 09/05/2025

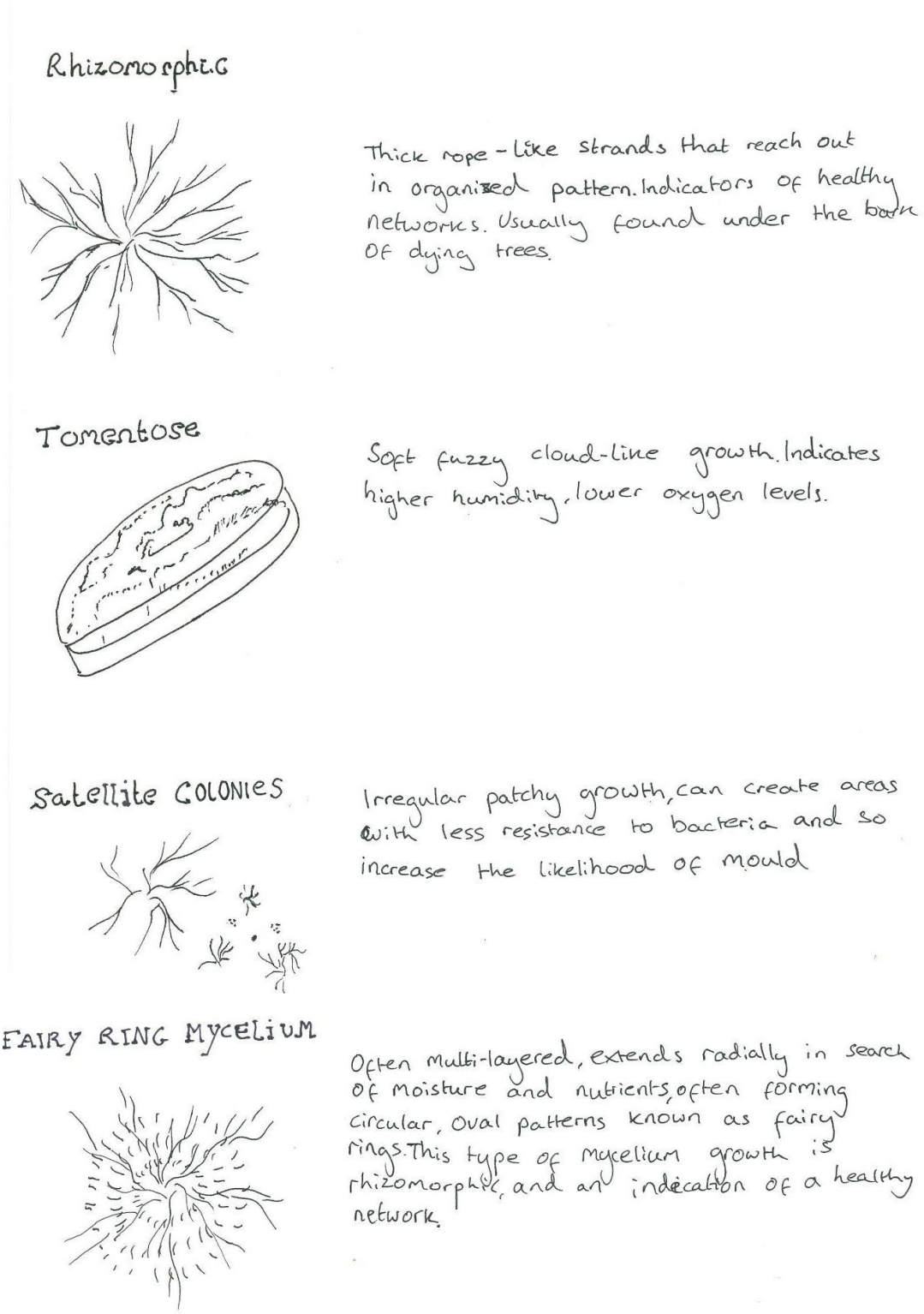


Figure 22

Three Mycelial Growth Examples (P. ostreatus mislabelled as P. parsonsiae.) Photos by Author 2025.



Results of Macroscopic Examinations during Round One of Home Experiment

Growth Rate

To gain an understanding of each species' growth behaviour, I initially recorded descriptive observations. *P. pulmonarius* produced long, fluffy hyphae, growing slowly at first before increasing in speed. *P. ostreatus* followed a similar growth pattern. Both species exhibited very slow initial development, followed by a steady increase in growth from day five onwards. *T. versicolor* displayed a comparable trend, though noticeable growth began slightly earlier on day four. From this point, *T. versicolor* exhibited increasingly steady growth, characterised by healthy rhizomorphic development. Overall, these patterns suggest that all three species developed increasing metabolic activity and vigour over time.

Appearance

P. pulmonarius initially displayed rhizomorphic mycelial growth before becoming enshrouded and discoloured toward the end of the observation period, indicating unfavourable conditions (Figure 23). *P. pulmonarius* was the only strain in which the PE-paper substrate showed visible signs of degradation. Brown discolouration was observed around the edges of the paper cup pieces from day seven onwards. Existing literature supports this observation as an indicator of biodegradation (Odigbo et al., 2023).

Figure 23

Enshrouded Tomentose Growth of P. pulmonarius Culture. Author, AUT 16/09/2025



As the first culture of *P. pulmonarius* displayed signs of unhealthy growth, the experiment was repeated. In the second culture, *P. pulmonarius* developed successfully, displaying fairy rings during early maturation and consistent, even, circular growth (Figure 24). *P. ostreatus* produced the same characteristic furry mycelial tendrils observed in *P. pulmonarius*, consistent with *Pleurotus spp.* being white-rot fungi. In contrast, *T. versicolor* formed a sparse, flat sheet of mycelium (Figure 25), clearly distinguishing its growth morphology from that of the *Pleurotus spp.*

Figure 24

Healthy Tomentose Growth of P. pulmonarius Culture. Photo by Author, AUT, 16/11/2025



Figure 25

Sparse Flat Sheet of T. versicolor Growth in Culture. Photo by Author, AUT, 16/11/2025



Results of Macroscopic Examinations during Round Two of Home Experiment

All three initial control group Petri dishes became contaminated. *T. versicolor* showed very sparse, dotted growth. *P. pulmonarius* initially grew much better; however, satellite colonies developed on the Petri dish, which later were identified as mould. *P. ostreatus* had healthy outward growth, then started thinning out before black mould growth appeared (commonly *Cladosporum* or *Aspergillus spp.*, not specified).

One further control plate of *P. pulmonarius* showed the healthiest growth out of all samples. As described for rhizomorphic growth, the hyphae were thick and bright white (Figure 26). The plate still became contaminated; however, the mycelium seemed strong enough to withstand the contamination and continue growing.

Figure 26

Healthy Rhizomorphic P. pulmonarius, small Mould Contaminants. Photo by Author, AUT, 16/11/2025



Results of Macroscopic Mycelium Growth on Homemade Agar with PE Paper Cup Pieces

Compared with pre-made agar plates from SporeShift Mushrooms, growth on my homemade agar was slower, sparser and thinner, indicating insufficient nutrients. *P. pulmonarius* developed the thickest hyphae, suggesting higher resistance to challenging environments.

Compared with control plates without paper cup pieces, mycelium on plates with such pieces grew considerably better and extended outwards evenly, but then also became contaminated.

Results Round Three of Experiments in a Professional Laboratory

Learning from rounds one and two, in my third set of experiments at the Sapro-Tech lab I used an established agar recipe developed and tested by their team, and their liquid culture method as described in the methodology section.

The daily observation and documentation schedule in my first two sets of experiments carried a risk of human perception and interpretation error, as it had become clear that one day was not long enough to allow for enough fungal growth to be perceived with certainty. For the final round of experiments, I therefore adapted my methodology, recognising that daily documentation was not helpful. Instead, I conducted regular checks of the Petri dishes for signs of obvious change and visible contamination, and recorded observations only when clearly noticeable changes had occurred.

The controlled laboratory environment at Sapro-Tech significantly reduced the risk of contamination and resulted in more consistent growth patterns. Cultures grown using the liquid culture method did not exhibit the typical radial growth associated with mycelium centrally inoculated on an agar plate as observed during my home experiments. Instead, they formed a dotted, furry morphology resembling individual colonies (Figure 27), which eventually merged, showing evenly distributed growth across the Petri dishes.

Figure 27

Even Mycelial Growth by Liquid Culture. Photo by Author, Sapro-Tech 20/11/2025

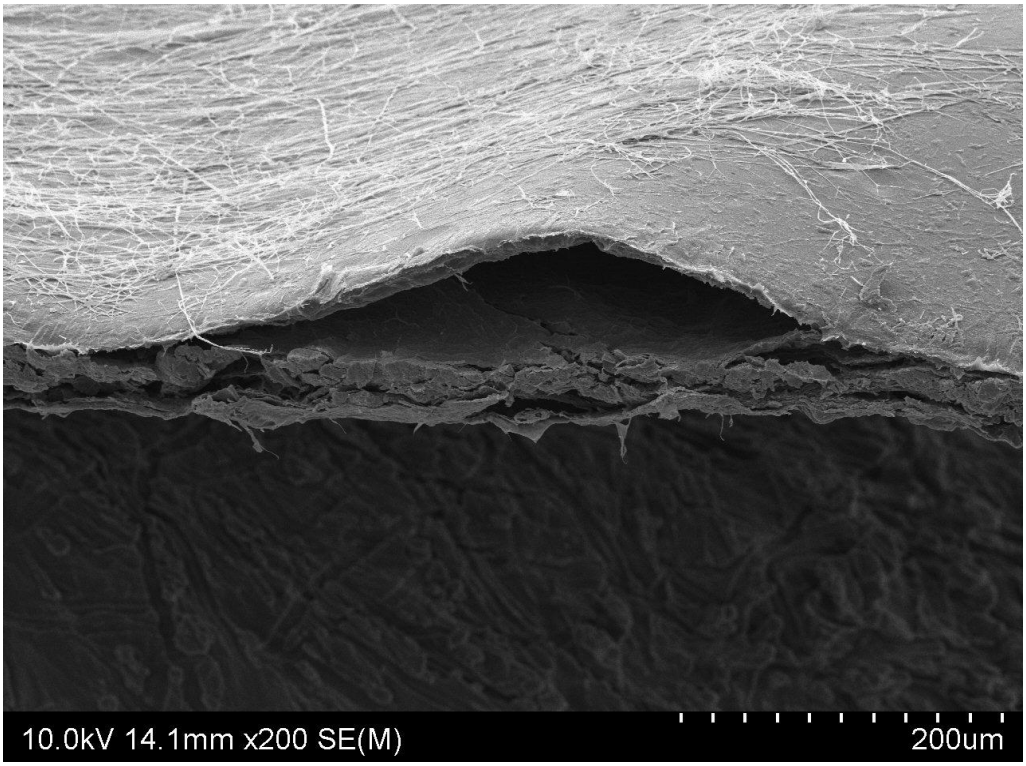


Terminology describing Appearance Indicative of PE Degradation on SEM Images

Three distinct progressive morphology changes of PE degradation visible on SEM images are flaking, fragmentation, and delamination. “Flaking” is surface-level peeling or indentation as an indication of early-stage degradation. “Fragmentation” refers to the cutting of PE chains into smaller compounds. This is followed by visible “delamination” of the material as a result of chain scission, causing a more substantial and deeper structural breakdown than flaking. The separation of layers as seen in Figure 28 occurred because the paper fibres and the plastic lining started to break apart and delaminate, as the material weakened.

Figure 28

SEM Image of PE Delamination on Paper Cup Piece with P. ostreatus. AUT November 2025



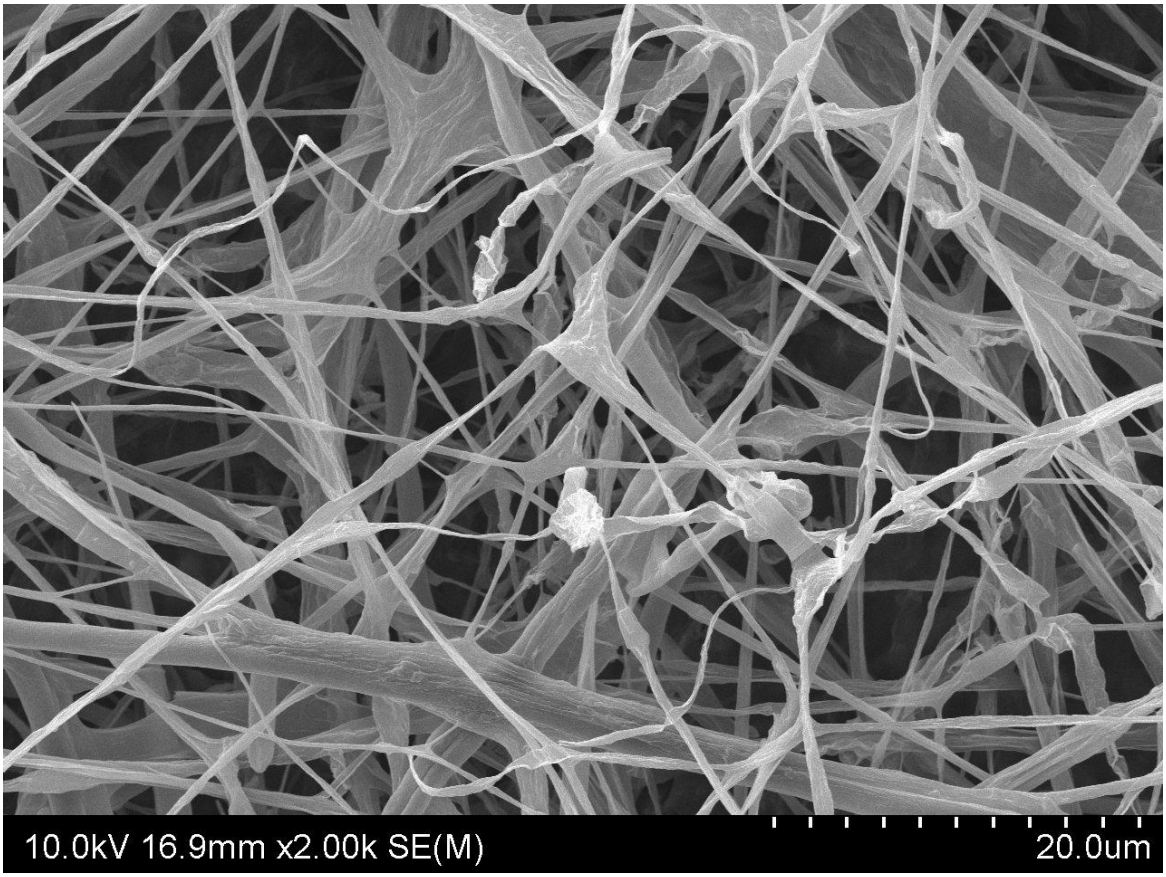
Comparative Results of SEM Images

At higher magnification, all strains showed signs of PE biodeterioration. Three perspectives were photographed for each strain: a cross-section, the washed surface and the unwashed surface. Cross-section imaging was the most effective for identifying delamination.

Changes in surface morphology were most visible after the samples had been washed, as otherwise the thick mycelial growth obscured the view onto the PE layer. In contrast, unwashed samples were sometimes too thick to reveal subtle structural changes, though they remained useful for comparing hyphal growth across strains (Figure 29).

Figure 29

SEM Image of Thick Hyphal Network of T. versicolor Unwashed Sample. AUT November 2025



The washed-surface scans of all three strains, *T. versicolor, P. pulmonarius* and *P. ostreatus*, showed clear surface-level erosion of the PE layer, exposing the darker-appearing paper substrate beneath. This transformation looked similar in all species. The exposed paper surfaces under the eroded PE seemed to act as trails enabling fungal hyphae advancement. Although flaking was present in *P. ostreatus, P. pulmonarius* and *T. versicolor*, it was more pronounced in *T. versicolor*. Cross-sectional scans confirmed that delamination had occurred in samples colonised by both *P. ostreatus* and *T. versicolor,* indicating that the fungal–material interaction had progressed beyond surface alteration (Figure 30 shows this well for *T. versicolor*).

The greater extent of visible flaking coupled with significant degrees of delamination suggest *T. versicolor* may be the strongest candidate for PE degradation among the strains tested (Figure 31).

A selection of SEM photos supporting the observation that degradation of PE took place and their associated strain are listed in Table 3.

Figure 30

SEM Image of PE Delamination of Paper Cup Piece with T. versicolor. AUT November 2025

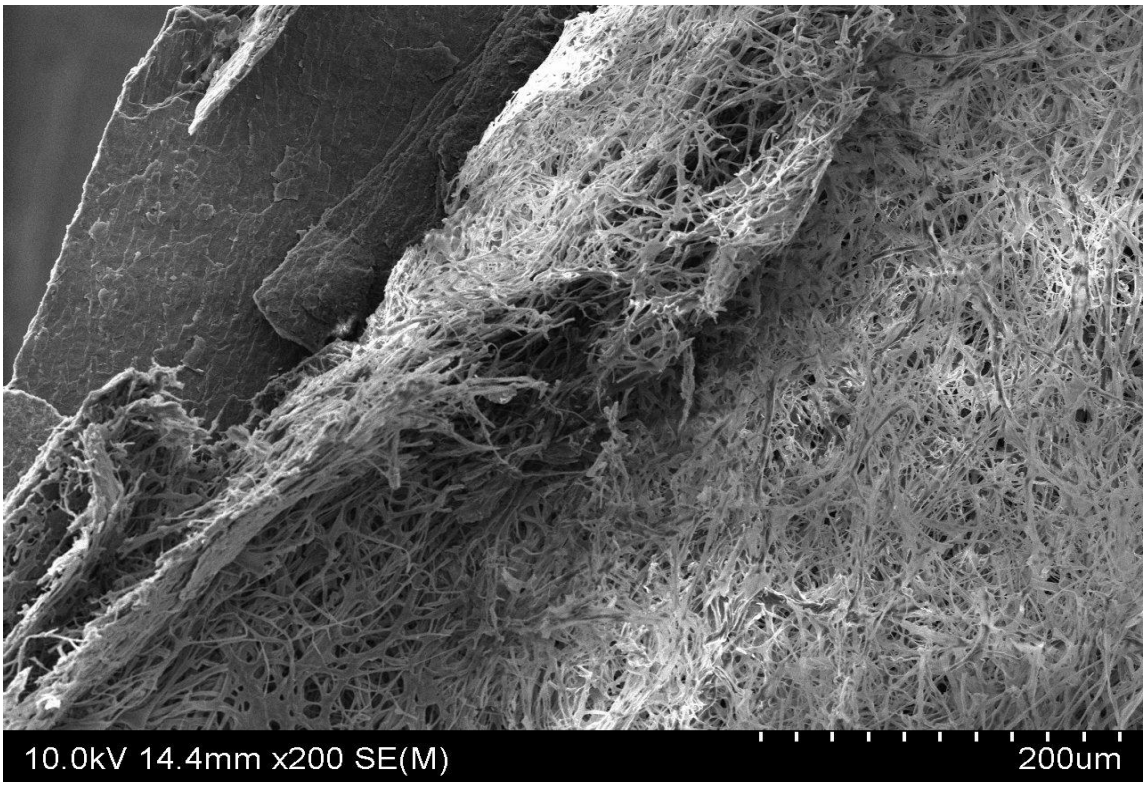


Figure 31

Surface and Cross-sectional SEM Images Showing Degradation of PE by T. versicolor. AUT 2026

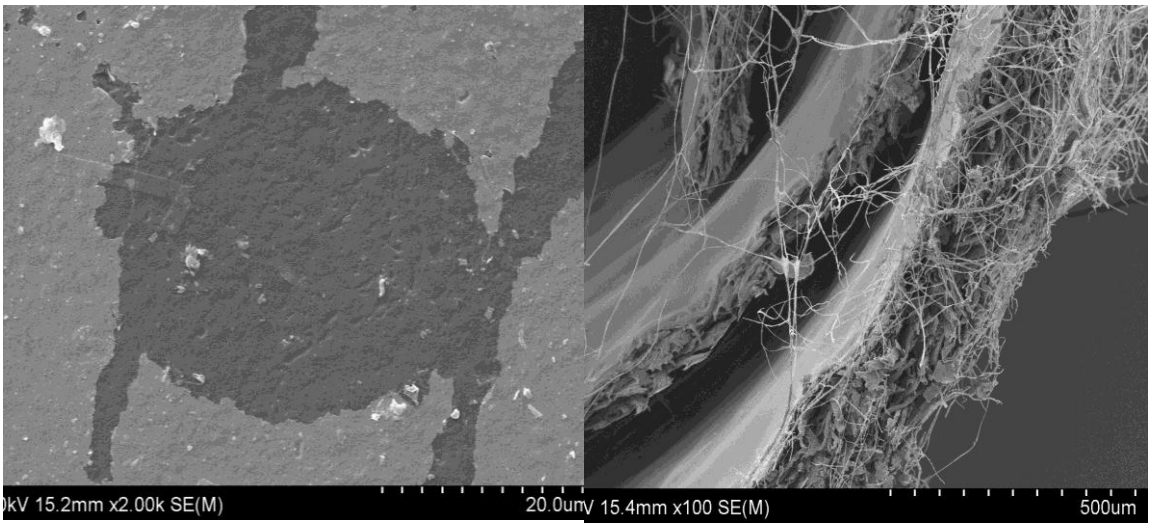
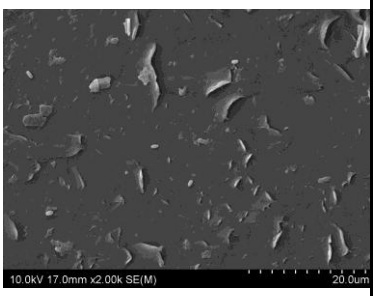
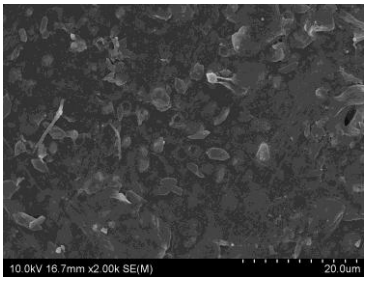
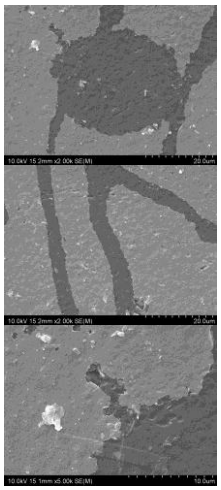
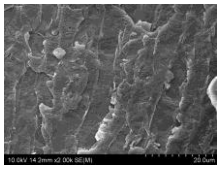
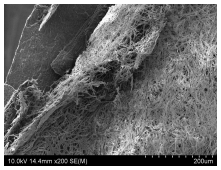
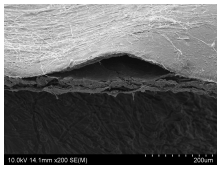
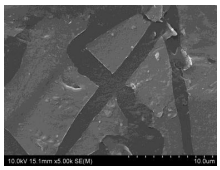
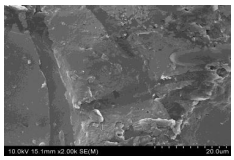


Table 3

Results Table showing PE-lining Degradation Visible on SEM Images

Strain + Date Scanned	Photo	Result
P. ostreatus Surface Paper cup Washed Round 3 Feb 2026		Flaking of PE, Suggesting initial stages of degradation are taking place
P. ostreatus Surface Bin liner Round 3 Feb 2026		Same as above
T.versicolor Surface Washed Round 1 Sep 2026		Two layers visible indicating the top layer of PE has been degraded, revealing the paper surface underneath
T. versicolor Surface PE Round 1 Sep 2025		Signs of flaking visible Mycelium induced roughening of PE surface
T. versicolor Cross-section PE Round 1 Sep 2025		Delamination Layer of PE or paper visible under thick layer of mycelium

P. ostreatus Cross-section Paper cup Round 2 Nov 2025		Delamination separation of layers
P. pulmonarius Surface Washed Round 1 Sep 2025		Paths of mycelium growth are shown and flaking
P. pulmonarius Surface Washed Round 1 Sep 2025		More prominent flaking

Moving Forward from Interim Conclusions

In conclusion, in my experiments all three known indicators of fungal PE degradation were observed by SEM: flaking, delamination and fragmentation indicative of surface-level erosion. Across the three experimental rounds, key procedural refinements reduced the risk of contamination and created a more controlled growing environment. These adjustments became necessary after identifying a wide range of mycelial growth patterns emerging from single strains over the growth period, suggesting rapidly shifting environmental conditions that may have placed the organism under evolutionary pressure. The most successful experiment took place in the Sapro-Tech lab, where I had access to laboratory equipment such as incubators and laminar flow hoods, and was supported by biologists and chemists working in the fungal biotech space who offered constructive advice and discussion of my work. After completing the final round of my experiments, I reflected that further experimental iterations were required to attain scientifically robust, reproducible findings. However, such iterations would not necessarily directly translate into catalysing the behavioural change that our environment needs.

Choosing to re-focus on this change marked an important turning point in refining the project's future direction and intent. Aside from the early speculative designs inspired by mycelium, I had not yet engaged creatively with the research topic. It became evident that the project should not be confined to demonstrating mycelium-driven PE degradation on Starbucks

paper cups. Rather, this example served as a tangible illustration of how collaborative relationships between humans and other organisms can help address climate change and adapt to rapidly shifting environmental conditions. Additionally, fungi's capacity for ecological restoration demonstrates the potential for alternative environmental futures in which ecosystems can regenerate and sustain diverse forms of life. Publicising this information may help counteract disengagement associated with doom-laden climate narratives and provide opportunities to empower individuals who feel immobilised by crisis-focused reporting.

The book *Entangled Life* by Sheldrake first sparked my curiosity in fungi. I then started exploring environmental storytelling as a method of bridging the gap between information usually reserved for academic literature, and the general public, to catalyse engagement and care for the environment. I considered the success of stories that have been passed through generations, such as fairy tales and old folklore, understood on a deeper, ancient, communal level (Bukenya, 2025), and the reasons for their timelessness. Common themes are simplicity, and almost all are accompanied by imagery and artwork. In comparison to oral and visual storytelling, which have shaped communication for tens of thousands of years, written storytelling is a relatively new cultural technology. Although the earliest writing systems date around 3000 BCE (Daniels & Bright, 1997), the high rate of distribution of written language was facilitated by the invention of the printing press in 1440 (Alley-Young, 2022).

Language can be divisive, not only when using scientific versus commonly understood words, but because people are generally divided by different languages. Pictures, however, have told stories for as long as humankind has existed, as evidenced by prehistoric cave paintings all around the world, address much older brain areas and are easier remembered (Grady, 1998). This established two core elements of *"A Future with Fungi"*: strong visual messaging and the tactile experience of a beautiful paper-book, with fold-outs requiring reader interaction.

Chapter Four: Journey Towards the book *A Future with Fungi*

A challenge of undertaking this project through a biodesign lens was balancing scientific experimentation with creative practice. During the experimental phase, the research often felt like two parallel projects: one requiring methodological consistency and empirical observation, and the other concerned with storytelling, visual communication, and public engagement. Ongoing reflection, conversations with others, and engagement with creative scientific literature gradually revealed a connection between these strands. Rather than presenting the findings solely as an academic dissertation, I became interested in how to translate the research into a form accessible to broader audiences.

This led to the development of *A Future with Fungi,* a book that combined scientific findings, speculative thinking, and environmental storytelling. Because this idea concerns interconnectedness, collaboration, and ecological relationships, a visual and narrative medium better suited these themes than a traditional scientific format alone. In the process, I learned that communicating scientific research to non-specialist audiences required balancing accuracy with accessibility. This tension remained one of the most challenging aspects of the design process.

Environmental storytelling can play an important role alongside scientific research in fostering engagement with environmental issues (Sustainability-Directory, 2025). Influential texts such as Mycophilia (Bone, 2013) and The Mycelia's Healer (Parker & Parker, 2025) emphasise the long-standing interdependence between fungi and other forms of life. This idea became a central design principle within A Future with Fungi, shaping both the narrative structure and accompanying visual imagery.

Visual imagery played an important role in supporting this narrative journey. I used large watercolour landscapes and illustrations of mycelial networks to communicate interconnectedness and encourage reflection rather than simply convey information. Placing imagery alongside scientific content created visual continuity throughout the publication while remaining accessible to readers unfamiliar with mycology. Through the design process, I learned

that imagery can bridge scientific knowledge and emotional engagement, helping readers connect with concepts that might otherwise feel abstract.

This approach drew on research on emotional responses to visual communication. In a (2026) study, Zhao found that naturally toned artworks generated significantly more positive emotional responses than geometric, high-contrast imagery. Associating information with positive emotions may increase engagement with environmental content and strengthen empathy towards the natural environment (Nair, Gandhapodi, & Chithra, 2025). Similarly, Nakano and Hondo (2023) suggest that emotional engagement and narrative-based communication can contribute to pro-environmental behaviour.

The final spread returned to the imagery of fungal hyphae introduced at the beginning of the book, using the networked structure of mycelium as a metaphor for collective action and the cumulative impact of small individual contributions. This circular narrative structure was intended to reinforce the publication's central theme of interconnectedness. While the narrative structure successfully connected multiple themes across the publication, maintaining a consistent level of scientific detail throughout each section proved challenging. Some spreads remained more information-dense than others, revealing an ongoing tension between educational depth and readability.

A challenge of undertaking this project through a biodesign lens was balancing scientific experimentation with creative practice. During the experimental phase, the research often felt like two parallel projects: one requiring methodological consistency and empirical observation, and the other concerned with storytelling, visual communication, and public engagement. Ongoing reflection, conversations with others, and engagement with creative scientific literature gradually revealed a connection between these strands. Rather than presenting the findings solely through an academic dissertation, I became interested in how the research could be translated into a form accessible to broader audiences.

This led to the development of *A Future with Fungi*, a book that combined scientific findings, speculative thinking, and environmental storytelling. The decision to use a book format

was informed by the project's central insight, that humans have always existed in relationship with fungi and other microorganisms. Because this idea concerns interconnectedness, collaboration, and ecological relationships, a visual and narrative medium was better suited to communicating these themes than a traditional scientific format alone. Through developing the publication, I learned that communicating scientific research to non-specialist audiences required balancing accuracy with accessibility. This tension remained one of the most challenging aspects of the design process.

A key outcome of my dissertation work was the realisation that collaboration with fungi is not a new necessity driven by the ecological crisis, but that we have always relied on partnerships with microorganisms and the fungal world. This understanding reinforced the idea that many contemporary solutions do not require innovation, but instead the unlearning of Western epistemologies driven by globalisation and a return to our previously interconnected relationship with the environment. Many Indigenous cultures worldwide still live this interconnection, and it is also part of Te Ao Māori. A value associated with this connection is “whanaungatanga”, an approach to learning that understands knowledge as emerging from connections between people, land, ancestors and ecosystems, emphasising responsibility, reciprocity and ecological interdependence (Harris et al., 2025).

Figure 32

Double-Paged Watercolour Picture in "A Future with Fungi", Author, 16 July 2026



Figure 33

Many Pages and Aspects Inviting to be Explored in A Future with Fungi, Author, 16 July 2026



Figures 32 and 33 illustrate a key creative decision within the publication: structuring the content as a narrative journey. Rather than presenting information as isolated facts, the book guides readers chronologically from the evolutionary history of fungi through contemporary applications and finally towards speculative futures. This movement from historical relationships to speculative futures was influenced by Tsing's (2015) discussion of moving beyond assumptions of control and progress to imagine alternative more-than-human futures. Furthermore, the choice of this sequencing drew on environmental storytelling approaches that build emotional engagement before introducing complex ecological issues.

Environmental storytelling can play an important role alongside scientific research in fostering engagement with environmental issues (Sustainability-Directory, 2025). Influential texts such as

Mycophilia (Bone, 2013) and *The Mycelia's Healer* (Parker & Parker, 2025) emphasise the long-standing interdependence between fungi and other forms of life. This idea became a central design principle within *A Future with Fungi*, shaping both the narrative structure and accompanying visual imagery.

Visual imagery played an important role in supporting this narrative journey. I used large watercolour landscapes and illustrations of mycelial networks to communicate interconnectedness and encourage reflection rather than simply convey information. Placing imagery alongside scientific content created visual continuity throughout the publication while remaining accessible to readers unfamiliar with mycology. Through the design process, I learned that imagery can bridge scientific knowledge and emotional engagement, helping readers connect with concepts that might otherwise feel abstract.

This approach was informed by research on emotional responses to visual communication.In a (2026) study Zhao found that naturally toned artworks generated significantly more positive emotional responses than geometric, high-contrast imagery. Associating information with positive emotions may increase engagement with environmental content and strengthen empathy towards the natural environment (Nair, Gandhapodi, & Chithra, 2025). Similarly, Nakano and Hondo (2023) suggest that emotional engagement and narrative-based communication can contribute to pro-environmental behaviour.

The final spread returned to the imagery of fungal hyphae introduced at the beginning of the book, using the networked structure of mycelium as a metaphor for collective action and the cumulative impact of small individual contributions. This circular narrative structure was intended to reinforce the publication's central theme of interconnectedness.

While the narrative structure successfully connected multiple themes across the publication, maintaining a consistent level of scientific detail throughout each section proved challenging. Some spreads remained more information-dense than others, revealing an ongoing tension between educational depth and readability.

Figure 34

Home-Use of the Book Demonstrating Fold-Out-Page, Author, 12/11/2026



Anna Tsing argues that much of our understanding of the future is shaped by inherited assumptions of control, progress and predictability (Tsing, 2015). By letting go of these assumptions, she suggests we can begin to imagine the “Third Nature”, the emergent, feral ecologies that arise in the ruins of industrial landscapes and point toward alternative, more-than-human futures. To be able to do so we must start with curiosity. “A Future with Fungi” encourages curiosity by posing open-ended questions. The fold-out feature (Figure 34) was included to encourage this curiosity through active participation in the reading experience. Rather than presenting information through a fixed linear sequence, the fold-out invited readers to physically explore the content and uncover additional layers of information. Upon reflection, though The fold-out feature successfully encouraged curiosity it also disrupted the reading experience, further iteration could explore more seamless integration of these interactive pages.

Anna Tsing argues that much of our understanding of the future is shaped by inherited assumptions of control, progress and predictability (Tsing, 2015). By letting go of these assumptions, she suggests we can begin to imagine the "Third Nature", the emergent, feral ecologies that arise in the ruins of industrial landscapes and point toward alternative, more-than-human futures. To do so, we must start with curiosity. "A Future with Fungi" encourages curiosity by posing open-ended questions and interaction. Rather than presenting information through a fixed linear sequence, the fold-out feature (Figure 34) invited readers to physically explore the content and uncover additional layers of information. Upon reflection, though, the fold-out feature successfully encouraged curiosity it also disrupted the reading experience. Further iteration could explore more seamless integration of these interactive pages.

Suitability for the intended audience and reflection on impact

Assessing the success of A Future with Fungi is challenging because its intended outcomes, including increased curiosity, environmental engagement, and shifts in perceptions of fungi, are difficult to measure within the timeframe of this study. Furthermore, gaining a comprehensive understanding of how the book was received would require formal audience evaluation methods, such as surveys, interviews, or other forms of reader feedback. As a result, the broader impact of the artifact cannot be conclusively assessed at this stage.

Furthermore, more expansive distribution methods would be necessary for the book to reach its intended audience: the general public and people who would not usually engage with sustainability. In the timeframe of this study, feedback was limited to friends, family and people interested in my work through seeing it on social media platforms, and therefore had a positive bias. Future dissemination methods could include public exhibitions, community events, educational programmes, and digital media such as video content, enabling engagement with a more diverse audience and providing opportunities for more robust evaluation of the artefact's impact.

Nevertheless, the completed artefact shows that scientific research can be translated into an accessible, visually engaging format for non-specialist audiences. By combining experimental findings with narrative and illustration, the book extends the research beyond academic contexts and provides a platform for public engagement with emerging fungal technologies. While the book's long-term impact remains to be seen, it successfully fulfills its immediate aim of making the project's themes and findings more accessible to a broader audience.

Chapter Five: Discussion and Final Conclusion

Research Aim

The two questions guiding my research were: can mycelium degrade the PE lining on paper cups to tackle plastic pollution, and if so, how can I, through creative mediums, use these results to engage more people in addressing the plastic crisis? These questions were investigated through three rounds of scientific testing, followed by the compilation of a book: *"A Future with Fungi".* Presenting scientifically validated results alongside creative explorations demonstrated how interdisciplinary approaches can aim to accelerate our progress in reaching sustainability targets. Apicerni et al. (2026) explained that the combination of creativity and scientific research leads to stronger outcomes. Saleh, Rabab and Brem (2023) referenced a large body of work suggesting that creativity can help overcome the behavioural and cultural barriers in place hindering the move towards a sustainable future.

Without my book, the primary output of such research would usually be a collection of photographs and data within the scientific literature documenting plastic degradation through fungal activity. While this is certainly an important way of publishing the capabilities of fungi, such reach is limited. In addition to linking in a wider community, there is a rapidly expanding landscape of other mycelium-inspired solutions across diverse sectors that I also wished to communicate. It became important to shift from a purely scientific account of mycelial-induced biodeterioration towards an output that many other people can connect with emotionally and intellectually.

Interpretation of Results

Linear SEM examination of fungal cultures showed patterns indicative of fungal growth potential under different conditions and allowed speculations about the utility of PE as a food source for the fungi examined.

The consistent contamination of agar plates hindering fungal growth in round two of my home experiments was an issue. The process of creating my own agar, in the limited sterility of

my home lab facilities, had allowed competing spores of other fungi and bacteria to enter before the mycelium (already struggling with sparse nutrients) had grown sufficently to be resilient.

Adding PE paper cup pieces to the homemade agar led to better mycelial growth, suggesting that the PE served as an additional food source.

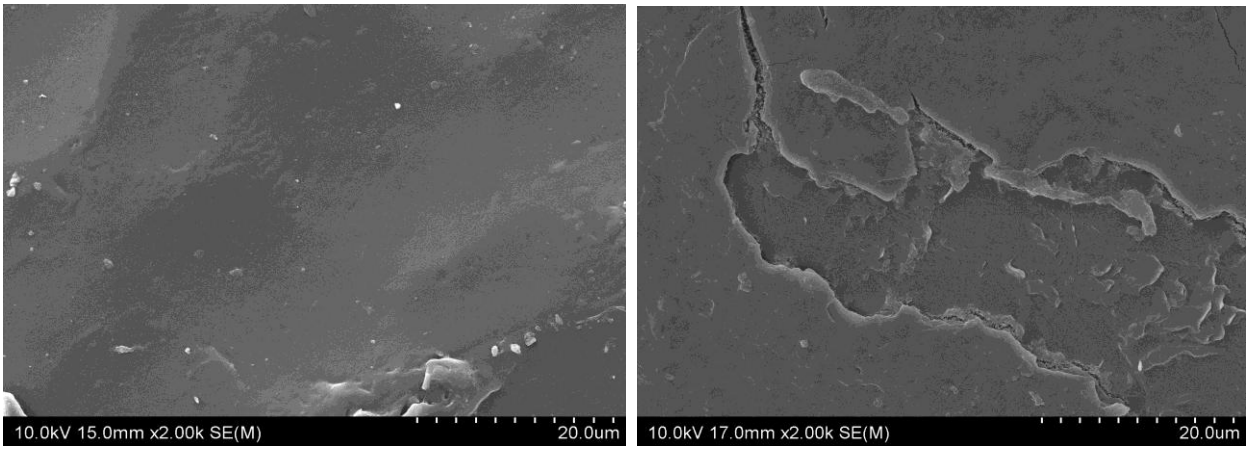
SEM of all samples exposed to mycelium strains *P. ostreatus*, *P. pulmonarius*, and *T. versicolor* confirmed biodeterioration of the PE layer on a paper cup. Surface morphology changes detected through SEM photography included delamination, abrasions, fractures, and flaking. Delamination, the process in which bonded layers separate, is regarded as the most advanced indicator of degradation of the list above. Based on these observations, *T. versicolor* and *P. ostreatus* were the most effective strains in promoting material degradation. Further descriptive terminology, e.g., biodegradation, biofragmentation, and biodeterioration, were taken from supporting literature such as that of Odigbo et al. (2023), Perera et al. (2023), and Shah et al. (2008). In a similar study conducted by Perera et al. (2023), the term biodeterioration was used when the PE had changed from its native properties and the release of carbon dioxide was detected. It is important to note that though biodeterioration and biofragmentation are part of biodegradation, the term "biodegradable" refers to the ability of a material to degrade into natural chemicals such as biomass, water, and carbon dioxide by the action of microorganisms (El Menofy & Khattab, 2022). As I could not measure what components my material broke down into, I cannot make this claim.

Positioning the Findings within Existing Literature

In a comparison of a control sample versus one post-exposure to *T. ostreatus* (Figure 35), the surface was no longer smooth; instead, it exhibited an uneven, granular texture that typically results when microbes or moisture begin breaking down surface-level polymer chains. Similar conclusions can be drawn from images of *T. versicolor* (Figure 35), although there is less peeling; rather, the layers of the material had become visible. These findings are akin to those of Bhatia et al. (2014), who used Pseudomonas (a bacterium) on low-density PE (Figure 37). Their discussion describes a "smooth morphology" prior to bacterial interaction, followed by "worn

out areas” with “randomly distributed cracks” post-interaction, highlighting the initial stages of degradation.

Figure 35



SEM Images of P. ostreatus Control Surface Unwashed on Left, versus Washed on Right. AUT 2026

Figure 36

SEM Image of Eroding PE Layers Achieved by T. versicolor. Yuan Tao AUT 2025

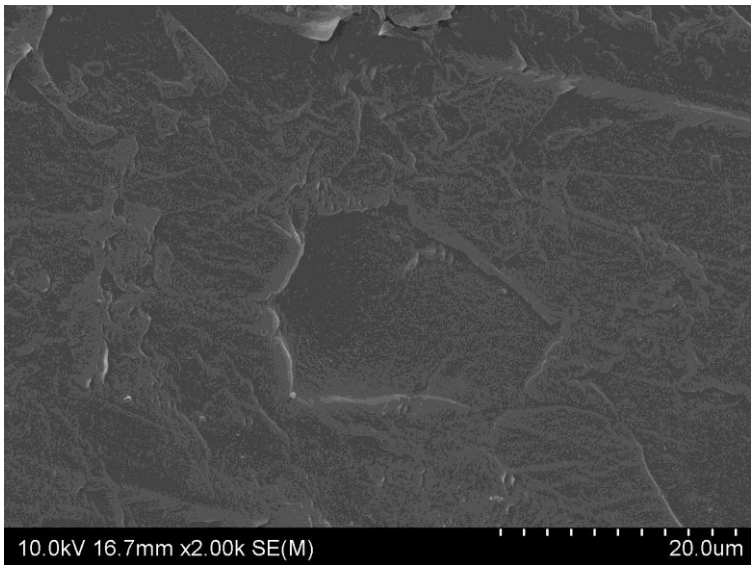
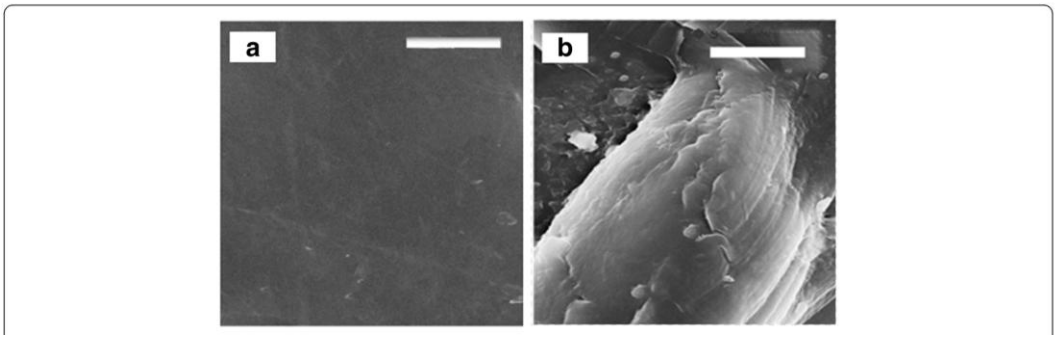


Figure 37

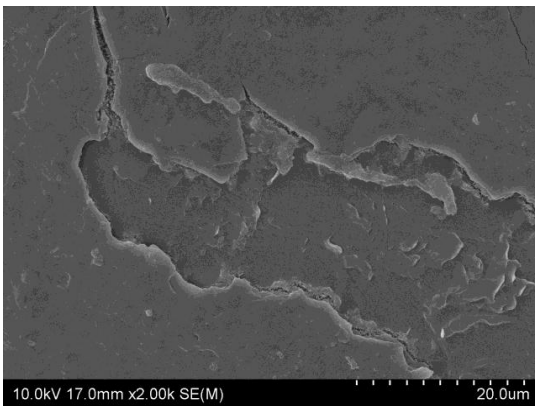
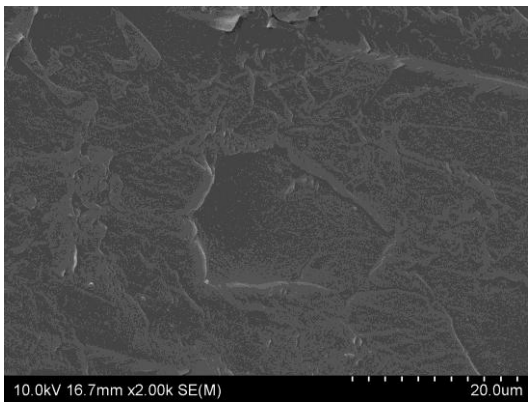
SEM Images a: Untreated b: Treated LDPE, Showing Degradation by Pseudomonas (Bhatia 2014)



Note. From *"Implications of a novel Pseudomonas species on low density polyethylene biodegradation: an in vitro to in silico approach"* by Bhatia, M., Girdhar, A., Tiwari, A., & Nayarisseri, A. (2014). Neuroscience and Biobehavioral Reviews, *186*(1), Article: 106685. https://doi.org/10.1186/2193-1801-3-497

Figure 38

SEM Images: Biofragmentation of Washed Paper Cup P. ostreatus vs. T. versicolor, AUT

	
P. ostreatus *Round 2 Nov 25*	*T. versicolor* *Round 2 Nov 25*

Odigbo et al. (2023) tested the ability of *P. ostreatus* and *P. pulmonarius* to degrade PE. Mycelium was grown in rice and soil substrates mixed with PE flakes. Their results confirmed biodegradation post-exposure to *P. ostreatus* due to the activity of lignocellulolytic enzymes produced on the surface of the plastic sheet. Shah et al. (2008) added that enzymes produced by *P. ostreatus* increased the attraction of PE's functional groups to water, making it easier for the polymer to break down into shorter molecules. PE's hydrophobicity is the presumed cause of its resistance to degradation (Kyaw et al., 2012). Removing this hurdle was a major advancement. It is the same mechanism that made degradation possible when using *P. ostreatus, P. trametes, and P. pulmonarius.*

Perera et al. (2023) stated that *T. versicolor* was well studied as a PE-degrader. Iiyoshi et al. (1998) described PE morphology changes detected following exposure to *T. versicolor*. Clear signs included surface pitting, irregular erosion patterns, and small cracks and fissures. Figure 39 depicts examples of these changes found on my samples following *T. versicolor* growth. A 2018 study into the mycelial degradation of bioplastics by Adamcová et al. (2018) supported this finding, concluding that the appearance of fractures, breaches, cavities, and holes were clear indicators of biodegradation (Figure 40). Figure 40 presents SEM images of three bioplastics and their degradation after 14 days. Figure 41 shows similar abrasions on the surface of the paper cups in my research, following exposure to *P. ostreatus* and *P. pulmonarius.*

Figure 39

SEM Images: T. versicolor Effect on PE Bin Liner and Paper Cup Samples

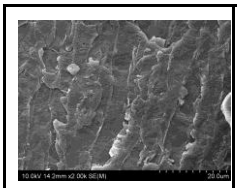
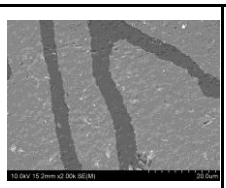
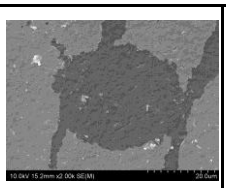
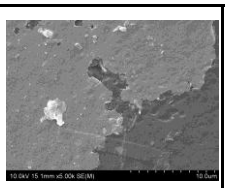
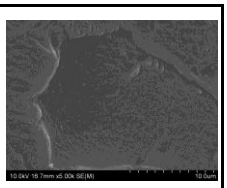
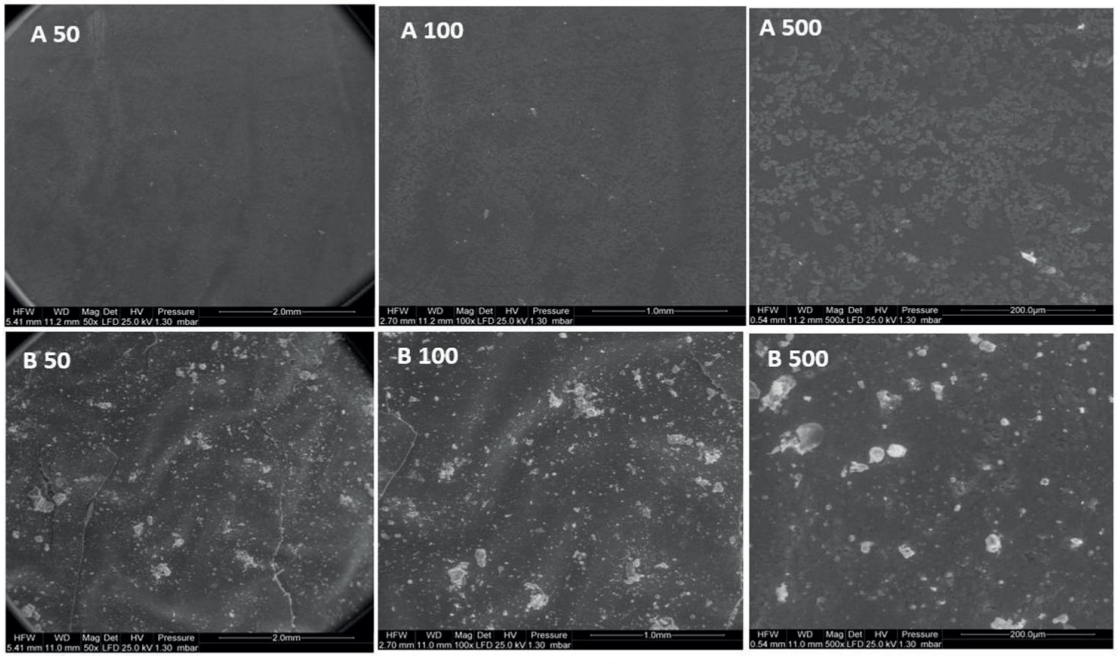
				
Trametes versicolor PE Surface Round 1 Sep 25	*T. versicolor* washed paper cup surface Round 1 Sep 25	*T. versicolor* washed paper cup surface Round 1 Sep 25	*T. versicolor* washed paper cup surface Round 1 Sep 25	*T. versicolor* washed paper cup surface Round 1 Sep 25

Figure 40

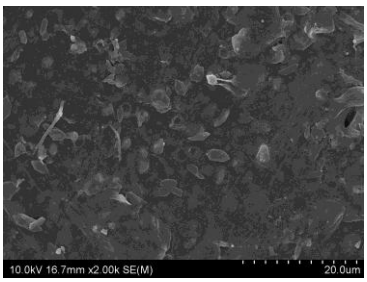
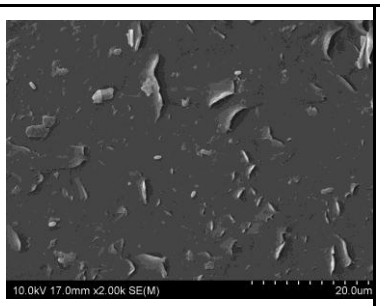
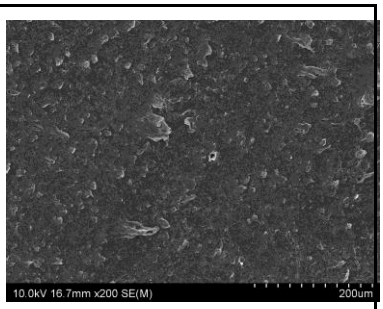
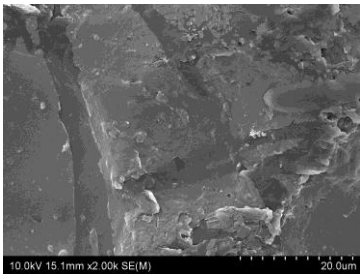
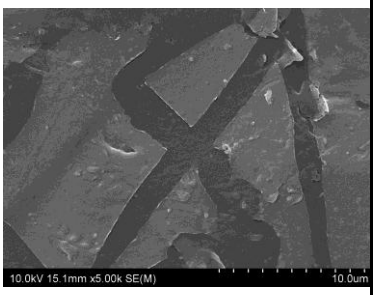
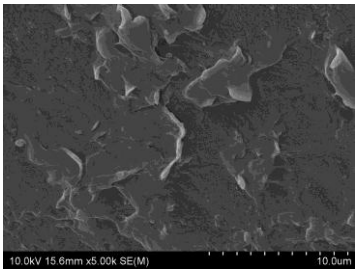
SEM Images: Original compared to Composted Samples, Adamcová (2018)



Note. From: "SEM Analysis and Degradation Behavior of Conventional and Bio-Based Plastics During Composting" by Adamcová et al. 2018, SpringerPlus 2014 3:1, (PDF) SEM Analysis and Degradation Behavior of Conventional and Bio-Based Plastics During Composting

Figure 41

SEM Images: Biodeterioration of *P. ostreatus and P. pulmonarius*

		
P. ostreatus PE-bin liner Round 2 Nov 25	*P. ostreatus* Washed paper cup Round 1 Sep 25	*P. ostreatus* PE-bin liner Round 2 Nov 25
		
P. pulmonarius Washed paper cup Round 1 Sep 25	*P. pulmonarius* Washed paper cup Round 1 Sep 25	*P. ostreatus* PE-bin liner Round 2 Nov 25

Biodeterioration can be described as surface-level degradation that modifies the mechanical, physical, and chemical properties of a material. Results, collected by Bhatia et al. (2014) of bacterial degradation of low-density PE (Figure 37), were similar to SEM images taken in my research of *P .ostreatus* and *T. versicolor* (Figure 38). In their study, cracks and disruption on the surface of the PE film highlighted degradation, as well as whiter areas showing erosion mechanisms. The biological processes by which bacteria and fungi degrade PE are different. However, it is interesting to see the similarities in the surface disruption of the two processes. Biofragmentation is the conversion of polymers to oligomers and monomers by the action of microorganisms (Adamcová et al., 2018), cutting long chains of molecules into shorter ones. As this is not visible through SEM, I cannot claim full degradation has taken place. El Menofy and

Khattab (2022) explain the three stages of decomposition. Biodeterioration, as visible in Figure 40, is the first stage, in which microorganisms change the chemical and physical properties of the material. The second stage is biofragmentation, and the final stage, known as assimilation, occurs when the microorganisms extract carbon, nutrients, and energy from the biofragmented polymer. In summary, the SEM evidence I have collected in my research proved that the first stages of decomposition were taking place.

Interestingly, in my studies on macroscopic examination of the culture plates, *P. pulmonarius* exhibited faster and denser growth than *P. ostreatus* (Figure 42). SEM comparison was not available of these samples due to restricted access. *P. ostreatus* had the best biodeteriorating evidence in the studies cited above, but those two *Pleurotus spp*. have not yet been compared in the literature.

Figure 42

P. pulmonarius growth (top) *compared to P. ostreatus* (*mislabeled parsonsiae*)*, Author. 11/9/2025*



Interpretation of Discolouration of Culture Plate Content

Odigbo et al. (2023) state that the discoloration of PET flakes noted in their research was a clear sign of degradation. Gok (2016, as cited in Odigbo et al., 2023) explains that moisture-induced yellowing occurs during chain scission as well as the "development of reactive intermediates (such as carboxylic acid and hydroxyl end units) which are a result of the growth and biodegradation enzymes produced by *Pleurotus spp."* In my experiment, discoloration of PE was achieved by *P. pulmonarius* (Figure 43).

Figure 43

Discolouration of PE by P. pulmonarius, Round One Experiments. Author 2025

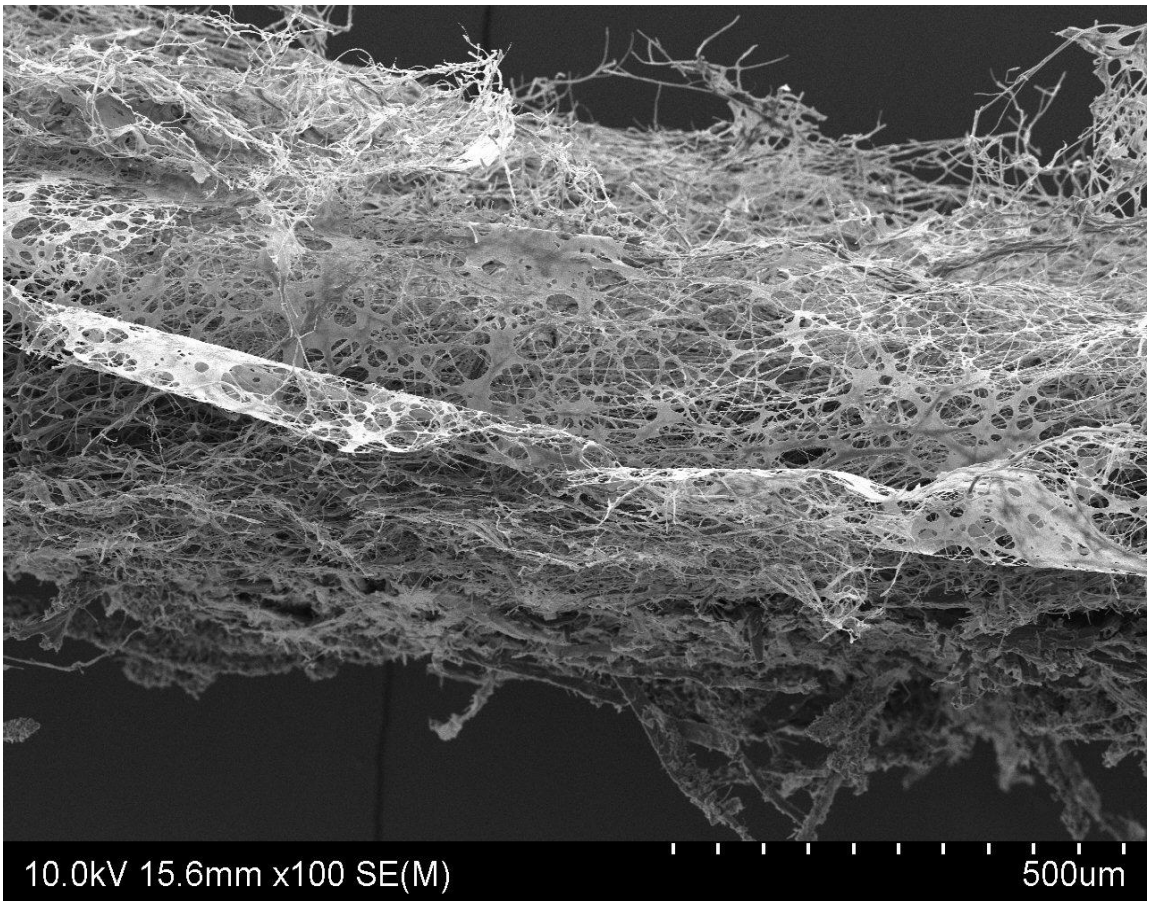


Reflection on the Choice of SEM Photography as Indicator of Degradation

Most of the SEM photos taken for me by the AUT lab technician were of lower magnification, for example, enlarging the image 100 times. At such lower magnifications, the mycelial network became visible, which showed whether the fungus was thriving, as seen in Figure 44. By analysing these, I learned that higher magnifications were required to see PE fragmentation, partial degradation of the lining, and delamination, typically associated with the initial stages of decomposition. An increased number of photos of higher SEM magnification would have provided more reliable insights into mycelial-induced biodegradation during my experiments.

Figure 44

SEM image taken by Yuan Tao of *T.versicolor.* 2026



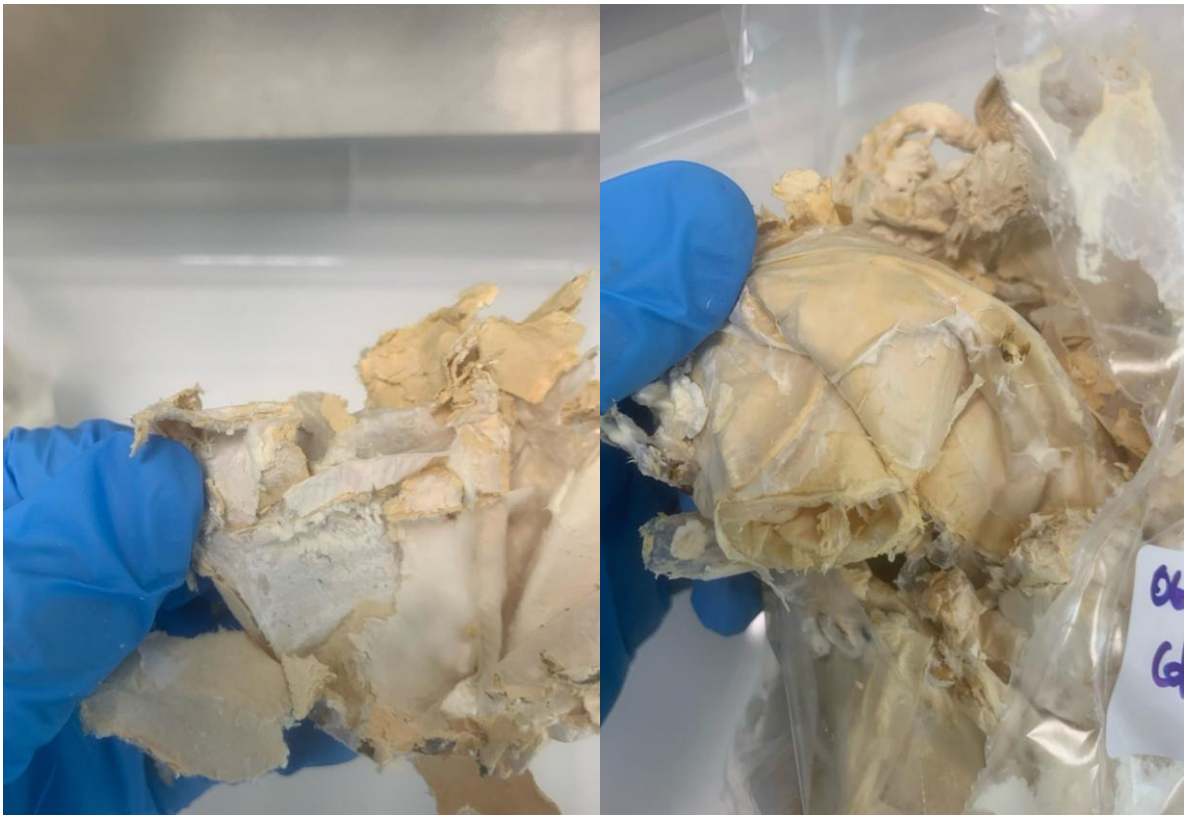
Adjustments to the method of detecting deterioration included taking cross-section SEM photographs as well as removing the upper layer of mycelium from the paper samples to gain deeper insights. Prior to this, only the top surface of the mycelium was visible, making it difficult to establish what interaction had occurred between the PE surface and the mycelium. Another limitation of SEM was that it only provided visible indication of degradation. To scientifically confirm biodegradation, the organic compounds released in the deconstruction of the material will need to be measured, which suitable laboratories may be able to address in future research.

Deductions after my Experimentation

In summary my results, showing fungal-induced biodeterioration of the PE-lining of paper cups, are in keeping with the existing literature regarding mycelial interaction with PE. This literature describes enhancement of the degradation process, causing biofragmentation, in which the longer chains get shortened so the molecule is easier to further degrade, or fully biodegrading the polymer into non-toxic elements. My experimental set-up could not show complete decomposition of PE. However, seeking the advice of another researcher working on mycoremediation processes, they confirmed that full degradation is hard to achieve (François Audrézet, 2025). Images from his study of paper cups exposed to *Pleurotus spp.* and *Ganoderma spp.* fungi also confirmed biodeterioration rather than biodegradation (Figure 45). This difficulty does not preclude the utility of mycelium in waste management, as fungi can successfully work synergistically with other treatments, for example ultraviolet light irradiation, accelerating biodegradation.

Figure 45

Photos Provided by François Audrézet showing Mycelial Deterioration of Paper Cups, 2025



Chapter Six

The Contribution of Creative Practice

The scientific component of this project provided evidence that selected fungal cultures can contribute to the degradation of polyethylene-lined cups. The creative outcome, *A Future with Fungi,* goes beyond communicating experimental findings. Rather than presenting fungi solely as a subject of scientific investigation, the book encourages readers to view fungi in relation to broader ecological systems and processes. It strives to encourage pro-environmental behaviour by making complex biological and climate-related solutions accessible using paintings, tactile learning and storytelling. This approach supports the project's aim of connecting scientific knowledge with public understanding.

This is the artefact's primary contribution: translating specialised research into a format accessible to audiences outside scientific disciplines. A second contribution is the integration of scientific and creative modes of inquiry by drawing on precedents from interdisciplinary research in textiles, architecture, and biotechnology. It demonstrates how creative practice can operate alongside laboratory-based research to explore environmental issues from multiple viewpoints.

Although exhibitions, workshops, documentaries, and other media formats may also support public engagement and warrant further exploration as dissemination strategies, the book format provides a durable and shareable resource that can be revisited over time. By integrating imagery, narrative, and scientific content, *A Future with Fungi* offers a mode of engagement that complements conventional science communication and supports ongoing reflection on environmental issues.

Significance

My book serves as an invitation to work differently: to learn through collaboration with both people and microorganisms, and to experiment within undefined, exploratory spaces. A human-centered hypothesis typically drives traditional scientific research. This can narrow the range of possible outcomes, as we become biased toward proving our starting hypothesis. At a time of urgent ecological crisis, we need new ways of seeing to imagine new solutions.

The desensitisation toward raw scientific data, particularly when it delivers uncomfortable truths about climate change, makes it unlikely to evoke critical environmental action. Creative design, however, may achieve this, possibly through hand-painted (rather than AI-generated) imagery presented in a beautiful storybook that invites readers to hold, enjoy, cherish, explore, and share it.

The completed artefact appears suitable for its intended audience of non-specialist readers interested in sustainability, design, and nature. The visual format enables complex ideas to be communicated in an approachable manner, while the narrative structure provides context that would be difficult to convey through scientific data alone. Feedback from readers and public engagement activities (a small exhibition) indicated that the book encouraged curiosity about fungi and their potential applications, suggesting that the artefact successfully supported the project's communication objectives.

The choice to communicate this research through an illustrated physical book was informed by literature suggesting that tactile and visual forms of communication can support engagement and retention of information (Umejima et al., 2021; Bischoff, 2026; Potter, 2014). These considerations shaped the emphasis on hand-painted imagery and the decision to develop a physical artefact rather than relying solely on digital dissemination.

Although a substantial body of literature supports the use of creative communication methods to enhance public engagement and knowledge retention, how successfully these outcomes were achieved through *A Future with Fungi* remains speculative. This represents a key

limitation of the study. Assessing the effectiveness of the book would require broader audience engagement and formal evaluation methods, which were beyond the scope of this research.

Furthermore, because the project consisted of two interconnected stages, substantial time was devoted to developing and iterating the scientific experiments, resulting in less time being available for the refinement and testing of the book itself. This was also the result of requiring an entirely new set of skills to engage with scientific study - Learning to cultivate mycelium. I spent considerable time iterating the experimental phase, seeking precision and clear outcomes. Consequently, the creative artefact did not undergo the same degree of iteration as the experimental component of the project. While this may be viewed as a limitation, it is difficult to separate the relative importance of the scientific and creative outcomes, as each informed and shaped the other throughout the research process.

The expansion in scope between Stage 1, which examined the degradation of polyethylene-lined cups by selected fungal cultures, and Stage 2, which situates this research within a broader exploration of fungi and sustainability, raises the question of whether the creative artefact strengthens the project or makes its relationship to plastic remediation less direct. While highlighting fungi's potential role in degrading PE was a central motivation for the scientific component of this research, the project was not intended solely as an investigation of plastic remediation. Rather, the experimental work provided a starting point for exploring how emerging scientific research might be communicated to wider audiences and contextualised within broader ecological and cultural discussions surrounding fungi. From this perspective, the value of the experiment is not reduced by distracting from it with a book. Rather, the two sections feed into each other, and the scientific experiment is a component of *A Future with Fungi*, and an execution of one of the technologies introduced. It was not intended to only communicate the findings of the experiment itself, but also to situate those findings within wider conversations about human relationships with fungi, sustainability, and environmental futures. If this was not clearly communicated, this suggests a limitation of the creative outcome and identifies an area for further refinement and iteration.

Highlighting fungi's ability to break down PE is important because it raises awareness of credible, nature-based approaches to plastic pollution. Although implementing such approaches at scale requires government action, investment, and restructuring of waste-management systems, increasing public awareness of sustainable technologies remains important for motivating individuals to advocate for environmental change. Without public demand and pressure, change at scale will not occur. This theme is reflected in A Future with Fungi through references to Brown's (2020) concept of emergence, which emphasises how small-scale actions and relationships can contribute to wider systemic change. The intention is to overcome a substantial barrier to environmental engagement; the perception that individual actions have little impact on broader environmental challenges.

The convergence of the multiple outcomes of this study points to one conclusion: we must adopt technologies that help us to re-engage with knowledge systems already present in nature, as exemplified in the world of fungi. Mycelial networks, often referred to as the "wood wide web", form an ancient planet-spanning mycelial intelligence that has been regulating ecosystems, distributing nutrients, and maintaining environmental balance since the beginning of life on Earth.

Humans have disrupted communication systems and lifecycles in nature responsible for the decomposition of organic matter and the release of nutrients which support new growth. One could argue that this has been one of the most detrimental impacts of human activity. However, utilising fungi to disassemble man-made "forever plastics" can enable individual compounds to be fed back into the nutrient cycle, rather than polluting ecosystems and damaging the health of humans and their environment alike.

Creative technologies are offering potential tools for re-connection. Reducing the widening disconnect between humans and the natural world, is critical to long-term survival and building resilience. Designing and integrating materials, infrastructures, and systems informed by mycelium can help repair the fractured relationship between human activity and ecological

stability. Fungi can be viewed as a symbol of resilience. Learning to collaborate with and think like them represents an epistemological realignment. It reintegrates humans into natural systems rather than continuing to act outside or above them, conducive to the long-term health of all life-forms.

Limitations of Working with Living Organisms

An emphasis of post-anthropocentric design is the shift away from designing for humans to designing for all life-forms. Co-designing with living organisms, such as mycelium, encourages this shift, transforming our role as designers from makers to facilitators. On co-design and collaboration with fungi, Christina Stadlbauer introduced an idea that my research has not addressed: whether working with living organisms challenges their agency. One limitation of this study is that there was no way to obtain consent from microorganisms and fungi. Learning how to recognize signs of stress as well as healthy growth will help to form and maintain relationships in which all involved parties benefit equally. However, there is continued concern that utilising fungi to solve human problems continues to feed into a system of exploitation. Future work could involve research into this space, such as developing technologies to interpret the language of other living organisms, and increasing our awareness and sensitivity.

Reflection on Research Journey

A reflection on the inductive and cyclical nature of this research is that the themes and ultimate meaning only revealed themselves to me gradually. Each stage of this project: Fabricademy, literature review, experimental work, and creative engagement only fully cohered in the final phase, when I began painting images that responded to the literature I had been engaging with throughout. This creative act revealed how my subconscious had been processing and integrating information across the project. Painting became a mode of thinking: a way of connecting with the material on a deeper, intuitive level that ultimately allowed me to see the project as a whole with clarity. This experience prompted me to investigate how people engage with information, and the positive potential for creative technologies to foster meaningful environmental engagement.

Conclusion

Most paper cups have a tightly bonded PE lining and are therefore currently very difficult to recycle. Fungi have shown promise in PE mycoremediation, but have not yet been tested in paper cups. My laboratory research showed that all three investigated fungi *T. versicolor*, *P. ostreatus*, and *P. pulmonarius* biodeteriorated the PE lining of Starbucks paper cups. *P. pulmonarius* appeared to outperform *P. ostreatus*. However, restricted access to SEM and scientific laboratory facilities limited the certainty of this finding. *P. pulmonarius* merits further investigation in future studies, which should also include chemical analysis to examine the extent of PE-biodeterioration achieved by all three investigated fungi.

Fungi initially helped other life on Earth to evolve, then helped other life-forms to communicate and thrive, and can now help find solutions to the plastic waste crisis. A positive, hopeful attitude can recruit people to participate in tackling the crisis one small step at a time, emerging through multiplication into powerful action.

Raw scientific facts about the benefits of collaborating with fungi may not be easily understood, which environmental storytelling supported by pictures can improve. My book *"A Future with Fungi"* contains the condensed hopeful message of my dissertation. Future publication may improve the positive impact to motivate change through a wider audience.

Reference list

Adamcová, D., Radziemska, M., Zloch, J., Dvořáčková, H., Elbl, J., Kynický, J., Brtnický, M., & Vaverková, M. D. (2018). Sem analysis and degradation behavior of conventional and bio-based plastics during composting. *Acta Universitatis Agriculturae et Silviculturae Mendelianae Brunensis*, *66*(2), 349–356. https://doi.org/10.11118/ACTAUN201866020349

Adamcová, D., Vaverková, M. D., & Břoušková, E. (2023). Wood decay fungi show enhanced biodeterioration of low-density polyethylene in the absence of wood in culture media. *Frontiers in Microbiology, 14*, Article 1229693. https://doi.org/10.1371/journal.pone.0288133

Akbulut, S., Akman, P. K., Tornuk, F., and Yetim, H. (2024). Microplastic Release from Single-Use Plastic Beverage Cups. *Foods*, *13*(10), 1564. https://doi.org/10.3390/FOODS13101564

Alley-Young, G. (2022). Printing press. EBSCO Research Starters: Communication and Mass Media. https://www.ebsco.com/research-starters/communication-and-mass-media/printing-press

Anand, A., Arce, M., Anand, K., Martinez Arce, A., Bishop, G., Styles, D., & Fitzpatrick, C. (2024). A tasty solution to packaging waste? Life cycle assessment of edible coffee cups. *Resources, Conservation and Recycling*, *201*(1), 107320. ttps://doi.org/10.1016/j.resconrec.2023.107320

Apicerni, V., Nicolais, F., Cocco, F., & Gravagnuolo, A. (2026). ArtScience collaboration: innovation trajectories towards strong sustainability. *Frontiers in Communication*, *11*, Article 1716729. https://doi.org/10.3389/fcomm.2026.1716729

Benyus, J. M. (1997). *Biomimicry: Innovation inspired by nature*. William Morrow.

Bhatia, M., Girdhar, A., Tiwari, A., & Nayarisseri, A. (2014). Implications of a novel Pseudomonas species on low density polyethylene biodegradation: an in vitro to in silico

approach. *Neuroscience and Biobehavioral Reviews, 186*(1)*,* Article: 106685. https://doi.org/10.1186/2193-1801-3-497

Bischoff, H., Meconi, F., & Crucianelli, L. (2026). Memories that touch deeply: Toward a neurobiological model of affective tactile memory. *Neuroscience and Biobehavioural Reviews*, *186,* Article: 106685. https://doi.org/10.1016/j.neubiorev.2026.106685

Blanchette, R. A., Haynes, D. T., Held, B. W., Niemann, J., & Wales, N. (2021). Fungal mycelial mats used as textile by indigenous people of North America. *Mycologia*, *113*(2), 261–267. https://doi.org/10.1080/00275514.2020.1858686

Bone, E. (2011). *Mycophilia: Revelations from the weird world of mushrooms*. Rodale Books.

Brown, A. M. (2017). *Emergent strategy*. AK Press.

Bukenya, K. T. (2025). The role of folklore in modern culture. *Research Invention Journal of Law, Communication and Languages*, *5*(2), 66–71. https://doi.org/10.59298/RIJLCL/2025/526671

Cho, N. (2025, July 23). *Are paper coffee cups compostable?* https://coffeexplore.com/are-paper-coffee-cups-compostable/

Clandinin, D. J., & Connelly, F. M. (2000). *Narrative inquiry: Experience and story in qualitative research.* Jossey-Bass.

Closed Loop Partners (2023). *NextGen Cup infrastructure report*. https://www.closedlooppartners.com/wp-content/uploads/2023/11/NextGen-Infra_FINAL_Nov2.pdf

Collet, C. (2021). Designing our future bio-materiality. *AI and Society, 36*(4), 1331–1342. https://doi.org/10.1007/s00146-020-01013-y

Cox, K. D., Covernton, G. A., Davies, H. L., Dower, J. F., Juanes, F., & Dudas, S. E. (2020). Correction to Human Consumption of Microplastics. *Environmental Science and Technology*, *54*(17), Article 10974. https://doi.org/10.1021/acs.est.0c04032

Cruz, I. D. A., Cruz-Magalhães, V., Loguercio, L. L., dos Santos, L. B. P. R., Uetanabaro, A. P. T., & Costa, A. M. da. (2024). A systematic study on the characteristics and applications

of laccases produced by fungi: insights on their potential for biotechnologies. *Preparative Biochemistry and Biotechnology*, *54*(7), 896–909. https://doi.org/10.1080/10826068.2023.2297697

Cronon, W. (1995). *Uncommon ground: Toward reinventing nature*. W. W. Norton and Company.

Cunsolo, A., & Ellis, N. R. (2018). Ecological grief as a mental health response to climate change-related loss. *Nature Climate Change, 8*(4), 275–281. https://doi.org/10.1038/s41558-018-0092-2

da Luz, J. M. R., Paes, S. A., Nunes, M. D., da Silva, M. de C. S., & Kasuya, M. C. M. (2013). Degradation of oxo-biodegradable plastic by *Pleurotus ostreatus*. *PLOS ONE, 8*(8), Article e69386. https://doi.org/10.1371/journal.pone.0069386

Dadachova, E., Bryan, R. A., Huang, X., Moadel, T., Schweitzer, A. D., Aisen, P., Nosanchuk, J. D., & Casadevall, A. (2007). Ionizing radiation changes the electronic properties of melanin and enhances the growth of melanized fungi. *PLOS ONE, 2*(5), e457. https://doi.org/10.1371/journal.pone.0000457

Daniels, P. T., & Bright, W. (Ed.). (1996). *The world's writing systems*. Oxford University Press.

Delaney, W. (2025, Dec 13). *Understanding Mycelium Growth Patterns. Mycelium Growth Patterns Explained | Mycology Science Guide - Spore Buddies*

Dennis, L. (2024). A brief history of the use of plastics. *Cambridge Prisms: Plastics, 2*, e19. https://doi.org/10.1017/plc.2024.17

DeVincent, K., Carretta, A., Colina, V., Laporte, I., Oung, T., & Gavin, H. E. (2026). As a component of aseptic technique, Bunsen burners do not universally decrease deposition of microbe-containing particles. *Microbiology Spectrum*. https://doi.org/10.1128/spectrum.01028-26

Griffiths, A. (2021, October 23). *The Living creates probiotic pavilion for Venice Architecture Biennale*. https://www.dezeen.com/2021/10/23/the-living-probiotic-architectural-alive-pavilion-venice-biennale/

Elsacker, E., Vandelook, S., van Wylick, A., Ruytinx, J., De Laet, L., & Peeters, E. (2020). A comprehensive framework for the production of mycelium-based flignocellulosic composites. *Science of the Total Environment, 725*, 138431. https://doi.org/10.1016/j.scitotenv.2020.138431

El-Sherif, D. M., Eloffy, M. G., Elmesery, A., Abouzid, M., Gad, M., El-Seedi, H. R., Brinkmann, M., Wang, K., & Al Naggar, Y. (2022). Environmental risk, toxicity, and biodegradation of polyethylene: A review. *Environmental Science and Pollution Research*, 29(54), 81166–81182. https://doi.org/10.1007/s11356-022-23382-1

Epicurus. (2026, May 5). *The greater the difficulty, the more the glory in surmounting it.* FixQuotes. https://fixquotes.com/quotes/the-greater-the-difficulty-the-more-the-glory-in-14229/

Etaywe, A., & Pinkerton, J. (2025). Building bonds and reader engagement through positive environmental journalism: Ideological positioning and ecocultural affiliation. *Environmental Communication, 19*(1), 1–18. https://doi.org/10.1080/17524032.2024.2345678

Filho, W. L., Salvia, A. L., Bonoli, A., Saari, U. A., Voronova, V., Klõga, M., Kumbhar, S. S., Olszewski, K., de Quevedo, D. M., & Barbir, J. (2021). An assessment of attitudes towards plastics and bioplastics in Europe. *Science of the Total Environment, 755*(Pt 1). https://doi.org/10.1016/j.scitotenv.2020.142732

Fletcher, I. A. (2025). Evaluating *Pleurotus ostreatus* growth for upcycling textile waste from the fashion industry. *Frontiers in Sustainability, 6, 1522527.* *https://doi.org/10.3389/frsus.2025.1522527*

El Menofy, N. G., & Khattab, A. M. (2022). Plastics biodegradation and biofragmentation. In A. M. Khattab (Ed.), *Handbook of biodegradable materials* (pp. 1–30). Springer. https://doi.org/10.1007/978-3-030-83783-9_22-1

Grady, C. L., McIntosh, A. R., Rajah, M. N., & Craik, F. I. M. (1998). Neural correlates of the episodic encoding of pictures and words. *Proceedings of the National Academy of*

Sciences of the United States of America, 95(5), 2703–2708. https://doi.org/10.1073/pnas.95.5.2703

Goethe, J. W. von. (1998). Der Zauberlehrling. In *Goethes Werke: Gedichte und Epen I* (Hamburger Ausgabe, Vol. 1, pp. 276–279). C. H. Beck.

GreenMatch. (2023, May 11). The effects of paper coffee cups on the environment. GreenMatch. https://www.greenmatch.co.uk/blog/2015/06/the-effects-of-paper-coffee-cups-on-the-environment

Harris, A., Leenen-Young, M., & Meihana, W. (2025). Whanaungatanga, teaching and connecting through responsibility and place. *AlterNative: An International Journal of Indigenous Peoples*, *21*(3). https://doi.org/10.1177/11771801251367818

Haraway, D. J. (2008). *When species meet*. University of Minnesota Press.

Haque, M. S. (2022). Inductive and/or deductive research designs. In M. R. Islam, N. A. Khan, and R. Baikady (Eds.), *Principles of social research methodology* (pp. 59–71). Springer. https://doi.org/10.1007/978-981-19-5441-2_5

Henry, J. (2023, May 7). *The psychology of storytelling: How narratives shape our thoughts and behavio*rs. Medium. https://medium.com/@shrey192000/the-psychology-of-storytelling-how-narratives-shape-our-thoughts-and-behaviors-f7a370031a30

Herziger, A., & Hurst, K. F. (2025). The role of cross- and interdisciplinary climate research centres. *Nature Climate Change, 15*(3), 228–230. https://doi.org/10.1038/s41558-025-02249-6

Iiyoshi, Y., Tsutsumi, Y. & Nishida, T. (1998). Polyethylene degradation by lignin-degrading fungi and manganese peroxidase. *Journal of Wood Science*, *44*(3), 222–229. https://doi.org/10.1007/BF00521967

Irwin, T., Tonkinwise, C., & Kossoff, G. (2020). *Transition design: The importance of everyday life and lifestyles as a leverage point for sustainability transitions*. Cuadernos del Centro de Estudios en Diseño y Comunicación, 105, 67–94. https://dspace.palermo.edu/ojs/index.php/cdc/article/download/4189/2334/

Islam, S. N., & Winkel, J. (2017). *Climate change and social inequality* (DESA Working Paper No. 152). United Nations Department of Economic and Social Affairs. https://digitallibrary.un.org/record/3859027

Jambeck, J. R., Geyer, R., Wilcox, C., Siegler, T. R., Perryman, M., Andrady, A., Narayan, R., & Law, K. L. (2015). Plastic waste inputs from land into the ocean. *Science*, *347*(6223), 768–771. https://doi.org/10.1126/science.1260352

Jeremic, D. (2014). *Polyethylene.* In Ullmann's Encyclopedia of Industrial Chemistry, (Ed.). https://doi.org/10.1002/14356007.a21_487.pub3

Kaiser, R., Bridgens, B., Elsacker, E., & Scott, J. (2023). BioKnit: Development of mycelium paste for use with permanent textile formwork. *Frontiers in Bioengineering and Biotechnology, 11*, Article 1229693. https://doi.org/10.3389/fbioe.2023.1229693

Kato Bukenya T. (2025). The Role of Folklore in Modern Culture. *Research Invention Journal of Law, Communication and Languages 5*(2):66-71. https://doi.org/10.59298/RIJLCL/2025/526671

Khajuria, M., & Kumar, A. (2022). *Holistic approach towards environment: That's the way to future*. *International Journal of Creative Research Thoughts, 10*(7), e717–e721. https://ijcrt.org/download.php?file=IJCRT2207618.pdf

Khan, M. A., & Al-Mahmood, A. M. (2024). The impact of social media usage on academic performance among university students. *Behavioral Sciences, 14*(10), 917. https://doi.org/10.3390/bs14100917

Kierkegaard, S. (1843). Journals, IV A 164. In N. J. Cappelørn, A. Hannay, D. Kangas, B. H. Kirmmse, G. Pattison, J. D. S. Rasmussen, V. Rumble, & K. B. Söderquist (Eds.), *Kierkegaard's journals and notebooks* (Vol. 4). Princeton University Press.

Kirk, T. K., & Cullen, D. (1998). Enzymology of lignin degradation. In M. P. Coughlin (Ed.), *Environmentally friendly technologies for the pulp and paper industry* (pp. 289–304). John Wiley & Sons.

Kumar, A., Chaturvedi, A. K., Yadav, K., Arunkumar, K. P., Malyan, S. K., Raja, P., Kumar, R., Khan, S. A., Yadav, K. K., Rana, K. L., Kour, D., Yadav, N., & Yadav, A. N. (2019). Fungal Phytoremediation of Heavy Metal-Contaminated Resources: Current Scenario and Future Prospects. In: Yadav, A., Singh, S., Mishra, S., Gupta, A. (Eds.) *Recent Advancement in White Biotechnology Through Fungi. Fungal Biology.* Springer, Cham. (pp.437–461) https://doi.org/10.1007/978-3-030-25506-0_18

Kurultay, A.B. (2026, May 11). *Consumer culture*. *Encyclopedia Britannica*. https://www.britannica.com/topic/consumer-culture

Kyaw, B. M., Champakalakshmi, R., Sakharkar, M. K., Lim, C. S., & Sakharkar, K. R. (2012). Biodegradation of low-density polyethylene (LDPE) by *Pseudomonas* species. *Indian Journal of Microbiology, 52*(3), 411–419. https://doi.org/10.1007/s12088-012-0250-6

Lalchhandama, K., & Lalchhandama, K. (2021). History of penicillin. *WikiJournal of Medicine*, *8*(1), 3. https://doi.org/10.15347/wjm/2021.003

Liboiron, M. (2021). *Pollution is colonialism.* Duke University Press.

Liu, J., Byrne, D., & Devendorf, L. (2018). Design for collaborative survival. *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems ACM, USA*, (40) 1–13. https://doi.org/10.1145/3173574.3173614

Montazer, Z., Habibi Najafi, M. B., & Levin, D. B. (2020). Challenges with verifying microbial degradation of polyethylene. *Polymers*, *12*(1), 123. https://doi.org/10.3390/polym12010123

Mylius, B. (2018). Three types of anthropocentrism. *Environmental Philosophy*, 15(2), 159–194. https://doi.org/10.5840/envirophil20184564

Nair, S., Gandhapodi, R., & Chithra, R. (2025). A psycho-emotional framework for environmental education: Integrating eco-emotions into learning for sustainability. *Frontiers in Education, 10*, 1657999. https://doi.org/10.3389/feduc.2025.1657999

Nakano, Y., & Hondo, H. (2023). Narrative or logical? The effects of information format on pro-environmental behavior. *Sustainability, 15*(2), 1354. https://doi.org/10.3390/su15021354

Odigbo, C., Adenipekun, C., Oladosu, I., & Ogunjobi, A. (2023). Polyethylene terephthalate (PET) biodegradation by *Pleurotus ostreatus* and *Pleurotus pulmonarius*. *Environmental Monitoring and Assessment*, *195*(10), Article 11153. https://doi.org/10.1007/s10661-023-11153-5

Olonisakin K, Mohanty A.K, Thimmanagari M., & Misra M.(2025). Recent advances in biodegradable polymer blends and their biocomposites: a comprehensive review. *Green Chem, 27(*38*),* 11656–11704. https://doi.org/10.1039/d5gc01294e

Parker, L. (2018, December 20). *Whopping 91 percent of plastic isn't recycled*. *National Geographic.* https://www.nationalgeographic.com/science/article/plastic-produced-recycling-waste-ocean-trash-debris-environment

Parker, K., & Parker, C. (2025). *The Mycelial Healer*. Rizzoli Publications.

Pattani, V., Kaneriya, J., Joshi, K., & Sanghvi, G. (2026). Microbial metabolic strategies for environmental detoxification: From enzymatic mechanisms to synthetic biology and omics. *Applied Biochemistry and Biotechnology*, *195* (2), 1–34. https://doi.org/10.1007/s12010-026-05797-5

Paleri, V. A., Buyst, N., & Stadlbauer, C. (2025). Mending cracks. *Cadernos de Campo (São Paulo, 1991)*, *34*(1), e233053. https://doi.org/10.11606/issn.2316-9133.v34i1pe233053

Perera, P., Herath, H., Paranagama, P. A., Wijesinghe, P., & Attanayake, R. N. (2023). *Wood decay fungi show enhanced biodeterioration of low-density polyethylene in the absence of wood in culture media*. *PLOS ONE, 18*(7), e0288133. https://doi.org/10.1371/journal.pone.0288133

Planet Spores. (n.d.). *Mycelium stalled? 7 reasons your mushroom grow has stopped*. https://planetspores.ca/mycelium-stalled-7-reasons-your-mushroom-grow-has-stopped/

Statista Research Department (2025, Mar 7). *Plastic waste worldwide – statistics and facts.* https://www.statista.com/topics/5401/global-plastic-waste/

Puig de la Bellacasa, M. (2017). *Matters of care: Speculative ethics in more than human worlds.* University of Minnesota Press. http://www.jstor.org/stable/10.5749/j.ctt1mmfspt

Plumwood, V. (1993). *Feminism and the mastery of nature*. Routledge.

Potter, M. C., Wyble, B., Hagmann, C. E., & McCourt, E. S. (2014). Detecting meaning in RSVP at 13 ms per picture. *Attention, Perception and Psychophysics*, *76*(2), 270–279. https://doi.org/10.3758/S13414-013-0605-Z

Pyzyk, K. (2023, July 11). *Consumers don't understand 'compostable' messaging on packaging, survey finds.* Packaging Dive. ttps://www.packagingdive.com/news/compost-recycling-report-BPI-closed-loop-partners/686039/

Ratuchne, A., Lonardoni, E. A., Bueno, C. E., Reis, G. F., Rezende, M. I., Urbano, A., Biz, G., de Almeida, R. S. C., & Panagio, L. A. (2023). Pleurotus ostreatus and a novel fungal composite: Development and bioremediation of plastic wastes. *Resources, Conservation and Recycling Advances*, *18*, Article 200167. https://doi.org/10.1016/j.rcradv.2023.200167

Saleh, R., & Brem, A. (2023). Creativity for sustainability: An integrative literature review. *Journal of Cleaner Production*, *388*, 135848. https://doi.org/10.1016/j.jclepro.2023.135848

Reyes, C., Poulin, A., Nyström, G., Schwarze, F., & Ribera, J. (2021). Enzyme activities of five white-rot fungi in the presence of nanocellulose. *Journal of Fungi, 7*(3), 222. https://doi.org/10.3390/jof7030222.

Stanley, J., Culliton, D., Jovani-Sancho, A.-J., & Neves, A. C. (2025). The journey of plastics: Historical development, environmental challenges, and the emergence of bioplastics for single-use products. *Eng—Advances in Engineering, 6*(1), Article 17. https://doi.org/10.3390/eng6010017

Stamets, P. (2005). *Mycelium running: How mushrooms can help save the world*. Ten Speed Press.

Seenivasagan, R., Karthika, A., & Poonkuzhali, K. (2022). In vitro and in silico study of the efficacy of fungi in low-density polyethylene degradation in a disposal paper cup. *Water, Air, & Soil Pollution*, 233(3), 77. https://doi.org/10.1007/s11270-022-05534-8

Shah, A. A., Hasan, F., Hameed, A., & Ahmed, S. (2008). Biological degradation of plastics: A comprehensive review. *Biotechnology Advances, 26*(3), 246–265. https://doi.org/10.1016/j.biotechadv.2007.12.005

Sheldrake, M. (2020). *Entangled Life: How fungi make our worlds, change our minds & shape our futures*. Random House.

Singh, G., & Agarwal, N. (2024). Degradation pathways and ecological consequences of use of polythene. In A. Sand & J. Tuteja (Eds.), *Polyethylene: New developments and applications*. IntechOpen. https://doi.org/10.5772/intechopen.1003241

Singh, A., Nath, G., Kaur, K., Landge, M., Urade, O., & Arya, S. (2024). The tower of consumerism in India: Consumerism and its impact on socioeconomic growth and environmental sustainability in India. In *RSD12: Relating Systems Thinking and Design Symposium* (Paper 111). https://rsdsymposium.org/wp-content/uploads/2024/01/RSD12_Paper_111.pdf

Singh, S., Singh, N. P., Agrawal, S., & Kumar, A. (2026). A comprehensive review on white-rot fungi for their pivotal role in degradation of pollutants. *Discover Water*, *6*(1), Article 28. https://doi.org/10.1007/s43832-026-00343-0

Somany, N. (2023). Greenwashing in business: Examining the impact of deceptive environmental claims on consumer behavior and corporate accountability. *International Journal of Social Science and Economic Research, 8*(4), 908-920. https://doi.org/10.46609/IJSSER.2023.v08i04.024

Sustainability Directory. (2025 May 1). *Urban mycelium structures: Building the future*. https://prism.sustainability-directory.com/scenario/urban-mycelium-structures-building-the-future/

Son, H. F., Hwang, S., Kim, Y., Ahn, J. H., Ko, J. K., Gong, G., Um, Y., Park, J. H., Park, H. J., & Lee, S.-M. (2025). Enzymatic depolymerization of polyethylene using a small laccase and its potential for bio-upcycling. *Journal of Hazardous Materials, 495*, Article 139021. https://doi.org/10.1016/j.jhazmat.2025.139021

Srikanth, M., Sandeep, T. S. R. S., Sucharitha, K., & Godi, S. (2022). Biodegradation of plastic polymers by fungi: A brief review. *Bioresources and Bioprocessing, 9*(1), Article 42. https://doi.org/10.1186/S40643-022-00532-4

Srivastava, A. N., Vuppaladadiyam, A. K., Koroth, R. P., Pfeifer, C., Kaviti, A. K., Fathi, J., Maslani, A., Barmavatu, P., Buryi, M., Pohorely, M., & Sikarwar, V. S. (2026). Circular economy approaches for sustainable waste management: A review on integration of AI, advanced technologies and policy recommendations. *Recycling, 11*(6), 99. https://doi.org/10.3390/recycling11060099

Stamets, P. (2005). *Mycelium running: How mushrooms can help save the world*. Ten Speed Press.

Stanley, J., Culliton, D., Jovani-Sancho, A.-J., & Neves, A. C. (2025). The journey of plastics: Historical development, environmental challenges, and the emergence of bioplastics for single-use products. *Eng, 6*(1), Article 17. https://doi.org/10.3390/eng6010017

Strullu-Derrien, C., Selosse, M. A., Kenrick, P., & Martin, F. M. (2018). The origin and evolution of mycorrhizal symbioses: From palaeomycology to phylogenomics. *New Phytologist, 220*(4), 1012–1030. https://doi.org/10.1111/nph.15076

Sustainability-Directory (2025, November 15). *Environmental Storytelling.* https://sustainability-directory.com/fundamentals/environmental-storytelling-fundamentals/

Thakkar, A. T., & Bhatt, S. A. (2020). Isolation, identification and optimization of laccase from *Alternaria alternata*. *Journal of Applied Biology and Biotechnology, 8*(3), 64–69. https://doi.org/10.7324/JABB.2020.803012

Treciokaite, G. (2025, May 5). *From waste to textiles: Creating biodegradable materials with mycelium.* Materials for Future. https://materialsforfuture.substack.com/p/from-waste-to-textiles-creating-biodegradable

Turner, H. L. (2024). *Evaluating Pleurotus ostreatus growth for upcycling textile waste from the fashion industry* (Master of Design exegesis, Auckland University of Technology). https://openrepository.aut.ac.nz/items/d1e59b14-5f84-4ec4-9e1a-9a40f9bf33b5

Tsing, A. (2015). *The Mushroom At The End Of The World: On The Possibility Of Life In Capitalist Ruins*. Princeton University Press.

Umejima, K., Ibaraki, T., Yamazaki, T., & Sakai, K.L. (2021). Paper Notebooks vs. Mobile Devices: Brain Activation Differences During Memory Retrieval. *Frontiers in Behavioural Neuroscience. 15* (2021). https://doi.org/10.3389/fnbeh.2021.634158

Van Dillewijn, P., Nojiri, H., van der Meer, J. R., & Wood, T. K. (2009). Bioremediation, a broad perspective. *Microbial Biotechnology*, *2*(2), 125–127. https://doi.org/10.1111/j.1751-7915.2009.00091.x

Wadhwa, H., Singh, R., & Chopra, C. (2023). Occurrence and Applications of Fungal Laccases: A Comprehensive Biotechnological Review. *Biological Forum - An International Journal. 15*(4). https://www.researchgate.net/publication/371292911_Occurrence_and_Applications_of_Fungal_Laccases_A_Comprehensive_Biotechnological_Review

Walker, M. (2022). *A Mycelium Connection: A study of the influence of mycelium bio-composites' senso-aesthetics on disgust, and other barriers to uptake in architecture (Version 1*). Open Access Te Herenga Waka-Victoria University of Wellington. https://doi.org/10.26686/wgtn.20621103

Wakkary, R. (2021). *Things We Could Design: For More Than Human-Centered Worlds.*The MIT Press. https://doi.org/10.7551/mitpress/13649.001.0001

Wattanavichean, N., Phanthuwongpakdee, J., Koedrith, P., Laoratanakul, P., Thaithatgoon, B., Somrithipol, S., Kwantong, P., Nuankaew, S., Pinruan, U., Chuaseeharonnachai, C., & Boonyuen, N. (2025). Mycelium-based breakthroughs: Exploring commercialization, research, and next-gen possibilities. *Circular Economy and Sustainability*, *5,* 3211–3253. https://doi.org/10.1007/s43615-025-00539-x

Wehi, P. M., Beggs, J. R., & McAllister, T. G. (2019). Ka mua, ka muri: The inclusion of mātauranga Māori in New Zealand ecology. *New Zealand Journal of Ecology*, *43*(3). https://doi.org/10.20417/NZJECOL.43.40

Wohlleben, P. (2016). *The hidden life of trees: What they feel, how they communicate – discoveries from a secret world* (J. Billinghurst, Trans.). Greystone Books.

Yang, W.K., Gong, Z., Wang, B.T., Shuang Hu, Ye Zhuo, Chun-Zhi Jin, Long Jin, Hyung-Gwan Lee & Feng-Jie Jin (2024). Biodegradation of low-density polyethylene by mixed fungi composed of *Alternaria* sp. and *Trametes* sp. isolated from landfill sites. *BMC Microbiol 24,* 321. https://doi.org/10.1186/s12866-024-03477-0

Yuhui, M. (2018). Problems and Resolutions in Dealing with Waste Disposable Paper Cups. *Science Progress*, *101*(1), 1–7. https://doi.org/10.3184/003685017X15129981721365

Zak, P. J. (2015). Why Inspiring Stories Make Us React: The Neuroscience of Narrative. *Cerebrum: The Dana Forum on Brain Science*, *18*(13), 4079–4085. https://pmc.ncbi.nlm.nih.gov/articles/PMC4445577/

Žgajnar Gotvajn, A., & Kalčíková, G. (2018). Delamination of plastic-coated waste paper by enzymes of the white-rot fungus *Dichomitus squalens*. *Journal of Environmental Management*, *228*(1), 165–168. https://doi.org/10.1016/j.jenvman.2018.08.111

Zhang, N., Ding, M., & Yuan, Y. (2022). Current Advances in Biodegradation of Polyolefins. *Microorganisms*, *10(8)*, 1537. https://doi.org/10.3390/microorganisms10081537

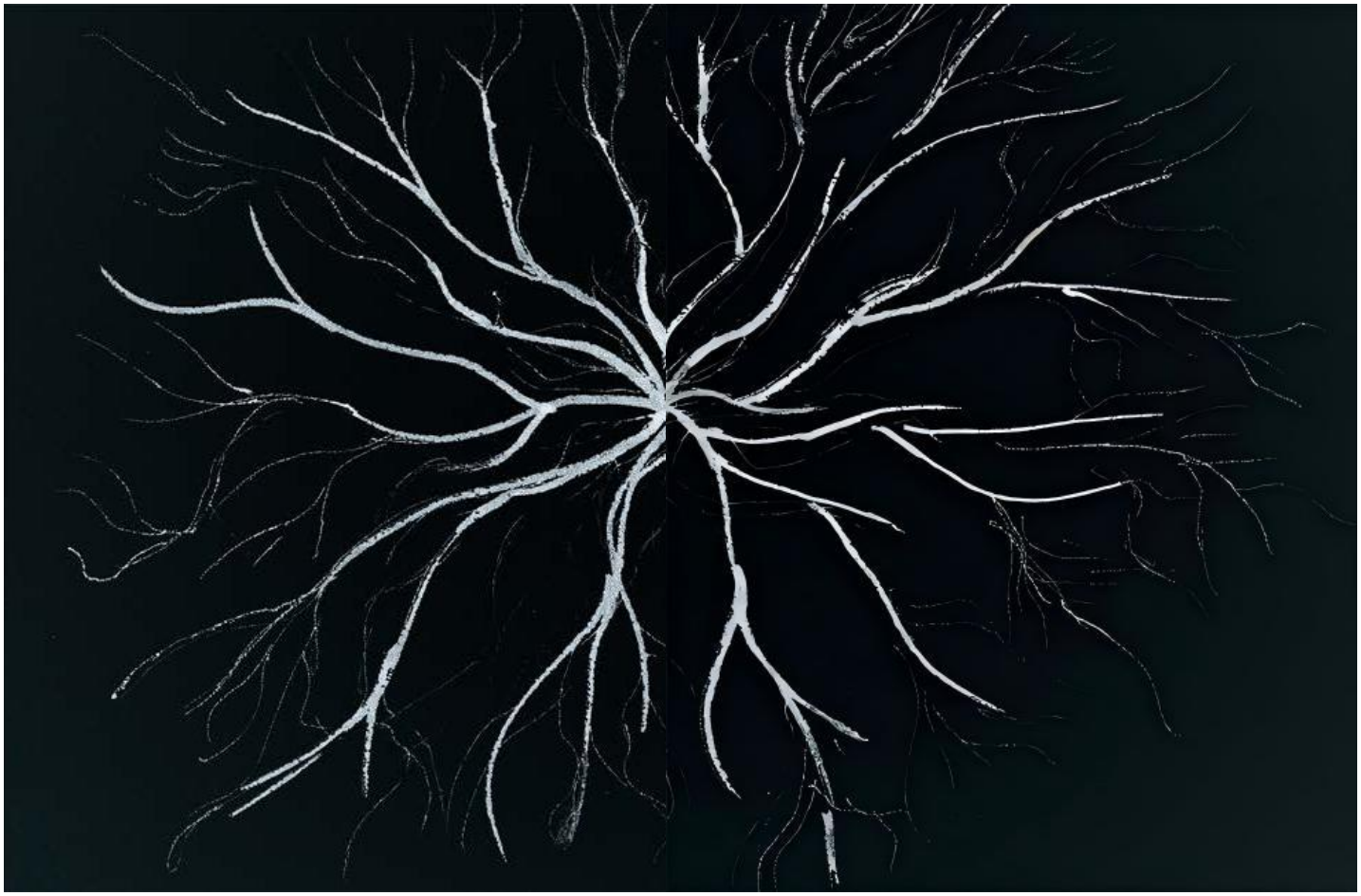
Zhao, J. (2026). The psychology of art and emotional experience: A theme-color-emotion framework for understanding viewer-reported emotional regulation. *Frontiers in Psychology*, *17*, Article 1357999. *https://doi.org/10.3389/fpsyg.2026.1357999*

Appendix A - ***A Future with Fungi***



A FUTURE WITH FUNGI

Karlena Dunn

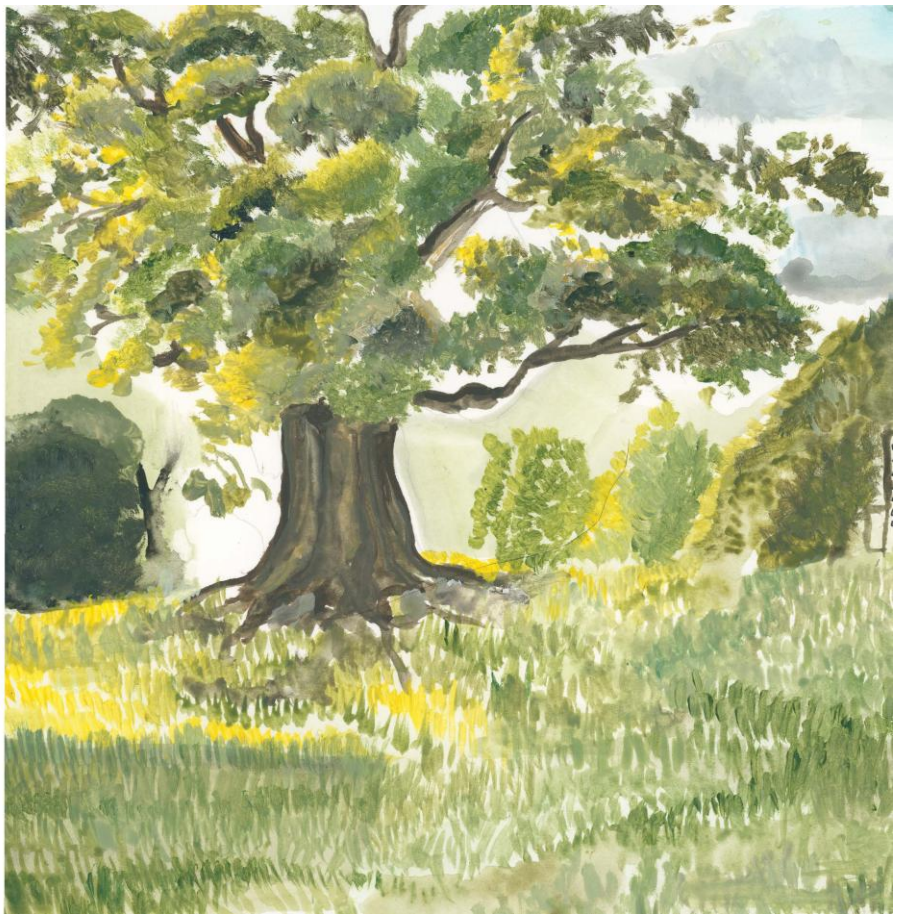


What do you think of when you hear fungi?
A mushroom perhaps?
The ones you find in a supermarket
or the spotted red and white fly agaric?

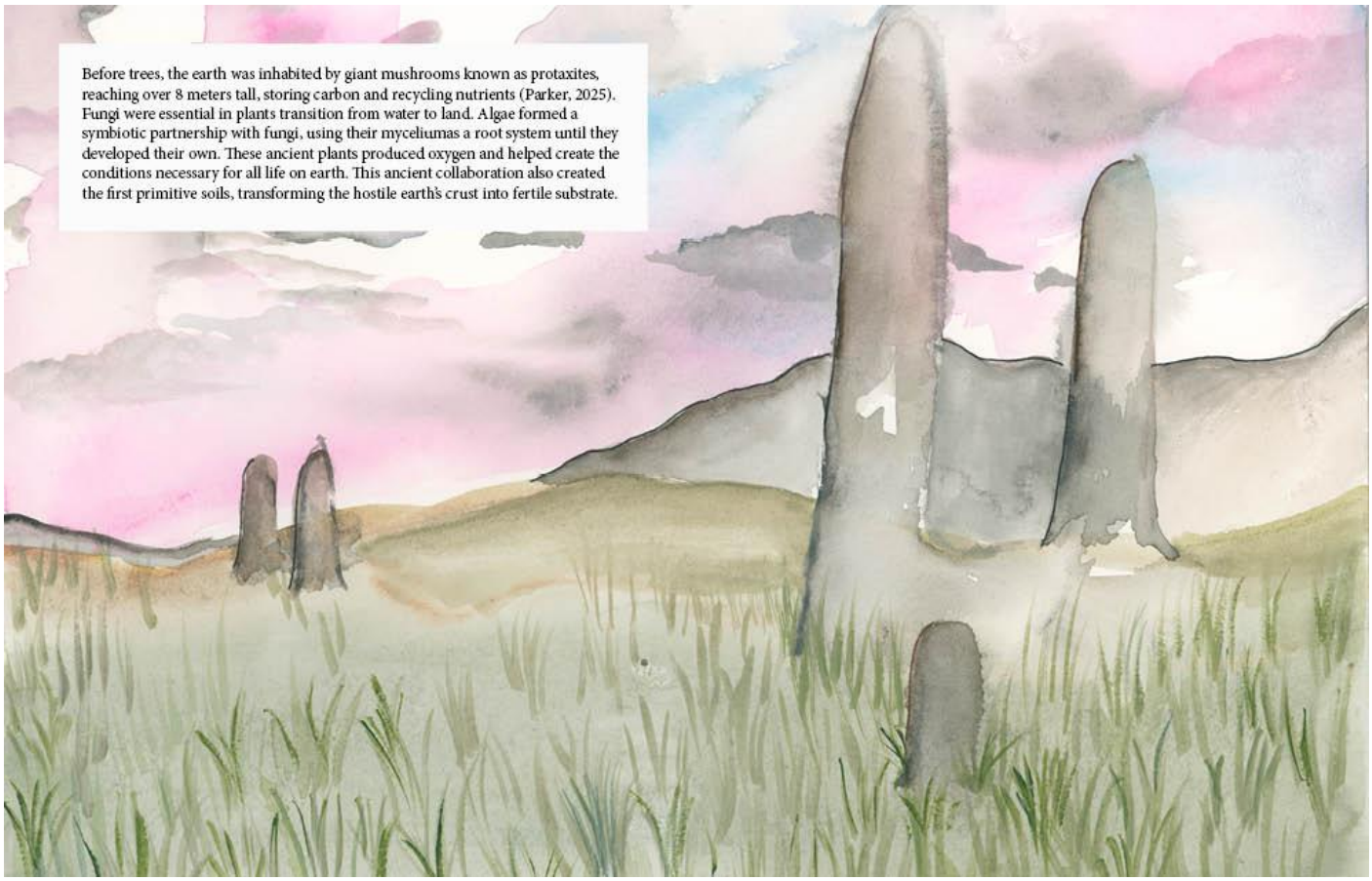
The mushroom is the fruiting body (sporophore) of the fungus and usually only makes up 5 percent of the organism. The mushroom is the visible part of the organism emerging only periodically for reproduction. Over 95 percent of fungi consist of a complex "root" system, of mycelia which transfers nutrients and sends electric pulses, much like the neurons of the human brain, throughout what can be an organism spread over a huge area.

The largest known mycelial network extends 9.6 km across, making it the world's largest single living organism (Bone,2011). As a class of organism, they are not part of the animal or plant kingdoms, fungi are everywhere. There are 1.5-5 million fungal species, with only 5% currently classified. Our lives are intertwined with and dependent on fungi, with which we have more in common than one might initially suspect.

It is thought that humans and fungi evolved from the same common ancestor, a single-celled organism known as a protist that lived over a billion years ago. There is a lot to learn from the fascinating biological Kingdom of Fungi (which includes mushrooms, yeasts, rusts, mildews, smuts and molds), and much more is still awaiting to be discovered. Finding ways to work with them, even operate like them, could help us navigate the challenges of climate change as well as build a moresustainable, equitable future. We have a longstanding history of collaboration with fungi, which emerged in the late Devonian period around 420 million years ago forming the world into which homo sapiens evolved about 300,000 years ago.






Before trees, the earth was inhabited by giant mushrooms known as protaxites, reaching over 8 meters tall, storing carbon and recycling nutrients (Parker, 2025). Fungi were essential in plants transition from water to land. Algae formed a symbiotic partnership with fungi, using their myceliumas a root system until they developed their own. These ancient plants produced oxygen and helped create the conditions necessary for all life on earth. This ancient collaboration also created the first primitive soils, transforming the hostile earth's crust into fertile substrate.


Our forests are still sustained by ancient partnerships between plants and mycelium, relationships that have evolved into vast, intricate networks beneath the soil. Walking through a woodland, we are often unaware of the hidden world under our feet. Beneath each step, there may be up to 300 miles of mycelium, and in every cubic metre of air, an estimated 1,000 to 10,000 fungal spores. Our lives are deeply intertwined with fungi. The health of both humanity and the planet depends on the continued communication between species.

The Secret Language of trees

Mycorrhizal fungi live on the roots of nearly ninety percent of all plants, helping them draw nutrients from the soil in exchange for photosynthesized sugars (Bone, 2011). This remarkable group of fungi are mutualists, forming symbiotic relationships that sustain thehealth and resilience of forest ecosystems. A single group of fungal species can colonise the roots of almost every tree in a forest, quietly maintaining their nutritional needs.

For centuries, many Western scholars believed humans were the only species capable of language.Yet research into forest mycorrhizal networks has revealed a constant flow of communication between trees, warning one another of threats, sharing resources, and redirecting nutrients toweaker seedlings (Simard et al., 1997).

This cooperation extends not only between trees of the same species, but also across species boundaries; nature collaborates to survive. While we once thought roots alone were a tree's nutritional pathway, it is the fungi living on and within those roots that provide most of the water and nutrients a tree depends on. Without its fungal partners, a tree may survive for a time, but it will eventually succumb to malnutrition. Around ninety percent of all land plants are believed to form these essential mycelial partnerships.





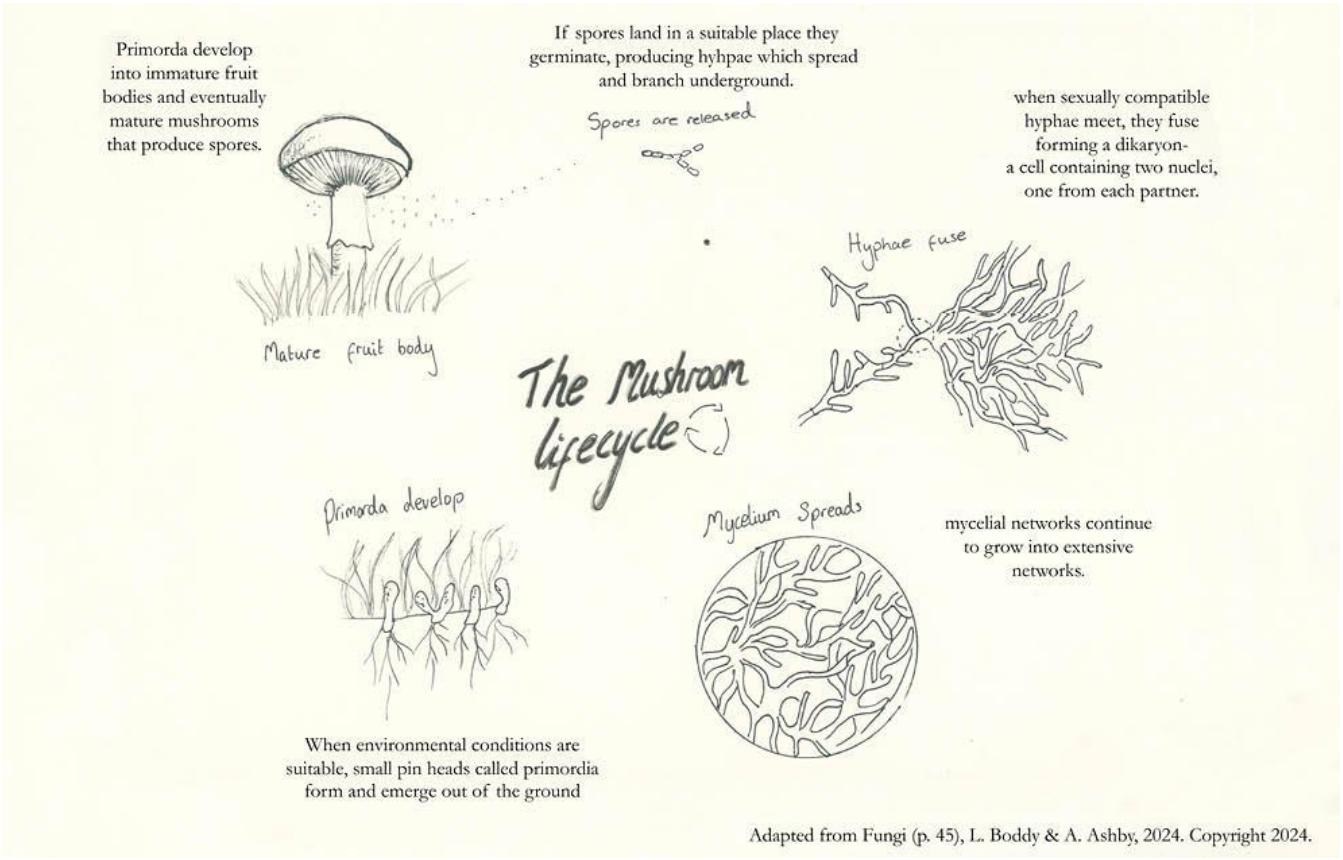
MUSHROOMS

Fungi spend the majority of their lifetime in the form of mycelium, only producing fruiting bodies (mushrooms) during reproduction - which accounts for less than one percent of their entire lifecycle. The class of fungi associated with this particular method of reproduction is known as Agaricomytes. (Bone, 2011).

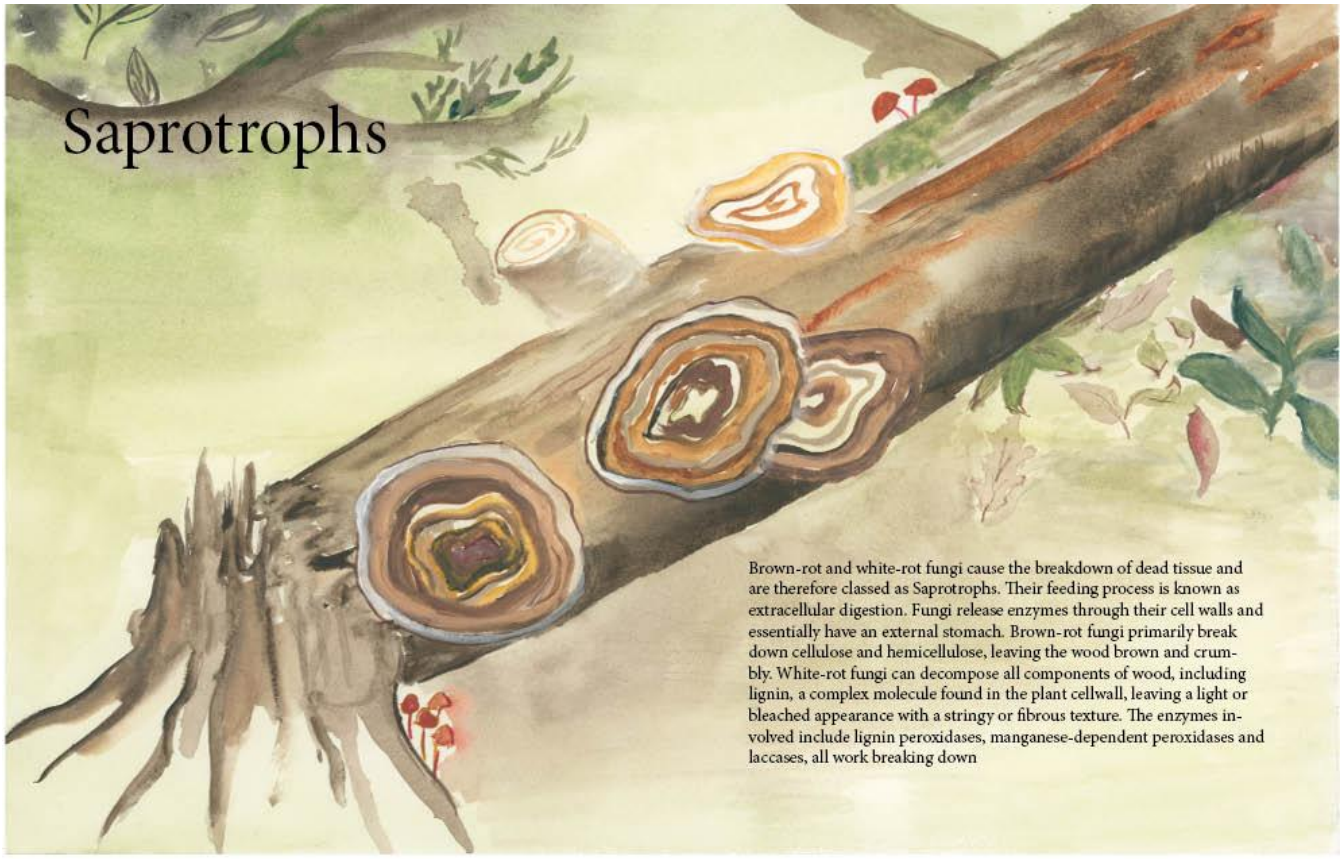
Usually, a mushroom forms when two primary mycelia fuse, which is a form of sexual reproduction. Once this secondary mycelium reaches critical mass, it forms a mushroom. Different parts of the hyphae become responsible for building different parts of the mushroom, some for the cap, and other parts for the stem. Once the mushroom has formed, the reproductive structures produce spores, which can be released at a speed of thirtyfive feet per second. If the conditions are right, they might germinate.

When a spore germinates after landing in a food-rich environment, the spore swells up and spits out hyphae, which grow one cell at a time from their tip, forming a string of cells which form the mycelial mat. Hyphae grow in different directions, constantly on the look-out for food. This growth- pattern gives a healthy mycelium its circular structure and maximises its chance of finding nutrition. For instance the dark green circle of a "fairy ring" spreads out evenly as the mycelium spreads out. Mycelium can cover vast distances, crossing over food-poor areas to find richer soil.

Another way a spore can germinate is through being eaten by a herbivore. The spore becomes activated through the heat of the animal's core temperature, then further activates on the dung and begins to decompose it. Reproduction through fusing hyphae is not the only way fungi reproduce. Some don't even need a partner to create offspring. In fragmentation, small pieces of mycelium break off and grow into new individuals. Moulds primarily reproduce asexually, releasing spores in moist and nutrient rich conditions which form new colonies.



Adapted from Fungi (p. 45), L. Boddy & A. Ashby, 2024. Copyright 2024.







Diverse cultures of saprotrophs have been found living in landfill, digesting card wood, paper and some plastics, and are able to clean oil spills. Petrol and lignin (key components of wood) are both composed of hydrocarbon molecules, indeed oil was formed by the breakdown of the carboniferous forests. Because they have similar bonds, both are vulnerable to being deconstructed by the enzymes that white rot fungi excrete (Bone, 2013). This process is known as mycoremediation.





The most famous trial of mycoremediation was carried out by Paul Stamets. It involved four test piles of soil contaminated with petroleum hydrocarbons. One pile was inoculated with Pleurotus ostreatus mycelium. The mycelium colonised the toxic soil and broke down the hydrocarbons into non-toxic compounds. Within weeks the once-dead soil became biologically active, producing large oyster mushrooms, which then attracted insects and subsequently birds. By the end of the study, the hydrocarbon load had decreased from 20,000 parts per million to 200 parts per million (Stamets, 2005).



Medicine

Many know the widely circulated story of the discovery of penicillin by Alexander Fleming in 1928 and consider it the mycelium medical breakthrough of the 20th century. History however shows evidence of medical fungi use as early as 7,000 years before Fleming's discovery. Examples include the use of mould and fungi in ancient Egypt as an early antibiotic, ancient Chinese medicine and indigenous cultures worldwide (Bone, 2013).

Modern Western medicine has contributed to our worldview placing pharmaceutical medicines in a hierarchy above traditional natural remedies. Thus, the knowledge of many ancient treatments has been lost, especially that reliant on word of mouth, as the extinction of native languages contributed.

There has been a revival of interest in some of this historic knowledge partially due to modern biomedical research but also the expansion of the 'health market'. Many of these areas of research overlap with traditional Chinese remedies such as the application of Shitaake and Reishi mushrooms for positive immunological effects, as well as a large group of fungi which can be used in support of cancer treatment (Parker, 2025).

A key ability of fungi which make them invaluable as medicines is their ability to construct polysaccharides (complex carbohydrates) from simple plant sugars. Of these polysaccharides many possess immunomodulatory, antioxidant, antimicrobial, anti-cancerous and anti-diabetic properties.

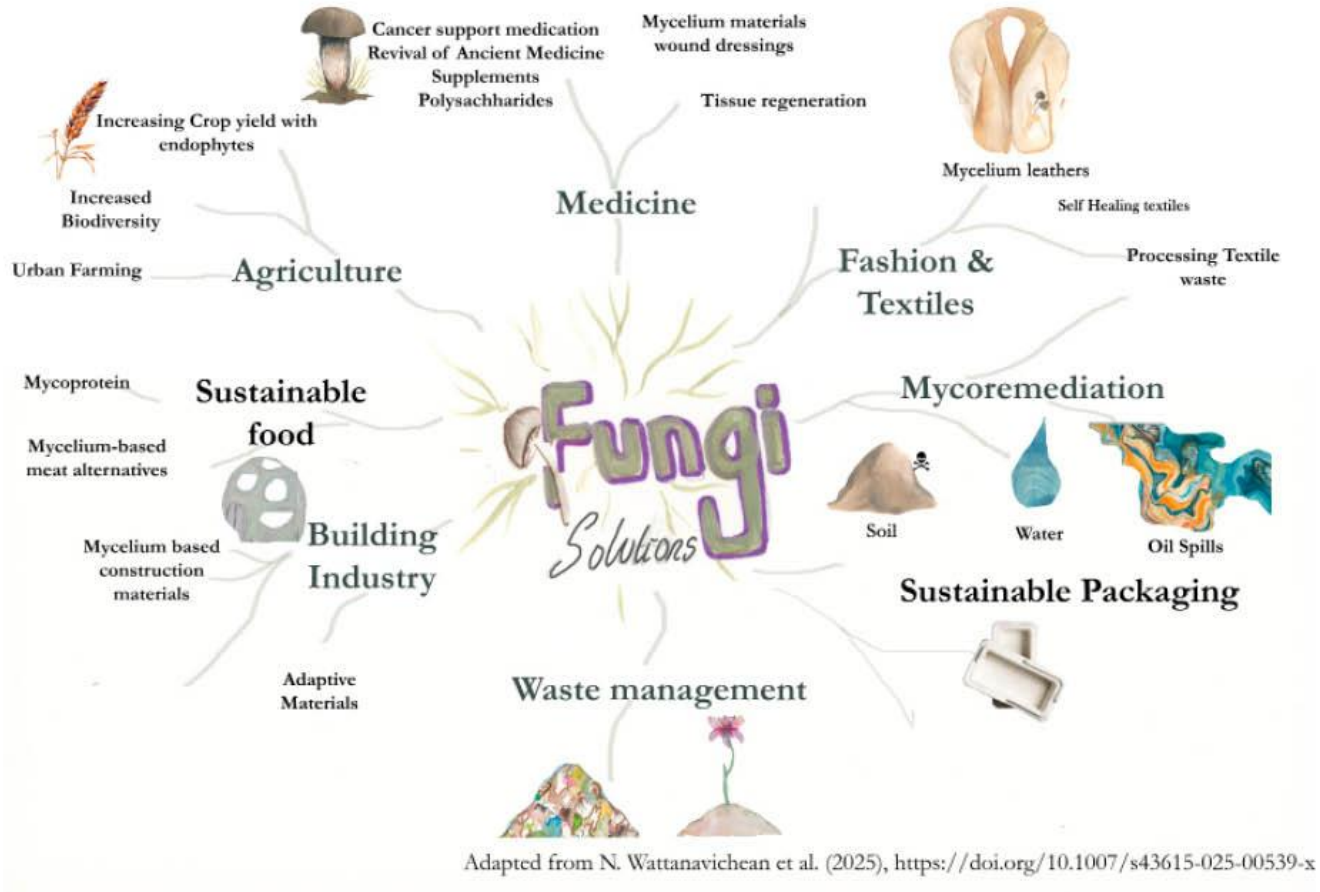


THE FEAR

There is a deeply rooted fear of fungi — and not without reason. Throughout history, fungi have been responsible for famines, crop failures, and human disease. One of the most infamous examples is the ergot fungus in medieval Europe, which infected grains and caused ergotism, a severe poisoning that led to hallucinations, convulsions, and death. Even today, fungal pathogens remain a major global threat to agriculture, responsible for the majority of plant-disease-related crop losses.

For some people, mycelium-based materials evoke an instinctive sense of disgust. This reaction is part of a protective mechanism that alerts us to potential danger (Curtis 2007 , as cited in Walker 2022). Fungi are also commonly associated with death and decay due to their role as decomposers and the visible spread of moulds, reinforcing these negative perceptions.

Whilst disgust is one possible response. Many people experience curiosity, fascination, or even a sense of calm when encountering mycelium materials. Research shows that exposure to natural textures and organic forms in architecture can have measurable psychophysiological benefits. Integrating mycelium into our built environment may therefore support health and wellbeing rather than threaten it. To embrace this shift, we must rewrite the cultural narratives that cast fungi as symbols of rot and danger, and instead highlight the many ways in which collaborating with them can enrich our lives and environments.

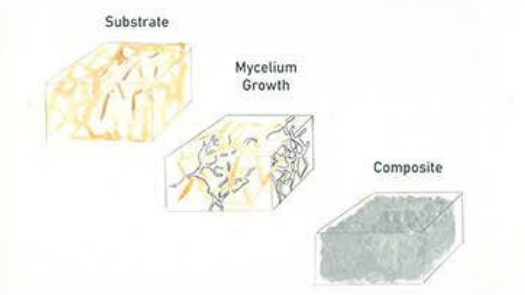


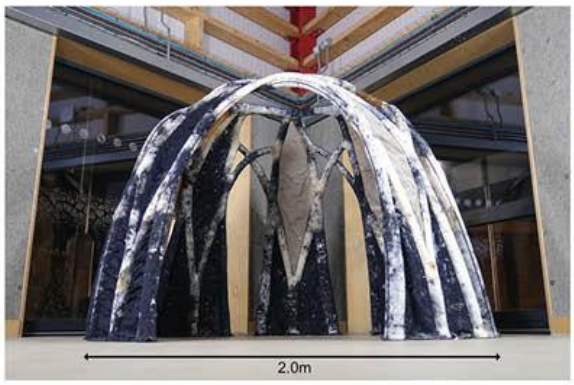
Adapted from N. Wattanavichean et al. (2025), https://doi.org/10.1007/s43615-025-00539-x

Mycelium based composites

Amidst growing concern over the environmental impact of the building industry, there has been a growing interest in the integration of mycelium based composites and their ability to reduce carbon footprint (Kaiser et al., 2023). Mycelium-based composites (MBCs) and pure mycelium materials (PMMs) are being explored as an alternative to bricks, insulation and as a potential replacement for concrete.Advantages over traditional materials include low density, good insulation values (both thermal and acoustic), inherent fire resistance, as well as the ability to be grown on existing waste streams.

Creating mycelium based composites is not difficult, it only requires a substrate, which can range from straw, wool and cellulose to less natural waste streams such as textile waste and fungal mycelia. Common strains used include Pleurotus and Ganoderma species. The substrate is inoculated and left to grow in a controlled environment for between 10 -21 days. Growth is usually stopped by drying or high temperatures which deactivate the fungi.





Reprinted from "BioKnit: Development of Mycelium Paste for Use With Permanent Textile Formwork," by R. Kaiser, B. Bridgens, E. Elsacker, & J. Scott, 2023, Frontiers in Bioengineering and Biotechnology, 11. https://doi.org/10.3389/fbioe.2023.1229693 .Licensed under CC BY 4.0

Providing the fungi have oxygen and a substrate, MBCs can grow in any shape. Researchers at Newcastle university demonstrated this with their project Bioknit, in which a knitted structure was injected with a mycelium substrate paste called mycocrete (Kaiser et al., 2023). The study revealed that the knitted wool tubes act as oxygen-permeable, flexible molds that facilitate any organic shape. This self growing structure creates a potential future reality in which we could have self growing houses that grow on waste streams and promote more integration between the human and natural world.



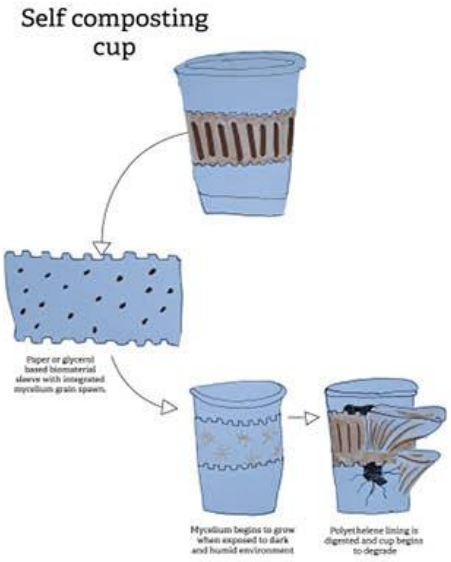
Living Materials

Given the proper conditions, there is no reason why fungi couldn't live indefinitely, raising the question of the possibility of self repairing structures.

An exciting future application of mycelium materials could involve intentionally keeping the material alive, utilizing the organisms ability to regenerate for self repair as well as self assembly and healing. This category of materials has been given the name - engineered living materials (ELMs) (Wattanavichean et al., 2025). Having a living material with the ability to change its properties based on its environment is appealing. This has been successfully trialled with mycelium leathers and microbial-mediated self-healing concrete fissures.



Mycelium composites also have applications for the packaging industry, providing a lightweight, biodegradable alternative to polystyrene, which is a petroleum-derived product. Ecovative has been applying this technology commercially since 2007, called Mushroom Packaging. Ongoing international research is striving to improve this technology, including in New Zealand at the Auckland-based biotech company Mushroom Material.



This Design for a self decomposing coffee cup is a possible future for living materials. Dormant spores of paper degrading fungi are integrated into the coffee cup sleeve which become activated due to an environmental shift- exposure to moisture post usage.

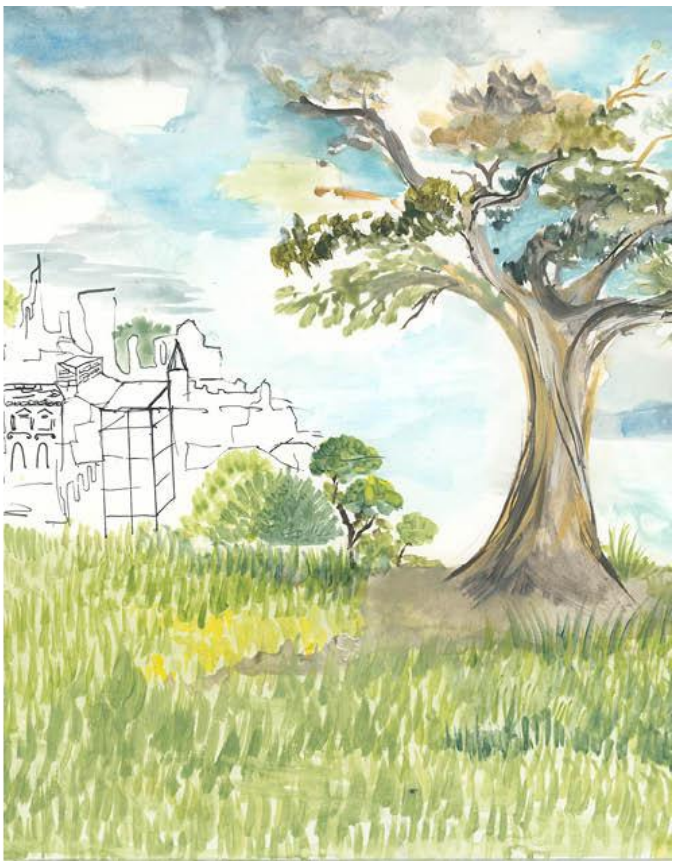


Self- reparing Mycelium leather jacket



Our shared future

Fungi have not only survived but also thrived through five mass extinction events. Tsing (2015) introduces the idea of collaborative survival, a way of looking to existing relationships in nature for inspiration on how to move forward in ways that benefit all life. The question is not whether there will be life on earth, but what it will look like and which species will have adapted to suit earth's rapidly changing climate. 'Emergence' is a term describing the way small actions and connections create complex systems, patterns that become ecosystems and societies (Brown, 2017). We are able to have a positive impact on future ecosystems. Every small action feeds into a larger network, as connected as hyphae in mycelium.



References

Boddy, L., & Ashby, A. (2023). Fungi. Dorling Kindersley Ltd.

Bone, E. (2013). Mycophilia: Revelations from the weird world of mushrooms. Rodale.

brown, a. m. (2017). Emergent strategy. AK Press.

Odigbo, C., Adenipekun, C., Oladosu, I., & Ogunjobi, A. (2023). Polyethylene terephthalate (PET) biodegradation by Pleurotus ostreatus and Pleurotus pulmonarius. Environmental Monitoring and Assessment, 195(5). https://doi.org/10.1007/s10661-023-11153-5 (doi.org in Bing)

Devi, D. R., Sivaji, K., Basavaiah, K., Anjali, A., & Kumar, P. S. S. P. (2026). Uses of mycoremediation in large-scale applications. In Emerging paradigms in pharmaceutical research (pp. 85–108). https://doi.org/10.1007/978-981-95-5743-1_5 (doi.org in Bing)

Kaiser, R., Bridgens, B., Elsacker, E., & Scott, J. (2023). BioKnit: Development of mycelium paste for use with permanent textile formwork. Frontiers in Bioengineering and Biotechnology, 11. https://doi.org/10.3389/fbioe.2023.1229693 (doi.org in Bing)

Parker, K., & Parker, C. (2025). The mycelial healer. Rizzoli Publications.

Simard, S. W., Perry, D. A., Jones, M. D., Myrold, D. D., Durall, D. M., & Molina, R. (1997). Net transfer of carbon between ectomycorrhizal tree species in the field. Nature, 388(6642), 579–582. https://doi.org/10.1038/41557

Stamets, P. (2005). Mycelium running: How mushrooms can help save the world. Ten Speed Press.

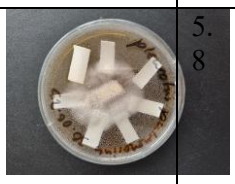
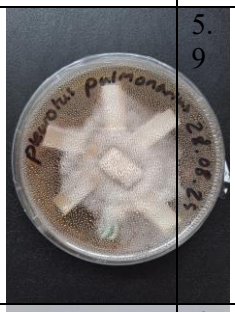
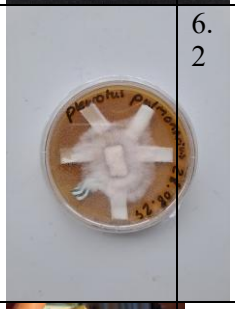
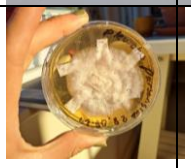
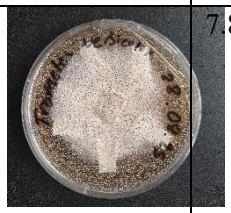
Tsing, A. (2015). The mushroom at the end of the world: On the possibility of life in capitalist ruins. Princeton University Press.

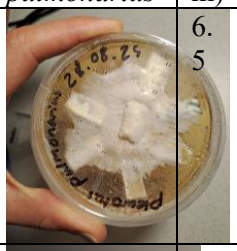
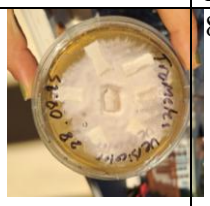
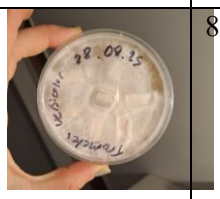
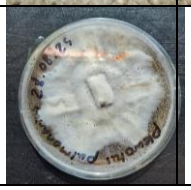
Walker, M. (2022). A mycelium connection: A study of the influence of mycelium bio-composites' senso-aesthetics on disgust, and other barriers to uptake in architecture (Master's thesis). https://doi.org/10.26686/wgtn.20621103



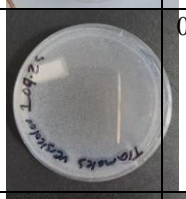
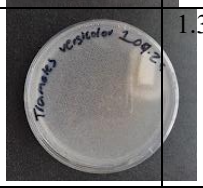
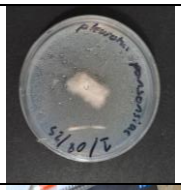
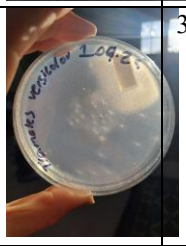
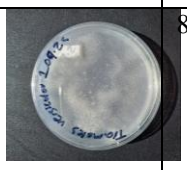
Appendix B - Condensed home experiments results tables

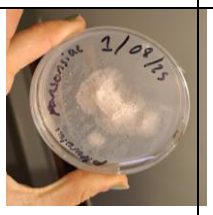
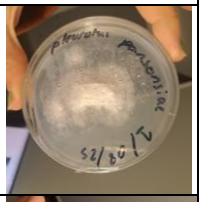
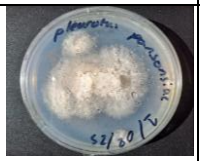
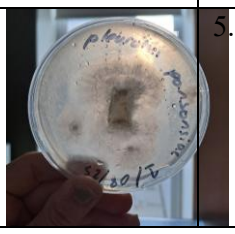
Day	Species name: *P. pulmonarius*	Size (cm)	Observa-tions	Species name: *T. versicolor*	Size (cm)	Observa-tions	Species name: *P. ostreatus*	Size (cm)	Observa-tions
1		0.8	N/A		0.9	N/A		0.8	N/A
2		0.9	Very minimal growth		0.9	Condens ation. Lowest growth among strains; no visible develop ment		0.9	Minimal growth
3	 	1.1	It has grown all around the agar wedge, including underneath.		1.2	Uneven growth develop ment.		1.1	Has begun to grow dominantly in one direction
4		1.6	Maximum growth increment observed so far		2.2	Greatest size increase for this strain so far.		1.4	Irregular growth continuing
5		3.8			4.3	Layered spherical growth in rings known as fairy rings. Even growth an indicatio n of good health.		2.7	Growth has reached paper piece.

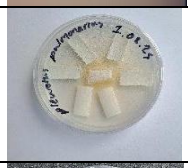
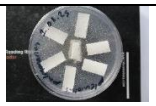
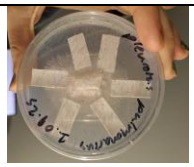
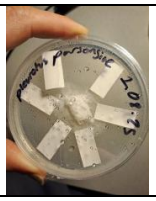
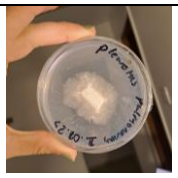
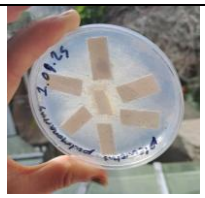
Day	Species name: *P. pulmonarius*	Size (cm)	Observations	Species name: *T. versicolor*	Size (cm)	Observations	Species name: *P. ostreatus*	Size (cm)	Observations
6		4.2			4.3	Growth covering all 6 paper pieces. Discolouration of paper visible		3.5	Though irregular, displaying healthy tomentose growth
7		5.8			5.7			4.2	Fairy rings have begun to develop
8		5.9			6.1	Growth has begun to lose density		5.2	Growth has become more regular.
9		6.2			7.4	Slower growth		7.1	Very healthy display of Rhizomorphic growth morphology
10		6.5			7.8	Pale appearance of myceliu m suggests there have been unfavour a-ble environ-mental changes.		7.2	Steady size increase

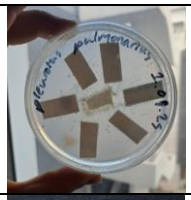
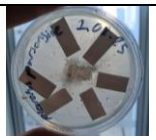
Day	Species name: *P. pulmonarius*	Size (cm)	Observations	Species name: *T. versicolor*	Size (cm)	Observations	Species name: *P. ostreatus*	Size (cm)	Observations
11		6.5	Star		8.5	Growth has continued		7.5	Slower growth rate than the first few days
12		6.5	Has stopped growing		8.7	Plate is fully covered in sparse myceliu m growth		8.00	Tomentose
13		8.2 cm	At largest bit		8.7	No longer increasing in size		8.2	
14		8.9				Experiment concluded		8.3	Reached 14 days in healthy state.

Repeat of *P. pulmonarius* and Control groups.

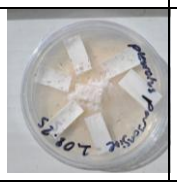
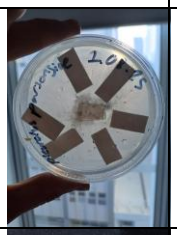
Day	Species name: *P. pulmonarius*	Size (cm)	Observa-tions	Species name: *T. versicolor* control	Size (cm)	Obser-vations	Species name: *P. ostreatus* Control	Size (cm)	Obser-vations signs
1		0.8	N/A		0.7	N/A		0.8	N/A
2		0.8	N/A		0.7	Conden-sation		0.9	Fluffy edges.
3		2	Fluffy hyphae visible		0.7	Conden-sation		0.9	Condens ation
4		2.6	Contact with first piece of paper		1.3	first signs of growth		1.5	Very small hyphal growth visible
5		3.2	Even growth		3.0	spotted satellite		1.7	Small satellite growth
6		4.9	Healthy Rhizomor phic morpholo gy.		8.4	experi-ment conclu-ded spotted growth across whole dish		2.3	Heavy condensa tion
7		5.0	No noticable change					2.7	Satellite growth

Day	Species name: *P. pulmonarius*	Size (cm)	Observa-tions	Species name: *T. versicolor* control	Size (cm)	Obser-vations	Species name: *P. ostreatus* Control	Size (cm)	Obser-vations signs
8		5.2	Growing upwards					3.0	Uneven but increasing density
9		5.4	Fairy rings visible					3.5	Cord like white hyphae
10		6.5	Condensation					7.2	
11		7.5						5.0	
12		8.0	Has stopped growing					5.6	Has continued to grow out in irregular pattern.
13		8.4	At largest bit					5.6	Mould

Day	Species name: *P. pulmonarius Control*	Size (cm)	Observations/signs of degradation	Species name: *P. pulmonarius Nutrient mix*	Size (cm)	Observations/ signs of degradation	Species name: *P. ostreatus*	Size (cm)	Observations
1		1.2	N/A		1.3	N/A		0.8	N/A
2		1.3	N/A		1.3	no visible development		0.9	Fluffy growth
3		1.4	Weak growth		1.5	Uneven growth development.		1.1	Heavy condensation
4		1.5			1.7	Greatest size increase for this strain so far.		1.4	Gradual growth
5		2.0			1.8	Layered spherical growth in rings known as fairy rings. Even growth as indication of good health.		2.7	Appears to be moving towards the paper
6		2.2	Increasing growth rate		4.1	Growth covering all 6 paper pieces. Discolouration of paper visible		3.5	
7		3.6	Thick hyphae		5.9			4.0	
8		4.1	Healthy White Concentrated growth top right		7.5	Growth has begun to lose density		5.2	Pale consistent growth

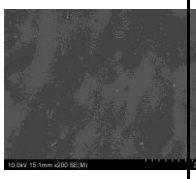
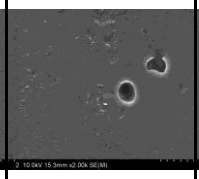
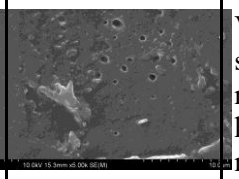
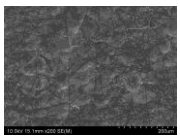
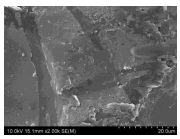
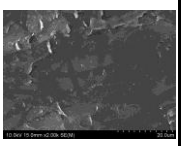
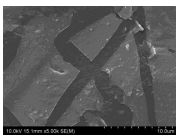
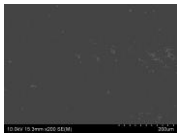
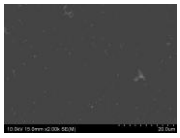
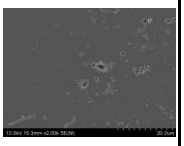
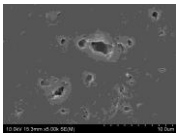
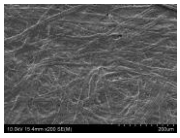
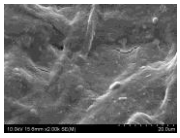
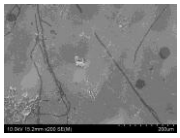
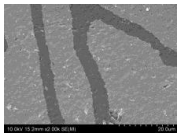
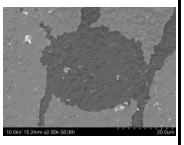
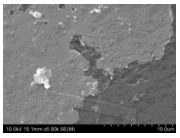
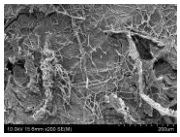
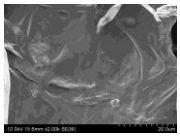
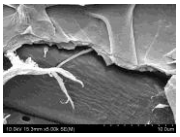
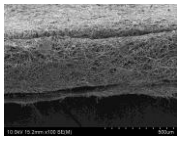
Day	Species name: *P. pulmonarius Control*	Size (cm)	Observations/signs of degradation	Species name: *P. pulmonarius Nutrient mix*	Size (cm)	Observations/ signs of degradation	Species name: *P. ostreatus*	Size (cm)	Observations
9		4.3	Mould		7.8			6	
10					8.5	Full plate		7.5	
11								8.5	Full plate

Day	Species name: *P. ostreatus* nutrient mix	Size (cm)	Obser va-tions	Species name: *T. versicolor* Paper	Size (cm)	Observa - tions	Species name: *P. ostreatus*	Size (cm)	Observa-tions
1		0.7 mm	N/A		0.9	N/A		0.8	N/A
2		0.7 mm			1 cm			0.9	Minimal growth
3		0.7			1.0			1.1	Has begun to grow dominantly in one direction
4		1.2			1.3			1.4	Irregular growth continuing
5					5			2.7	Growth has reached paper piece.

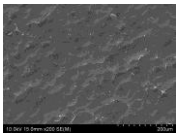
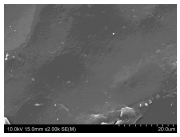
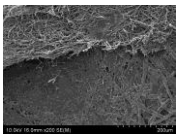
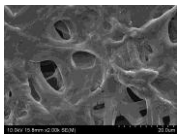
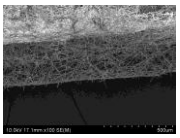
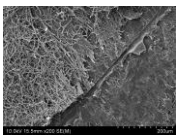
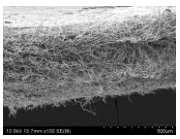
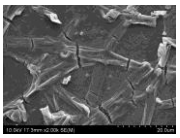
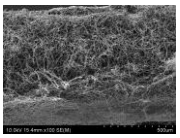
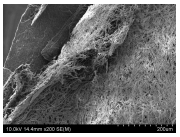
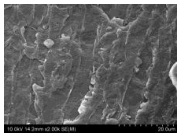
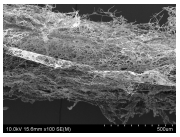
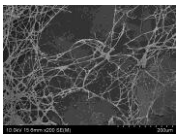
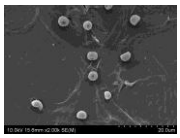
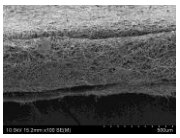
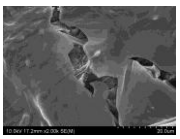
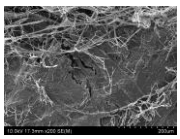
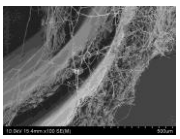
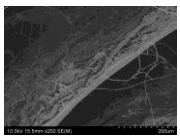
Day	Species name: *P. ostreatus* nutrient mix	Size (cm)	Obser va-tions	Species name: *T. versicolor* Paper	Size (cm)	Observa - tions	Species name: *P. ostreatus*	Size (cm)	Observa-tions
6		2.3			5.8			3.5	Very pale
7		3.4			6.9 r			4.2	Density increasin g
8		3.7			8.5	Thin coverag e		5.2	Growth has become more regular.
9		4.0						7.1	Very healthy display of Rhizomo rphic growth morpholo gy
10		6						7.2	Steady size increase
11		7.5						7.5	Slower growth rate than the first few days

Appendix C - SEM Scans

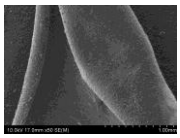
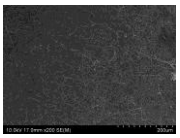
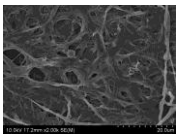
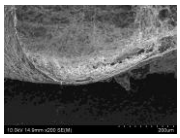
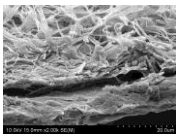
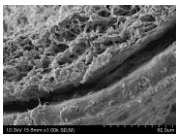
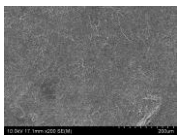
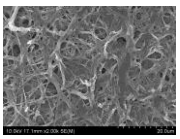
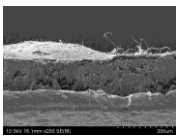
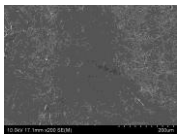
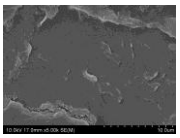
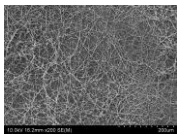
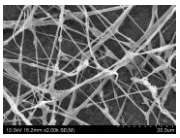
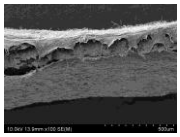
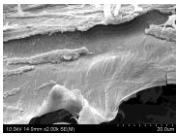
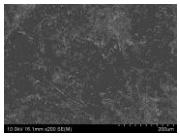
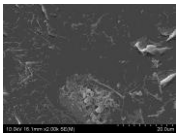
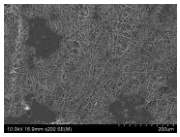
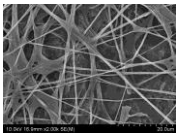
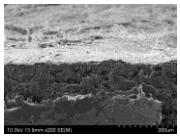
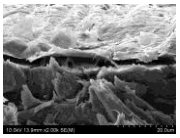
Home experiments. SEM files received September 2025.

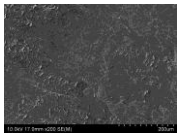
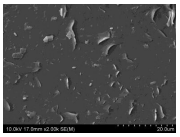
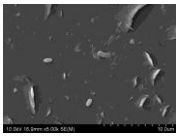
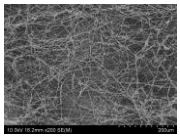
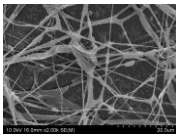
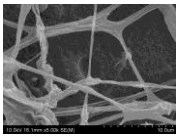
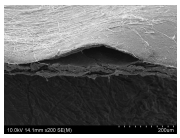
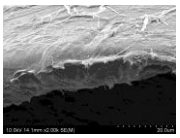
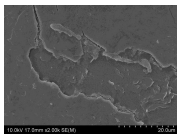
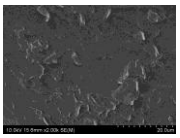
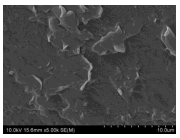
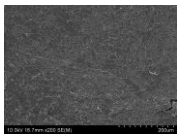
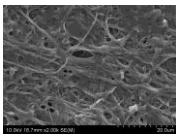
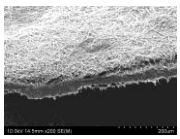
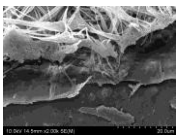
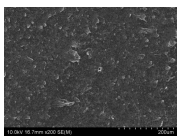
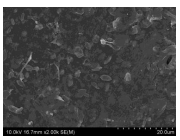
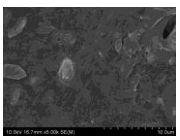
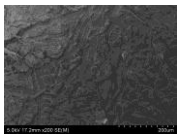
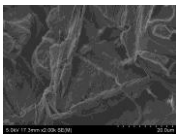
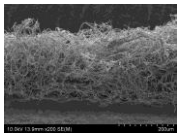
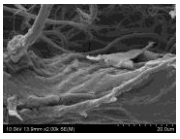
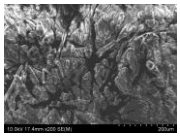
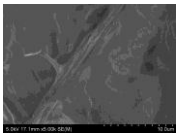
Description	Image 1	Image 2	Image 3	Image 4	Observation
P. ostreatus Surface Round 1 Washed					Very slight surface abrasion noticeable at high magnification.
P. pulmonarius Surface Round 1					Clear signs of flaking at a range of magnifications present.
P. pulmonarius 2 Surface Round 1 Washed					Minimal surface disruption
T. versicolor Surface PE* Round 2 Washed					No visible signs of degradation, appears to be a thick layer of mycelium restricting view of the surface.
T.versicolor Surface Round 1 Washed					Visible flaking.
T.versicolor Surface PE Round 2 Washed					Images 1.2 don't reveal much 3.4 could be delamination - the separation of layers
T. versicolor Cross-section Round 1					

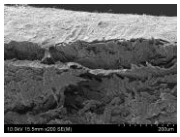
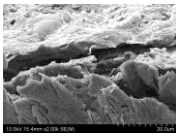
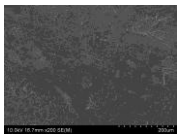
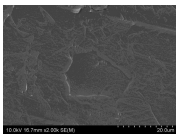
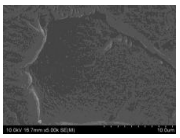
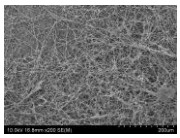
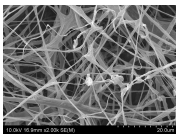
Folder two of SEM images Sent by Yuan Tao. Received September 2025.

Description	Image 1	Image 2	Fungal Strain Date of scan	Image 1	Observation
Species not specified Surface Control					Smooth surface morphology
P. ostreatus Surface Round 2			*P. ostreatus* Cross section Round 2		Only Mycelium visible
P. pulmonarius Surface Round 1			*P. pulmonarius* Cross section Round 1		Only Mycelium visible
P. pulmonarius Surface Round 2			*P. pulmonarius* Cross-section Round 2		Image of surface shows cracking however this is most likely due to the high temperatures during scanning
T.versicolor Surface PE Round 2			*T.versicolor* Cross-section PE *Round 2*		Flaking and delamination
T.versicolor Surface Round 1			*T. versicolor* Cross-section Round 1		
T.versicolor Surface Round 2			*T.versicolor* Surface Round 2		

Sapro-Tech Round 3 experiments. SEM Images received February 2026

Image description	Image 1	Image 2	Image 3	Observations
T. versicolor Surface Bin liner				No observations to be made.
T. versicolor Surface Bin liner				No signs of degradation
T. versicolor Cross-section Paper cup				Image
T. versicolor Surface Paper cup Washed				Flaking visible at multiple magnifications
T. versicolor Surface Paper cup Washed				Interesting insight of mycelium growth
T.versicolor Surface Paper cup				This could be delamination however it is hard to tell.
T.versicolor Surface Paper cup Washed				Minimal flaking
P. ostreatus Surface Paper cup				Mycelium growth is blocking view of surface
P. ostreatus Cross-section Paper cup				Separation of layers and flaking.

P. ostreatus Surface Paper cup Washed				Light flaking
P. ostreatus Surface Paper cup				No observations of paper surface to be made.
P. ostreatus Cross-section Paper cup				Best example of delamination visible across all strains
P. ostreatus Surface Paper cup Washed				Flaking
P. ostreatus Surface Plastic bin liner				Only shows Mycelium network.
P. ostreatus Plastic bin liner Cross-section				Two distinct surfaces visible, the Mycelium growth and the Bin liner.
P. ostreatus Surface Plastic bin liner Washed				Flaking visible at multiple magnification
T. versicolor Surface Paper cup				
T. versicolor Cross-section Paper cup				Mycelial Network.
T. versicolor Surface Paper cup Washed				Poor image quality

T. versicolor Cross-section Paper cup				Delamination
T. versicolor Surface Paper cup Washed				Flaking
T. versicolor Unwashd Surface Paper cup				Mycelium-

Appendix D – Physical workbook

Week 1 experiments – no laminar flow so using heat and hydrogen peroxide to create a sterile workspace



Straw is a fantastic substrate for growing fungi due to its high cellulose content it is also easy to pasteurise in bulk which makes it suitable for begginer cultivators. Due to discussion on the plausibility of the mushroom spore coffee cup sleeve I will primairily be comparing 5 readily available fungal strains from Sporeshift nz. This Nz based company also provides a basic lab equipment set up which I will be purchasing in order to work fully sterile when growing my mushroom strains. Until this arrives I will work on my literature review and test out integrating cultivated oyster mushroom grains (Pleurotus Ostreatus) into a glycerol + gelatin biomaterial

30/07/2025 — Coffee grounds + gelatin

29/07/2025 — straw + glycerol + gelatin — 19.5°

7/07/2025 — mycelium + mould; just mould; no growth

Sporeshift Nz

Grey oyster = pleurotus ostreatus = 22.50 → less well known for ability to decompose polyethelene

Cladosporium is less readily available because it's considered a mould genus and has allergenic properties [X]

pleurotus ostreatus can be bought from sporeshift as can Lentinula edodus - no direct evidence found for nzs ability to.

Nz oyster is the only other one RN and Turkey tail. I will start with these and work from there





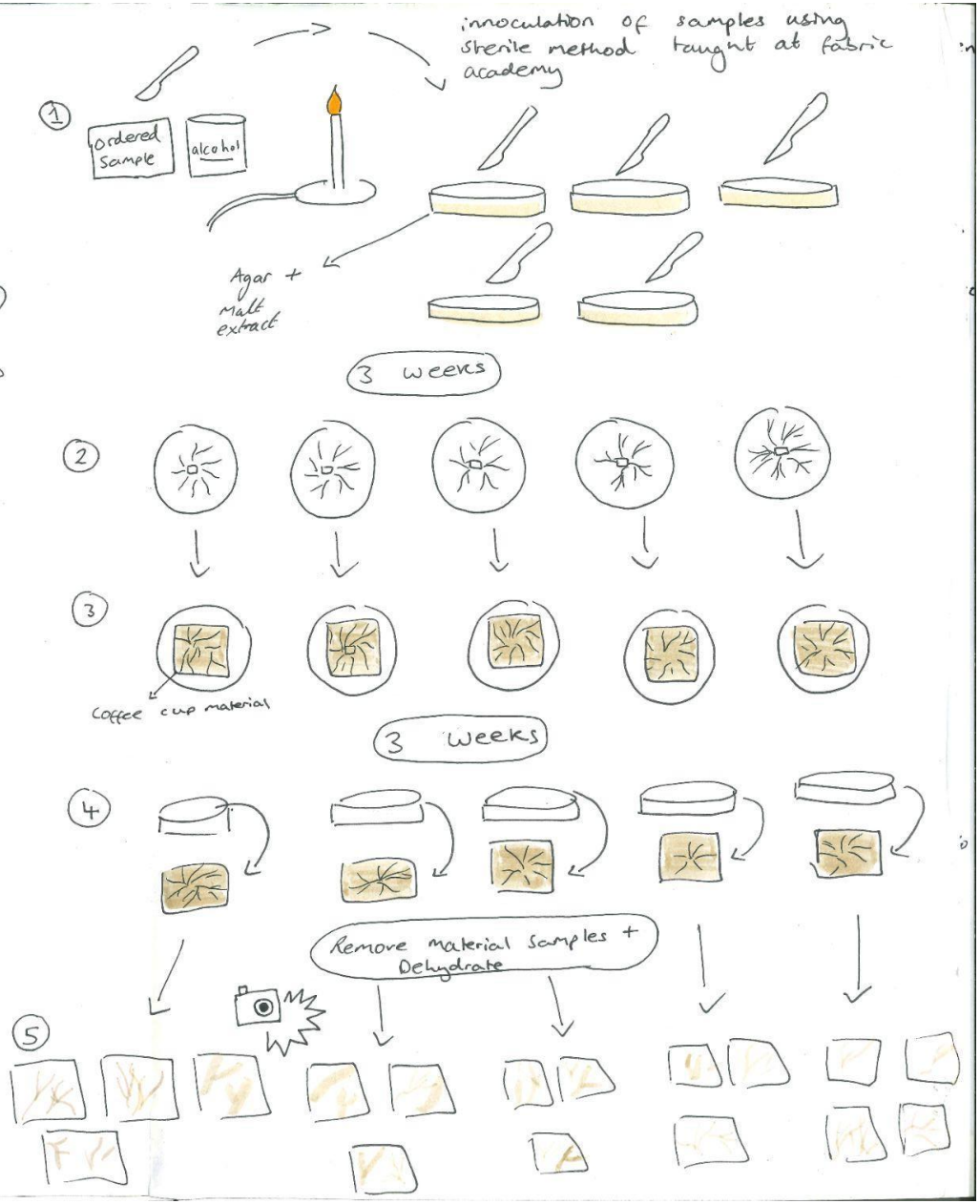


Price list + equipment sourcing

Fungus	plastic types degraded	sourced from	price
Pleurotus Ostreatus	PET, LDPE green polyethelene	Sporeshift NZ	$22.50
Pleurotus pulmonarius	PET, polyethelene	sporeshift NZ	$22.50 p kg
Lentinula edodes	DEHP (plasticiser)	sporeshift or 3 petals biotech	$22.50 p cultured plate (skip step 1)
Stropharia rugosoannulata		sporeshift	$40 for large bag (way too much 26
Cladosporium		Landcare research	cultures can be requested for research
Agar plates		sporeshift	20 pack $36.00
steralising alcohol		Surgical supplies	500ml $14.50
DIY bunsen burner for steralising		Bunnings Warehouse	$50
Autoclave/ pressure cooker			Second hand $20
Glass bottles		Labwarehouse	$1.09

Total: $229.09

Take photos using SEM to identify which fungal strain is most successfull at degrading the polyethelene lining found on coffee cups →



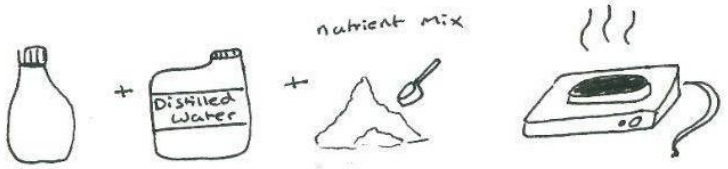
Experiment plan

Materials

- Sterile petri dishes with MEA (malt extract agar) or PDA agar
- Sterile cup fragments cut into 1-2 cm squares
- Mycelium culture
- Parafilm or grafting tape
- Alcohol spray 70%. isopropyl alcohol

1. Sterilize the paper cup pieces. by pressure cooking them at 121°C for 15-20 minutes
   - Or soak them in 70% ethanol

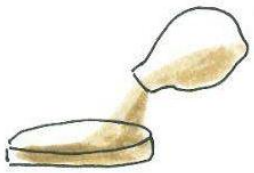
2. Prep agar plates
   - Mix 1 litre of distilled water into  scientific bottle
   - stir in 5 grams of nutrient mix
   Or desired amount following table below



- Allow ingredients to fully dissolve whilst avoiding boiling
- cover flask with foil and pressure cook at 15psi for 30 minutes
- Allow to cool to 50-55°C

3. Using a bunsen burner which has a sterile zone around it pour agar plates ensuring tip of bottle has been held in flame to sterilize initially.





Allow to cool to harden →



experiment plan p.g 2



mycelium dish

Scalpel



ethanol/ isopropyl



Bunsen burner



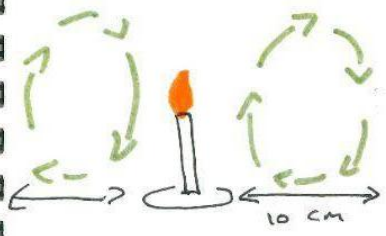
Dish containing agar

① Steralise the scalpel by holding it in the ethanol and then placing it in the flame.

② Wait a couple of seconds before dipping the tip of the scalpel somewhere in the dish which is not containing mycelium and listen for a hissing noise

③ Cut a small (0.5mm x 0.5mm) square of mycelium out of the dish, open the dish containing agar, place in this dish and seal with tape.

④ Make sure you are working within the sterile radius of the bunsen burner



Observation table example:

Day	photo	cm wide	written observations
1			
2			
3			
4			
5			
6			

Initial colonization takes 2-4 days

full plate colonization takes 7-14 days

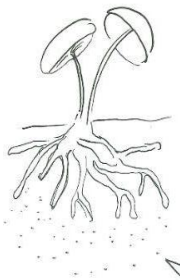
Signs of degradation takes 2-4 weeks

Trametes versicolor has been shown to biodegrade low-density LDPE

Laccase enzymes produced by T. versicolor was able to degrade LDPE strings

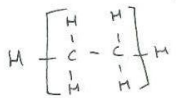
Laccase is an oxidative enzyme which breaks down complex polymers via mono-electronic oxidation

decomposition is measured by weight loss, I'm unsure if this would work using regular scales however I will look into buying scientific scales



Laccase enzyme





polyethethelene

↳ Chains of C_2H_4 held together by covalent bonds which means it requires a lot of energy to pull them apart

(Frances son, et.al, 2025) Are exploring the degredation of products using a Laccase enzyme as an opportunity to convert PE into bioenergy! cool

The biodegradation of polyethelene or low density polyethelene is known as enzymatic depolymerization as the enzyme breaks the polymer chain

Polyethelene (PET) terephthalate

Chioma Obeybo et.al

Chemical inertness + durability make pet a suitable material for the packaging of mineral + soft drinks.

Polymers are long chains of monomers usually bonded with ____ bonds made formed under high temperatures - they are what make it so hard to for hex bo decompose a breaking these bonds proves very difficult.

Keywords

"The enzymatic cleavage of

Frances + Son et.al 2025

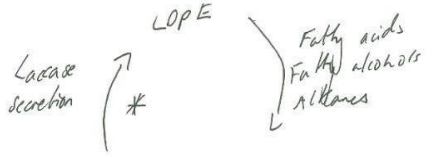
'A small laccase was identified as effective in polyethelene biodegradation known as ASLAC"

"potential for upcycling" and the process creating energy in 'green catalysis'

"maintained robust activity across various pH, temperature + solvents"

What is PE bio upcycling

ASLAC enriches the biocatalyst toolkit for the sustainable management of PE waste.



They used

The chemical structure of polyethelene.

ethelene in a process called polymerization opens up

ethelene $CH_2 = CH_2$ → $-CH_2-CH_2-CH_2-CH_2-$

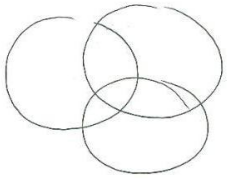
covalent bonds

"A new road map is emerging

"To establish a co-working partnership with a living organism, designers need to provide a suitable environment for growth"

look at the paper on india → they talk about systems

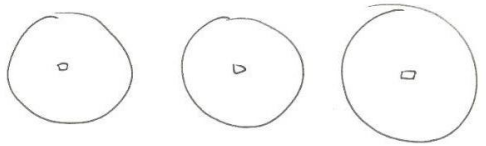
Oh i'm deep diving systems - donnela



look @ presentations

Research question in introduction - what is my research question

3 mushroom strains ordered from sporesloyt



Grey oyster pulmonarius

Day 7

NZ oyster parsonsiae

Day 1

0.8

0.9

0.1 mm growth

1 hydril moving into the agar

no signs of mould

Turkey tail versitolor

Day 1

0.9

0.9

0.0 mm growth

- What is the coffee cup 2 pages
- Label each sample make taste
- moving towards bioprocess + biomaterials
- Heidi

