Exploring Materials to Reconcile with More than Human Worlds

by

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B.Arch., Bangladesh University of Engineering and Technology, 2020

Thesis Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Arts

in the
School of Interactive Arts and Technology
Faculty of Communication, Art and Technology

SIMON FRASER UNIVERSITY
Spring 2024

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Ethics Statement

Abstract

This thesis presents insights from material investigations for two ongoing projects, both of which are aimed at designing for multispecies worlds. Our ecology is continually impacted by the adverse effects of the toxicity stemming from smart devices, electronics, batteries that are running it and plastics that are encasing it. While there are ongoing and emerging researches on built environment and environmental science there remains a lag in the field of computing science especially in Human Computer Interaction (HCI). In this work, I explore materials and their making practice during three iterative phases of prototyping two ongoing Research through Design cases. The firsthand experiences from these explorations are analyzed through annotated portfolios and critical reflections, leading me to six key lessons: 1) beware of greenwash, 2) considering imperfection, 3) hustling with the machine, 4) considering nonhuman agency 5) meeting multispecies, and 6) material recomposition. Further, the investigations were guided by the more-than-human approach of designing-with that was further refined with ideas of reconciliation ecology, an ecological approach to reconciling human interventions with our environment. The thesis offers these lessons to encourage material designers to design-with material reconciliation in their everyday design practices.

Keywords: Sustainable material; Biomaterial; Biography of Material; More than Human Design; Digital fabrication

Acknowledgements

To my supervisor, Ron Wakkary, I extend a multitude of gratitude for his unwavering patience and care in guiding me. His scholarly pursuits and innovative approach to design research have left a permanent mark not only on me but on countless other students and researchers in the field. It leaves me in awe, contemplating how I was fortunate enough to find myself under his wing. I am indebted to him for continually inspiring me to evolve into a sharper thinker, a more rigorous researcher, and a more thoughtful designer. The opportunities and guidance he generously provided during my time at the Everyday Design Studio have been priceless.

I express my gratitude to Gillian Russel for her invaluable advice and insightful feedback. I am fortunate that I enrolled in one of her courses on co-creation research methods, which has significantly shaped this thesis and beyond.

My journey would not have been as smooth if I hadn’t been accompanied by my fellow graduate students at the Everyday Design Studio and Homeware Lab. They have nourished my soul with their inspiring conversations, their exchange of ideas that have become a wellspring of sustenance! Without their steadfast companionship, this journey would have been a lonely, tiring trek indeed.

And lastly, my loving family and dear friends - your unconditional love, your untiring encouragement, your steadfast presence, have been the very foundation upon which I have built my academic and personal pursuits.

Table of Contents

List of Figures

Chapter 1. Introduction

In our modern life, the essential items we use daily - smart devices, electronics, batteries, plastics - are becoming omens of an ecological apocalypse. These indispensable materials, while powering our world, are often toxic and non-biodegradable, leading to environmental degradation. It's a cruel irony that as we drive species like elephants towards extinction, we simultaneously produce pollutants equivalent to the weight of a billion of these majestic creatures. In 2017 alone, our world churned out 8,300 million metric tonnes of plastic, with a staggering 58% ending up in landfills, 24% incinerated, and a mere 9% recycled (Geyer et al., 2017). Projections suggest that this figure could skyrocket to 12 billion tons by 2025 (Alqattaf, 2020).

In this face of this ecological crisis, researchers in the field of Human-Computer Interaction (HCI) are shifting their focus from human-centered design to a more-than-human centric design (Clarke et al., 2019; Forlano, 2016, 2017; Wakkary, 2021). This approach seeks to mitigate ecological harms throughout the life of a system and promotes multispecies cohabitation when designing technologies in urban ecology. This shift necessitates a rethinking of materials, with a focus on biomaterials for designing these technologies.

The use of biomaterials is being researched in various industries including industrial design, (Hitti, 2019; Mackenzie, 2015), architecture (Mogas-Soldevila et al., 2015; Sameh, 2014; Shafique & Xiaowei, 2019) and packaging industry (Cherrington, 2023; Cohen et al., 2023; Pohan et al., 2023), and more recently in HCI (Karana et al., 2018). However, designing more-than-human centric technologies to reconcile with ecology in HCI is a relatively new approach revealing unique challenges. These technologies need to be both biodegradable and robust. They need to be designed in such a way that the electronics can be retrieved after use, and the material part can be either decompostable or be left for multispecies habitation, thus it must be biologically safe.

This thesis presents material investigations that are part of two ongoing design cases, Turner Box and wi-fi-no-tifier. The design cases are informed by Wakkary's theory of *designing-with* (Wakkary, 2021). Here Wakkary proposes concept of *biography,* which, from a more-than-human perspective, holds designers accountable for what they inscribe and leave behind (Wakkary, 2021). This fosters an awareness that should be integrated into the design process. As I navigate the material exploration of these two designs, I see the possibility to incorporate some form of reconciliation with it. Ecologists and conservationists employ *reconciliation ecology* (Rosenzweig, 2001, 2003) as a process to transform human-dominated landscapes into diverse habitats that could sustain a multitude of species. I see this as an opportunity, a way in our making and material practice to transform human domination through technology to reconciling with ecologies and multispecies that comprise our worlds. Hence, I adopt this approach in my making and material explorations alongside *designing-with.*

1.1. Two Design Cases

The two design cases are Turner Boxes and wi-fi-no-tifier. These projects stem from the collaborative efforts of Everyday Design Studio under the guidance of Professor Ron Wakkary. Assigned to a crew of current graduate students, research assistants, and Mitacs interns, these projects set varied responsibilities. While both the cases entail the development of electronic components and potential long-term deployment, I was responsible to design the physical form of the devices through an exploration of diverse materials.

The shared challenge that drew me to these projects as subjects for material exploration was their shared destiny: both were to be embedded with electronics and deployed outdoors. This presented a unique conundrum. The device enclosure needed to be both ecologically reconcilable and biodegradable, yet robust enough to protect the delicate electronics, batteries, wires, and sensors housed within. This created a friction of material temporality, where the material must degrade or decompose only after the electronics have served their purpose, or been claimed by non-human species. This delicate balance makes these projects prime examples of multispecies - or more-than-human - material interaction. In this section I will provide a concise overview of these two design projects and how they serve as contexts for my exploration of materials.

1.1.1. Turner Boxes

The Turner Boxes project, inspired by early 20th-century zoologist Charles Turner, is a network of sensing devices designed to capture moments of bee foraging nectars to explore non-instrumental human-bee interactions in urban environments (Wakkary et al., 2023). Rejecting the existing paradigm of stewardship and extraction, the Turner Boxes project asks for more-than-human and multispecies relations.

It also delves into the very concept of cohabitation, acknowledging the entanglement of non-human species within the technological environment of the urban landscape - a world of radio frequencies, electricity, and transportation. Yet, the systems and technologies we design in our cities remain stubbornly human-centric, with the interaction and relation with non-human species often an afterthought, if considered at all.

The starting point of the inspiration for the form and shape of these devices, which is intended to deploy in outdoor garden, were from Turner’s (1911) research instruments used in his color perception experiments on bees (Figure 1).

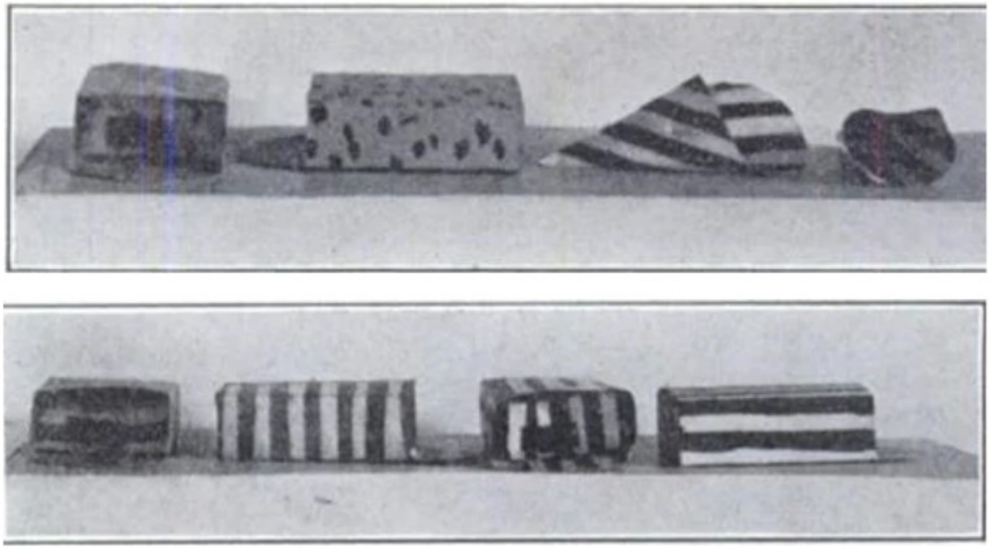

Figure 1. Various colored and patterned artifacts Charles Turner created for his experiments in 1911 (TURNER, 1911)

Unlike Turner's devices, the boxes use cameras to monitor bees' natural foraging habits. These cameras, housed within the boxes, are set to take pictures at specific intervals, guided by a machine learning algorithm. This algorithm will consider forecasted weather data such as cloud cover, humidity, flowering periods of plants, air pollution, and hourly temperatures, as these factors that might significantly affect bee foraging patterns (Wakkary et al., 2023).

My responsibilities in this project involve exploring different materials for the Turner Boxes and designing different iterations to house both electronics and wild bees. Much of this thesis is based on this project's material exploration, particularly the exploration of two shapes - rectangular and conical - for the Turner box.

1.1.2. wi-fi-no-tifier

wi-fi-no-tifier is an extension of a different project called wi-fi-no-wi-fi by using salvaged electronics and parts from its predecessor. This device, like the original, detects wi-fi networks and indicates their presence or absence in a physical form. The wi-fi-no-tifier is the afterlife practice of the wi-fi-no-wi-fi, as exploration of the designers' accountability for the technological waste left in the wake of their creation. In other words, it is the biography of wi-fi-no-wi-fi. Given the fact that electronics cannot be returned to the ground through biological decomposition, the components found a second life in the wi-fi-no-tifier.

Designed for outdoor placement in areas with limited awareness of wi-fi connectivity, it takes on a rectangular form with two-sided colored paddles to signal wi-fi presence. In doing so, it engages in an interaction with the multispecies around it, informing them of the presence or absence of wi-fi electromagnetic radiation. The housing is made from an organic composite, and the structure is supported by a skeletal frame and spike formed from PHA. The design is guided by established principles, carrying forward the more-than-human ethos of the wi-fi-no-wi-fi. My role was to shape the electronic housing and to introduce organic materials into the design. This was a crucial aspect of the project, as the wi-fi-no-tifier, unlike its predecessor, was destined to exist outdoors, so it can engage the richer presence of a more-than-human world.

1.2. Research Objective and Questions

The central objective of this thesis is to learn material and making practice, specifically focusing on how designers can craft and incorporate materials, that are to be designed for more than human worlds. The goal of this research is not to pioneer new biomaterials. Rather, to conceptualize the insights collected from my first-hand exploration, lessons that could potentially enrich the dialogues in HCI and interaction design research.

Through different phases of the material investigations, I found ways to align and deepen the ideas of designing-with with ideas of reconciliation on a material level. For example, throughout the process, I continually adjusted the material and design choices to coexist with bees, interact with other species, and consider material temporalities of degradation and endurance. However, this proved more challenging than anticipated. I encountered difficulties with each and every material. Through my hands-on exploration, I have grown to appreciate the nuances of material and craftsmanship, which I believe is essential to share with more-than-human designers.

This brings us to the main question that drives this research: **How can designing-with material reconciliation provide guidance for material practice toward more-than-human interaction design?** In addressing the question, this study makes a contribution to the field of more-than-human design (Biggs et al., 2021; J. Liu et al., 2018), multispecies design (Clarke, 2020; Mancini et al., 2016; Mancini & Lehtonen, 2018) and material-driven design (Elvin et al., 2015; Goveia Da Rocha & Andersen, 2020). This is achieved by, outlining six reflective lessons from my hands-on material exploration, which shows the shift in relationship with the material, designer and their practice.

1.3. Thesis Outline

This section summarizes each chapter in this thesis in chronological order, summarizing the focus of each chapter.

Chapter 1 introduces the topic of biomaterials for designing more-than-human centric technologies, and the challenges and opportunities they present for HCI and interaction design research. Here, I present the two design cases, Turner Box and wi-fi-no-tifier, in an attempt to reconcile with ecology and multispecies. I state my research objective and research question: How can designing-with material reconciliation provide guidance for material practice toward more-than-human interaction design?

Chapter 2 describes the theoretical and material foundations of two design cases that explore multispecies relationships in urban environments. The two design cases adopt Wakkary's designing-with theory and for my material exploration I draw ecological perspectives of reconciliation. The chapter reviews the literature on the material turn in HCI and identifies a gap in the material practice of HCI.

Chapter 3 explains my explorative design research approach, such as Research through Design (RtD) and first-person research, to investigate material practice for more-than-human interaction design. I provide data collection and data analysis methods in this chapter.

Chapter 4 explores three phases of materials for the two projects. After each phase I reflect on the challenges, insights, and implications of working with these materials.

Chapter 5 presents the lessons learned from three phases of material exploration. I identify six lessons that emerged from the material and design process: beware of greenwashing, considering imperfection, hustling with the machine, considering non-human agency, meeting multispecies, and material recomposition.

Chapter 6 discusses about my research question, methods, and limitations. I address my research question by summarizing the lessons as guidance for material designers. I reflect on the first-person design research approach and the challenges and benefits of speaking for the nonhuman actors in the design process. I acknowledge the limitations of the design cases, the multispecies interaction, and the first-person bias.

Chapter 7 concludes the thesis and proposes future research directions and questions for HCI and sustainability.

The design cases and material explorations that form the foundation of this thesis were the product of extensive collective decision-making among the research members of Everyday Design Studio. Through a process of feedback and iteration, our collective vision takes shape. In conveying the narrative journey of this thesis, I find myself oscillating between the singular "I" and the plural "we". When I employ the first-person singular, I aim to share my direct, intimate experiences with the materials and the lessons learned therefrom. Yet, there are moments where the collective voice of "we" emerges, as I recount the shared decisions made within the studio.

Chapter 2. Background and Related works

The contexts for the material investigations are two design projects that are inquiries into multispecies relationships in urban environments. In this particular section, I provide a description of their theoretical underpinnings. Informed by these theories, I aim to draw from ecological perspectives to seek literature on reconciliation, which further guide me in my material exploration phase. I then describe the growing body of research works on the role of materials in HCI. Finally, I identify the gap of HCI for interaction with multispecies ecology.

2.1. Designing-with: Theoretical underpinning of the cases

In this section, I present the theoretical framework that forms the foundation of the two ongoing projects described in previous chapter. Both the projects are rooted in Wakkary's *designing with* (Wakkary, 2021), a broader theory of designing for more-than-human worlds. In this context, the value of effective design is determined by its contribution to the harmonious cohabitation of our worlds, where a human is no longer the sole bearer of the designer title. Instead, an assemblage of human-nonhuman designers is gathered for a more-than-human world. Wakkary proposes several concepts to portray a clearer picture, one of which is the *biography*. Wakkary's interpretation of biography diverges from and expands upon the conventional understanding of the term, which is typically associated with the events of a human life. Instead, from a more-than-human perspective, things and human designers share a biography. These biographies are not merely a collection of past events but are ongoing, dynamic, and relational. Thus, a biography is "accountable for what it inscribes and leaves behind" (Wakkary, 2021, p. 174).

Wakkary employs the well-known tale of the plastic bag, a biography intertwined with convenience and environmental injustice. Its non-degradable polyethylene essence leaving an indelible legacy of microplastics, even as we near the end of its life. Similarly, wireless technologies are ubiquitous in our urban environment, becoming part of our nonhuman, multispecies, more-than-human world. The Turner boxes and wi-fi-no-tifier projects explore these relations and other aspects of biographies to not to repeat the biography of the plastic bag. The theoretical framework thus underscores the designer's responsibility for the life and afterlife of the thing designed, fostering an awareness that can be incorporated into the design process from the beginning.

2.2. Designing-with Material Reconciliation

As we engage in the task of working with the shape and material of the electronics enclosure, we realize the necessity of selecting materials that can establish a kinship with the more-than-human ecology. This is particularly important as these devices are meant for outdoor deployment. However, upon reflection, we may ponder why we have become so distant from nature that we now seek this kinship. The places we now call home, the societies we have built, were once wilderness, marshlands, a sanctuary for a myriad of species. In the realm of ecology, the role of humankind is no less significant than that of a colonial and settler.

Indigenous scholarly work, unfolds reconciliation as a complex and contentious concept encompassing legal and political recognition of rights, the restoration of state control over territories (Hibbard et al., 2008), and a peacemaking paradigm centered on rebuilding relationships (Short, 2003). However, our focus is on an ecological approach. Ecologists and conservationists have adopted an approach of reconciliation in pursuit of conserving nature and biodiversity. Michael Rosenzweig coined the term “Reconciliation Ecology” to describe a process, a transformation of human-dominated landscapes into diverse habitats that could sustain a multitude of species (Rosenzweig, 2001, 2003). It is the redesign of rooftops (Francis & Lorimer, 2011; Rosenzweig, 2016), the enhancement of seawalls and the creation of living shorelines (Chapman & Blockley, 2009).

In the present day, human-dominated landscapes are now littered with a flood of technical artifacts, the responsibility of which falls upon the HCI designers as well. During this time of climate change and biodiversity loss, HCI designers and digital fabricators have contributed to the increased use of materials that are neither biodegradable nor decompostable. In line with designing-with theory I see the concepts of reconciliation as a starting point to reconcile and reshift the anthropocentric material practices in HCI.

2.3. Material shift in HCI

Robles and Wiberg (2010) introduced the *material turn,* a shift marked by the HCI communities' growing interest in the materiality of computation and the diminishing divide between the physical and digital realms. This shift emphasizes the increasing mediation of interaction through physical materials and the heightened importance of considering material conditions in interaction design. This trend has been reflected in the rise of smart objects, interactive systems, augmented reality, and the Internet of Things (IoT), blurring the boundaries between the digital and physical territories.

Within this shift, some HCI researchers have turned their attention to sustainability by exploring the use of biomaterials in design. This work involves the use and development of biodegradable materials (Bell, Ofer, Frier, et al., 2022; Camere & Karana, 2018) for a range of fabrication methods (Buechley & Ta, 2023; Gough et al., 2023), prototypes (Arroyos et al., 2022; Vasquez & Vega, 2019a), and frameworks (Karana et al., 2020; Pataranutaporn et al., 2018). Through their work with various living materials, HCI researchers have introduced new concepts into interaction design. For example, Dew & Rosner's (2018) ethnography study of woodshop revealed some of the unique characteristics of wood as a living material. Karana et al. (2020) proposed a design framework for living artifacts based on three principles: Living Aesthetics, Mutualistic Care, and Habitabilities. Recently, Bell et al (2022) has been working with various biomaterials, bringing insights such as care, patience, and understanding to the design process. They argue that these values can help designers create more playful, thoughtful, and sustainable designs.

Furthermore, Pataranutaporn et al. (2020) have delved into the concept of Living Bits, framing microbes as bio-computers with genetic circuits functioning as biological logic gates. Additionally, there have been instances of utilizing biological structures and natural materials in HCI, such as prototyping circuit boards and enclosures for computer mice using biomaterials, (Arroyos et al., 2022) as well as designing wireless heating interfaces (Song et al., 2022) and decomposable supercapacitors (Song & Paulos, 2023) using natural materials.

Alister and her colleagues engaged with biological processes, such as the fermentation of kombucha SCOBY (Ofer & Alistar, 2023) or genetically engineering DNA and bacteria (Alistar & Pevere, 2020). Their work provides a platform for further recognizing the need to frame our relationality with nonhuman microbes. They have also explored food-grade bioplastics (Bell, Al Naimi, et al., 2022) and biomaterial made from compost (Bell, Ofer, & Alistar, 2022), which can incorporate interactive elements such as photochromic or thermochromic inks. Notably, mycelium has emerged as a promising alternative to plastic in HCI, given its growability, decomposability, and moldability (Gough et al., 2023; Karana et al., 2018; Vasquez & Vega, 2019a, 2019b; Weiler et al., 2019).

2.4. Gaps in HCI material practice

The literature points to a shift in sustainability and materiality within HCI, with emerging works exploring the living and biomaterial application and experience with the maker. However, when it comes to interaction between material and the multispecies ecology, particularly in HCI, there is yet much left to explore. I recognize a lack of tools and approaches for material practice in this field of more-than-human designs. It requires a shift in how designers approach crafting materials and their relationship with the materials.

This thesis explores materials for two design projects that transcend anthropocentrism, focusing on a more-than-human perspective. It follows the theoretical framework of designing-with, aiming to understand the necessary approach to engage with multispecies ecology. In my tactile hands-on approach of material exploration, I bring ecological perspective of reconciliation to bridge the gap in material practice within HCI. The act of making, thus, transforms into an indispensable instrument for acquiring practical knowledge and for the evolution of a theoretical perspective.

Chapter 3. Research Design and Methodology

This chapter explains the methodological choices I make as the design researcher to conduct this study. I have approached the research question primarily through practice-based explorative design research methodologies. I have engaged in two design cases to explore material practice for more than human interaction design.

3.1. Methodological Approach

My approach for this thesis is explorative design research mainly driven by curiosity and aiming at producing new knowledge within the field. The specific approach to conducting design research that I have chosen is Research through Design (RtD) and First-person research. I will explain these methods in detail in following section.

3.1.1. Research through Design

Research through Design (RtD) was initially introduced by Frayling (1994), and has since been utilized in various ways. Zimmerman et al. (2010) later defined it as a research approach that incorporates methods and processes from design practice as a legitimate method of inquiry. Described as a process in which design work is an integral part of research (Mäkelä, 2007; Stappers & Giaccardi, 2017), RtD is a practice-based method, often resulting in artefacts as concrete outcomes, in the form of prototypes. This approach is commonly employed in design research methods within interaction design (Djajadiningrat et al., 2004; B. Gaver & Bowers, 2012; Odom et al., 2016; Wensveen & Matthews, 2014; Wiberg & Stolterman, 2014).

Research prototypes play a pivotal role in generating knowledge in the field of Human-Computer Interaction (HCI), enabling observations and insights that would otherwise be unattainable. (B. Gaver & Bowers, 2012; Koskinen et al., 2013). They also allow empirical data from the real world to become observable (Stappers & Giaccardi, 2017) and can stimulate discussion, showcase new design possibilities, and facilitate critical inquiry (Blythe et al., 2008; Boer & Donovan, 2012; Pierce & Paulos, 2014; Wakkary et al., 2015, 2016, 2022). Pierce (2014) coined the term ‘Design research artefacts’, defining them as artefacts produced in a research context and living in it, rather than as commercially available products. Design research artefacts often serve to extract and abstract knowledge at a higher level of research contributions (B. Gaver & Bowers, 2012; Löwgren, 2013). Artefacts such as Turner Boxes and wi-fi-no-tifier are drawn from the concept of “Material Speculation” (Wakkary et al., 2016). Material Speculation utilizes actual and situated but counterfactual artefacts in the everyday world as a site of critical inquiry, as a way of critically exploring and questioning possible, and preferable futures.

Researchers utilize RtD for doing philosophy through design (Encinas et al., 2020; Hauser et al., 2018; Wakkary et al., 2018) serving as a meeting ground for diverse perspectives and disciplinary backgrounds, advocating for innovative approaches to scholarly research. The field has recently begun to recognize the value of detailed processes as forms of knowledge-making, shifting the focus from finished artifacts and designs to the journey of their creation (Desjardins & Key, 2020; Gatehouse & Chatting, 2020). My work aligns with this trend, taking a first-person research approach and exploring material and making practice. I also employ annotated portfolio, (B. Gaver & Bowers, 2012), a recognized method for analysing and communicating knowledge contributions in the context of RtD.

3.1.2. First-person research

In this thesis, the research was centered on hands-on material exploration, involving a variety of basic experiments with materials. The approach emphasizes understanding materials through direct experience, rather than purely analytical means, in order to grasp their behavior, characteristics, and unique qualities. This understanding is essential for effectively utilizing and integrating materials into the specified two projects. Thus, this research adopts a first-person research perspective, prioritizing my first-hand experiences as a form of knowledge inquiry. This thesis is not about user studies, deployments, or interviews. It is a critical process of reflecting on the actions. This reflective process is often cyclic and progressive, encompassing both "reflection-in-action" and "reflection-on-action” (Schön, 1983).

In the field of Human-Computer Interaction (HCI), there is a growing interest in first-person approaches like autoethnography (Cecchinato et al., 2017; Lucero, 2018; Spiel, 2021), autobiographical design (Desjardins & Ball, 2018; Neustaedter & Sengers, 2012), micro-phenomenology (Prpa et al., 2020), design memoirs (Devendorf et al.,

2020) and more. These approaches, as suggested by Wakkary (2021, p. 248), can shift the designer’s perspective, transforming them from an outsider to an insider, which I find instrumental for my work toward a more-than-human world.

These approaches are descriptive, revealing the mundane, the intimate, the often overlooked aspects of design practice. In a survey of autobiographical design, Desjardins and Ball (2018) offer three recommendations for researchers: 1) strive for sincerity, honesty, and transparency, 2) acknowledge and respect the collaboration and authority of all actors involved, and 3) be inventive and creative in addressing tensions, especially in reporting on projects. In line with these recommendations, I provide a detailed description of each material and address the challenges and failures encountered through reflections in each phase of exploration, which ultimately contributed to the main findings of the research.

3.2. Research Method

In the following section, I detail how I collect the data and gather my reflection from my exploration and first hand experience. Later I describe how annotated portfolio served as an analytical tool to organise the reflections, extract theme and conceptualize them into a set of lessons.

3.2.1. Data Collection

In the span of two years, I have immersed myself in two design projects, a journey that has yielded a rich collection of data for my research. The process of design and fabrication was meticulously documented - through images, videos, design notes, 3d models and various phases of the prototype have constituted a comprehensive chronology of my experience. The primary source of data was images, snapshots taken at different stages of the development process. Design notes, sketches, meeting notes, and 3D models, provided supplementary data, adding depth and detail to the instances that would later form part of my analysis process in the chapters to come.

This data is stored on my personal computer and in a Dropbox project file, shared with the project team members. Later, I use Miro, a virtual tool, to organize this data into an annotated portfolio. The process of this organization is detailed in the following section.

3.2.2. Data Analysis

Annotated portfolios, a method of juxtaposing designs to create a systematic body of work, allows for the examination of similarities and differences in the works presented. It provides a means to capture the nuances that are often difficult to express in written text (B. Gaver & Bowers, 2012). Gaver and Bowers propose that carefully articulated annotations can communicate a design from a very specific perspective, thus creating a more generalizable theory, legible to a wider audience. Especially within Research through Design, a research field which generates knowledge through the act of designing (W. Gaver, 2012), understanding the dialogue between the designer and their prototype could provide valuable insights.

The goal of this thesis, as stated earlier, is to learn the material practice for more-than-human interaction design through first-hand experience. Thus, there is a need to generate a comprehensive understanding of the materials and their interconnectedness, an understanding that has its origins in the details of each material (e.g. the tools and materials used, competencies as a designer, etc.). The utilization of Annotated Portfolios facilitates the attainment of this comprehensive perspective on the materials.

Figure 2. Screenshot of the Miro board

By laying out all the materials in the portfolio, it helped me to critically reflect back to my actions and analyze common themes between different phases of explorations. The annotated portfolio consists of a mix of images from different stages of material making and ending, with screenshots from the 3d drawing and softwares. The selected images were organised in a table in Miro board (Figure 2). While organizing the research data, annotated portfolio was an analytical strategy, extracting themes from the actions and explorations involving materials. These themes were expanded into descriptive sections of reflective lessons I learnt.

3.3. Summary

In this chapter I described the research approach as explorative design research using Research through Design (RtD) and First-person perspective. These methods allowed me to generate new knowledge through design practice and first-hand experience, and to articulate the perspectives of the nonhuman actors in the design process. I then explain how I collect data from the different iterative phases of material exploration for the two ongoing projects and analyze them using annotated portfolios.

Chapter 4. Material Explorations

This chapter is divided into three phases of material explorations, each delving into different design forms and projects. I begin with the materials explored for the project 'Turner Box' in the first section, specifically focusing on the rectangular box design. Here I describe Jute fibre-ecopoxy composite and plywood –bamboo prototype. The second section is devoted to describing the other shape, the cone, where I try gypsum and corn based organic material. Lastly, I discuss the explorations for the project 'Wifi-no-tifier' in the final section, where I apply a different recipe of the corn based one. Each section offers a detailed account of the actions and reflections derived from the exploration.

Although the chapter is structured in distinct phases, it does not imply that the exploration followed a linear, unambiguous process. On the contrary, it was a circular process, heavily reliant on iterations and feedback. This is also visible in the way I choose and switch between different materials. While the aim was to explore bio-based and organic materials and to avoid synthetic materials, the functions of the projects and the shapes also dictated the material choices.

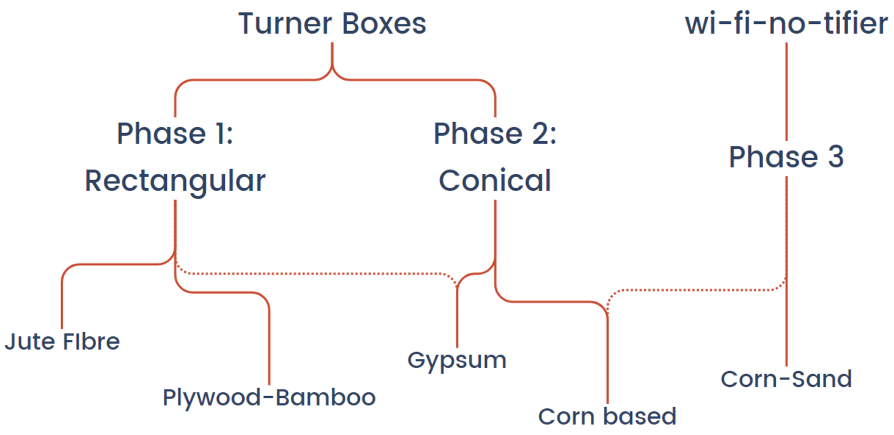

Figure 3. Overview structure of the Material Exploration Phases

For example, the Turner Boxes were designed to interact with bees, which later led to the incorporation of bee nests, in a cohabitation with technology. In this case, the material choices were governed by the need to be bee-safe, leading to the use of materials like bamboo and bee bricks, modeled with gypsum. Furthermore, since the shape of the Turner Boxes was inspired by the rectangular and conical instruments of Charles Henry Turner, the materials used to fabricate the rectangular forms, such as plywood, were chosen for their suitability. Similarly, for the conical forms, gypsum was preferred due to the ease of mold-making.

From Phase 1 to Phase 2, the exploration became clearer regarding the camera electronics and the required space, also leading to the introduction of material temporality. This, in turn, prompted the exploration of food-grade materials with a 3D ceramic printer. Phase 3 continued this exploration with the wi-fi-no-tifier, but with a molding technique, as the shape reverted to a rectangular form, eliminating the need for complex 3D printing.

Throughout this process, there was a continuous interplay between the materials and observations, with insights from one phase influencing the direction of others (Figure 3).

4.1. Phase 1: Rectangular Turner Box

The exploration journey begins with Charles Henry Turner's rectangular box design. Initially intended for holding a camera and observing bee activity, our design team decided to place the box in our backyard as a potential meeting point for human and bee interactions. After subsequent iterations, I realized that bees do not require a landing platform. Instead, I repurposed this feature for shading the camera. To support cohabitation later this phase, I incorporated a bamboo nest for bees, resulting in two plywood boxes, with the inner one serving as an electronics holder and fitting inside the outer one (Figure 4).

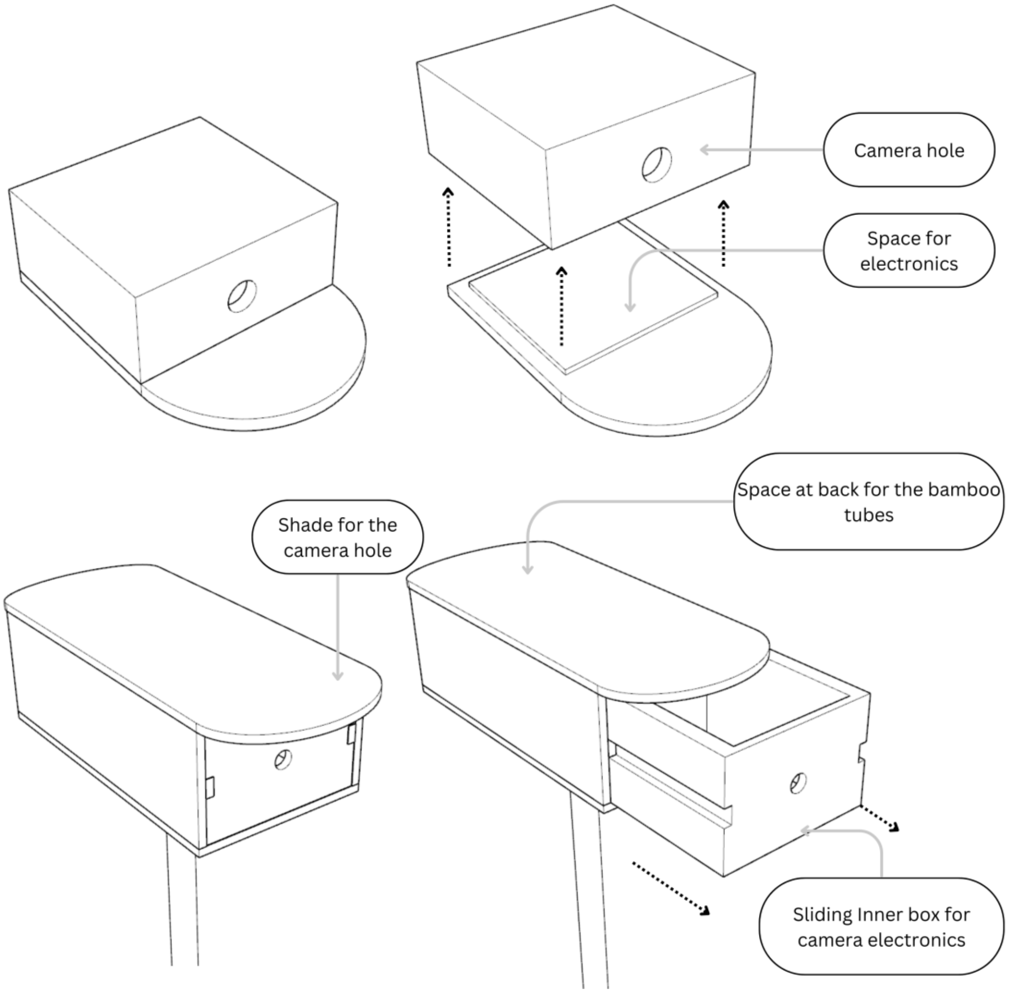

Figure 4. Initial design of Turner box as a camera holder (top); Later iteration of Turner box with a sliding inner box for camera electronics (bottom)

In the following sections, I provide details of the materials I explored in this phase and reflections from my explorations.

4.1.1. Jute fibre composite

Jute fibers, derived from the stem of jute plants primarily grown in India and Bangladesh, are widely used in the packaging industry and for producing products like bags, rugs, mats, and clothing due to their high stiffness and strength-to-weight ratio (Sarkar & Sengupta, 2015). Jute products can be environmentally beneficial, as jute plants enrich the soil with micronutrients that maintain soil fertility (Suriya & Sangeetha, 2023), absorbs CO2, and emits O2 (Islam & Ahmed, 2012). However, the retting process of jute can negatively impact water quality due to the release of chemicals and organic matter (Ali et al., 2022; Majumdar et al., 2019). There is ongoing research exploring alternative retting methods, such as dry retting, to mitigate these environmental impacts (Chakrabarti et al., 2022). Despite this, the environmental impact of jute production is considered lower than that of synthetic fibers (Gonzalez et al., 2023).

During the fabrication phase, jute fiber requires a stiffener or binder agent. In my search for biobased materials, I use two types of resin: ecopoxy and pine resin. Below, I will describe the fabrication process separately for each of these resins.

Ecopoxy

Epoxy is a synthetic resin that has become widely popular in a variety of applications, including coatings, adhesives, and composites. In search of a biobased alternative, I found several options online, including Naturepoxy, Ecopoxy, Entropy Resin, Bio Epoxy, and Fairpoxy. I chose to work with Ecopoxy due to positive reviews and availability. Ecopoxy is a Canadian farm-based company committed to creating biobased epoxies from renewable resources[1].

To create fiber composite parts, I first used the hand lay-up or hand laminating method, followed by compression molding to ensure that the resin was equally distributed. Compression molding is a process in which molding compounds are formed and cured, usually in metal molds, under high pressure and often under high temperature. I used plastic molds to create the fiber composite parts. However, the mold became stuck and impossible to demold without destroying it. To solve this problem, I designed a mold with multiple parts (Figure 5) and layered the fiber on top. The result was much better and easier to demold. Overall, the process turned out to be more sequential, with a focus on how to set up the molding compound during designing and preparing technical drawings of the mold.

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[1] https://www.ecopoxy.com/pages/about-us

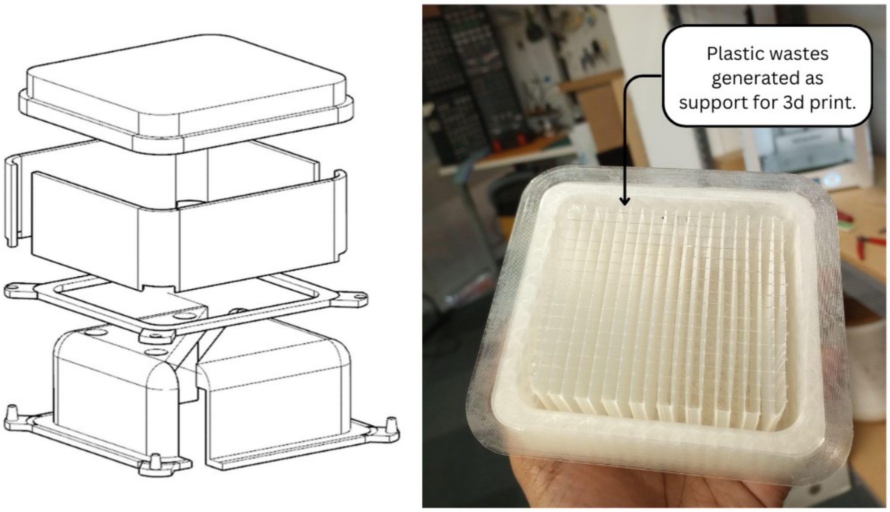

Figure 5. Isometric exploded drawing of how the mold parts are assembled (left); 3d supports generated on the other side to achieve smoother casting surface (right)

It is essential to consider how the molds will be 3D printed because the surface that the jute fiber ecopoxy will be applied to needs to be smooth. One of the best practices to keep the surface smooth is to avoid printing any supports on the surface that will interface with the jute fiber composite. However, achieving this can be challenging, and I often had to print the molds upside down to avoid generating plastic supports on the casting surface (Figure 5). This resulted in a lot of plastic waste.

While fabricating the rectangular Turner Box, I began to question the eco-friendliness of ecopoxy. I wanted to know how much of it was biobased and how it would biodegrade or decompose. However, it was challenging to find any peer-reviewed publications or scientific work on ecopoxy. After reviewing the material datasheets of different ecopoxy products, I found that they typically contain around 12-32% biobased content, which is still petroleum-based (*Biopoxy Technical Data Sheet*, n.d.; *UVpoxy Technical Data Sheet*, n.d.). Due to their chemical structure and resistance to degradation by microorganisms, these products do not easily break down in the environment. The additives and compatibilization used to optimize the properties of products like ecopoxy make it difficult to biodegrade by affecting the hydrophilicity of the polymer and enzyme activity (Meereboer et al., 2020).

Pine Resin

In search of an alternative to synthetic resin, the prominence of pine resin emerged as a dominant choice. Derived from pine trees, this natural resource offers a compelling substitute to its artificial counterpart. Pine resin has garnered widespread favor across diverse industrial sectors, such as adhesive, coating, printing inks, soap production and in medicine.

The extraction of pine resin is rather a questionable process. The process, known as tapping, involves removing the bark of a living tree and applying a chemical stimulant to the wounded exposed surface to promote the flow of resin. This process is similar to pearl harvesting. Just as pearls are harvested from the tears of oysters, pine resin is harvested from the tears of trees. The extraction process for pine resin can be seen as an example of anthropocentric and human domination over nature. While pine resin may be seen as a better alternative to synthetic resin, unsustainable harvesting and extraction practices can contribute to climate change, greenhouse gas emissions, and air pollution (Génova et al., 2014; Moura et al., 2023).

Although the current harvesting and extraction processes for pine resin may have sustainability issues, I found myself captivated by the inherent biodegradable essence of this substance. Recent studies have illuminated the potential of pine resin derivatives in conjunction with thermoplastic starch (TPS) for food packaging solutions (Aldas et al., 2021; Pavon et al., 2021). These blends showed increased hydrophobicity and stiffness while maintaining the ability to break down under composting conditions within a certain timeframe, indicating their suitability for biodegradable applications.

Pine resin gum powder can be used as a jute fiber composite by heating the powder until it becomes liquid, then casting it into a mold. In the exploration, a silicone mold was made using a 3D printed plastic mold, and the hot liquid pine resin was poured into the silicone mold, lined with jute fiber burlap, acting as the reinforcement material. After around 30 minutes for the resin to fully cure, the part was demolded.

I placed the rectangular box outside to test its water resistance and heat sensitivity. Several days later, during a scorching day at 35°C, I noticed that the shape of the box had become deformed (Figure 6). If I had laid the jute fiber densely, I might have been able to prevent this deformation. The temperature fluctuations between day and night caused the surface of the pine resin to become less solid, resulting in a fractured pattern that made it easy to break down (Figure 6). If there were any intricate small or thin details, they would be more likely to break down as well. The pine resin became sticky and, due to the high temperature outside, the two parts of the Turner box stuck together (Figure 6). Initially designed as a straightforward rectangular box where the top part would rest on the bottom part by gravity alone, the stickiness of the material emerged as an unforeseen factor. This experience highlights the need to rethink the traditional design process and consider the material properties when designing objects.

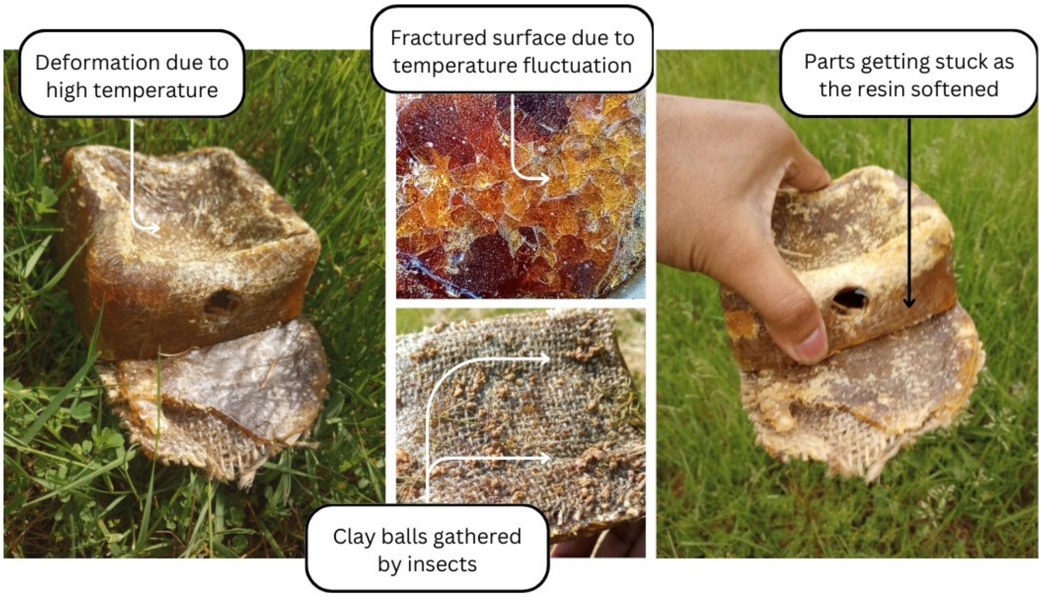

Figure 6. Annotations of the material's behavior outside environment and its interaction with bugs

I discovered something interesting when I turned the bottom part of the Turner box upside down. I found small clay balls, which are typically used by ants or other insects to build their colonies (Figure 6). Since I had left the rectangular box on the ground, the uneven woven patterns of jute fiber on the bottom part may have provided the perfect spot for bugs or ants to start building their colony. This observation later sparked my interest in learning more about and utilizing bioreceptive patterns (section 5.2.1).

4.1.2. Plywood & Bamboo

In this phase, I updated the rectangular box design by compartmentalizing it into two sections: a 100mm x 100mm compartment for camera electronics and the rest for bee cavity nest. The bee cavity nest is made up of various diameter bamboo sticks ranging from 6mm to 14mm and depths of 100mm to 200mm (Kraemer et al., 2014; Krombein, 1967). I created the electronics compartment on one side of the box and the bamboo nest on the other side using plywood. Studies have shown that Bees prefer bilaterally symmetrical vertical patterns over asymmetrical horizontal patterns (Giurfa et al., 1996; Srinivasan, 2021). Study also suggest that bees are unable to distinguish randomly patterned dots and instead prefer dots in rows and columns (Srinivasan, 2021). They can better discriminate colors in the green-blue spectrum (Giurfa & Gabriela de Brito Sanchez, 2020). I used food-grade colors to create the vertical and dot patterns and applied wax polish over it to make it weatherproof (Figure 7).

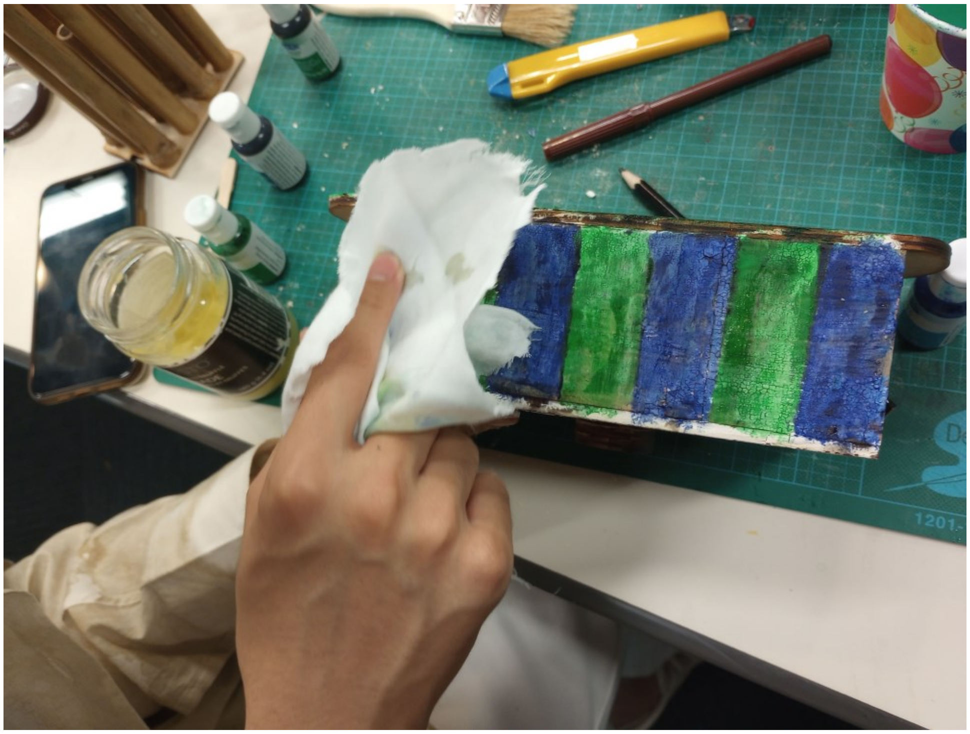

Figure 7. Applying food grade green- blue color and beeswax polish.

The bamboo reeds were sized and cleaned to ensure that there were no obstructions for the bees to entry and nest. I placed the bamboo reeds of various depths on a plywood platform, which can be slid into the Turner Box. Although it was in the middle of summer during this phase and most solitary bees select their cavity nest during spring and early summer in our vicinity [2], I placed few Turner Boxes in our backyard for observation purposes (Figure 8).

Figure 8. Turner boxes placed in backyards

Unfortunately, due to the timing of placing the cavity nests, I did not observe any bees nesting inside them. However, I did observe other species finding habitat in the nests. In two boxes, I saw spiders occupying two culms instead of bees (Figure 9). I also noticed a white cotton-like substance inside some of the reeds in one of the boxes (Figure 9). Although I had cleaned all the reeds before placing them in the box, I was curious about where this substance came from. Was something new growing inside the bamboo reeds? It turns out that this could be a type of fungal species that can grow inside bamboo culms (Schmidt et al., 2013). These observations later led us to reflect on the need of greater multispecies design framework.

Figure 9. Annotations of multispecies invasion in the culms

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[2] https://www.sfu.ca/people/eelle/bee_info.html

4.1.3. Reflections from Phase 1

I have described the first phase of my first-hand material exploration, detailing my experimentation with jute-fibre composite, plywood, and bamboo. Our design approach has evolved to integrate habitation for the bees, where I face some interesting challenges. In this section, I present the reflections that occurred during this hands-on exploration. Subsequently, these reflections will undergo analysis alongside those from subsequent phases presenting the common reflective lessons in Chapter 6.

Doing Material Research and Fact checking

In every material, there are tradeoffs to consider. At the end of the day, everyone tries to make their supply profitable. Whether it is organic, biobased, or sustainable material, I tried to verify every material through research. I looked at how it was produced, the process involved, the potential environmental impact, and the end-of-life disposal. By understanding the full biography of each material, I was able to weigh the pros and cons of each. It appeared that

Ecopoxy, with its modest 12% biobased composition, still bears the mark of petroleum's touch. Suppliers often wrap their supply in eco-friendly gourmet, capitalizing on environmental trends while concealing less savory truths. Natural materials like jute fiber and pine resin have their own farming and extraction processes that may cast shadows over their ecological impact. These considerations demand scrutiny when choosing materials for a project.

Sensing Materiality

I explored the perceptual sensory aspects of jute fiber and pine resin. By touching and handling the materials, I could sense their fragility, which is important for designers to understand the material's materiality. The imperfections of the surface and edges also influenced our design choices, limiting us to create snap-fit, friction fit, or hinge designs for product enclosures. I relied on the simplest form of design, where the top part and bottom part were held together by their weight.

As my exploration continued, I discovered that the stickiness of pine resin caused the two parts to join together, which I had not initially considered. This was a surprising way of finding out new material qualities.

Multispecies Guests or Intruders

Lastly, I encountered some unexpected guests with these materials. The fabric texture of the jute fiber allowed bugs or maybe ants to collect clay balls to start building their colony. The bamboo culms, on the other hand, were invaded by spiders and fungus, both of which can be a threat to bees. However, who am I to judge who is invited and who is not?

4.2. Phase 2: Conical Turner Box

In the second phase of the exploration, I ventured into the design of the conical shape of the Turner box. In this instance, as we are using the Turner box as a camera enclosure and accommodating a bee nest in continuation of the previous phase, I divided the conical Turner box into two parts, top and bottom (Figure 10). The bottom part houses a cavity for the nest and provides ample space to rest the camera electronics. The upper part fits like a lid with a hole for the camera lens.

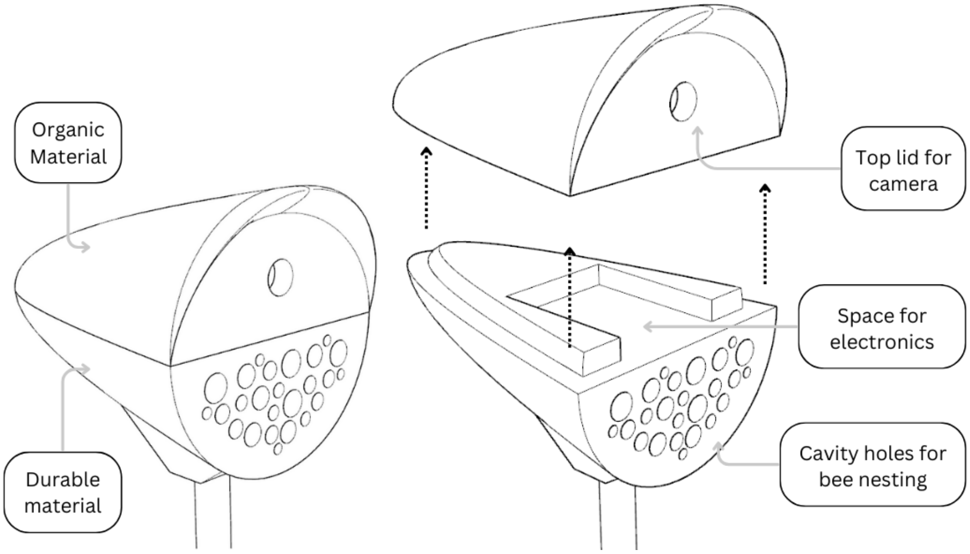

Figure 10. Conical Turner box integrated with cavity nests

However, in this phase, the temporal scale of the design in the Turner box gains importance. Since the cavity nest will contain the bee's brood cells and new bees will emerge from there, the bottom part must be made of a material that can withstand a year. Therefore, my investigation led me to consider durable materials like gypsum brick. On the other hand, since the camera will not be needed after the bee's active season and the electronics will be retrieved, the top part can be disposed of after 3-4 months. This led me to explore organic corn-based materials for the top part. In the following sections, I provide details of the materials explored during this phase and reflections from the explorations.

4.2.1. Gypsum

As we wanted to incorporate a bee brick into the design, I decided to use plaster first, also known as gypsum, which is a white powder that can be mixed with water. To cast gypsum, it needs to be poured onto a mold, and silicone is the most suitable material for making the mold. However, I skipped the step of creating a silicone mold and directly 3D printed the plastic mold to avoid wasting materials and time. Nevertheless, designing the plastic mold required more consideration to ensure that it was easier to demold. Gypsum-plaster can be fragile, especially if it is not properly dried before demolding. The drying time can be affected by the surrounding air flow and humidity. If the plaster is demolded before it is completely dry, it can crack on the process. I eventually found Jesmonite[3] as an alternative to gypsum plaster, which is more durable and resistant to water due to its acrylic mixture. The mixture ratio for Jesmonite is typically 2.5 parts powder to 1 part liquid.

I utilized visual scripting in Grasshopper to design a bioreceptive pattern on the outer surface, ensuring it was not excessively uneven (Figure 11). The maximum depth of the pattern was set to 2mm, gradually decreasing to zero along the bottom. While the primary purpose of the pattern was to facilitate moss growth, I also believed it could aid in bee visual recognition

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[3] https://jesmonite.com/

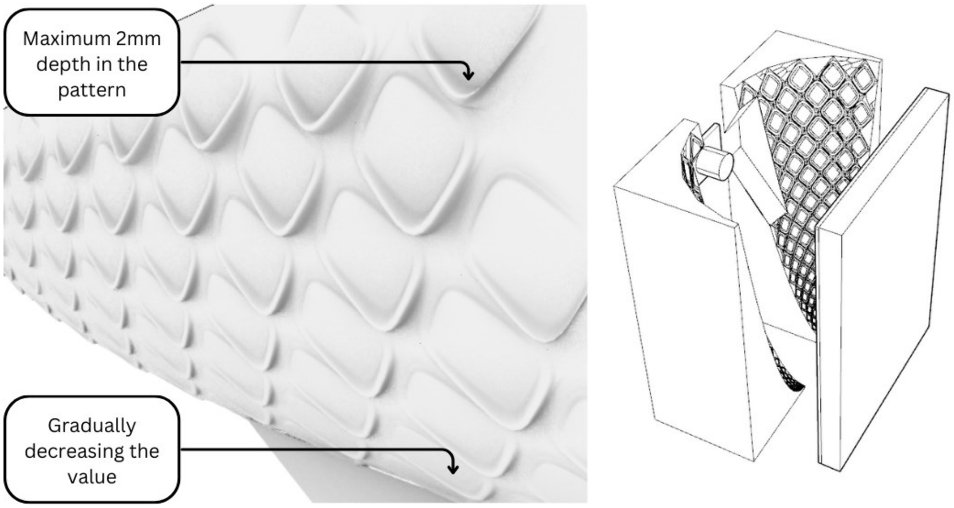

Figure 11. Applying bioreceptive surface pattern (left); 3d drawing of the multiple parts of the mold (right)

Initially, I considered using wood dowels to create the holes for the cavity nests before casting the gypsum. However, I soon realized that removing the dowels after the gypsum had cured would be challenging. As an alternative, I decided to drill the gypsum blocks. While drilling, I encountered some resistance from the material, with both the drill bit and the gypsum experiencing some wear and tear. The pressure of the gypsum powder caused the flute of the drill bit to clog, leading to the bit getting stuck in the gypsum block (Figure 12). To resolve this, I had to put in extra effort to remove the bit from the block. In subsequent attempts, I approached the drilling process with caution, taking breaks to clean out the powder and ensure the smooth operation of the machines.

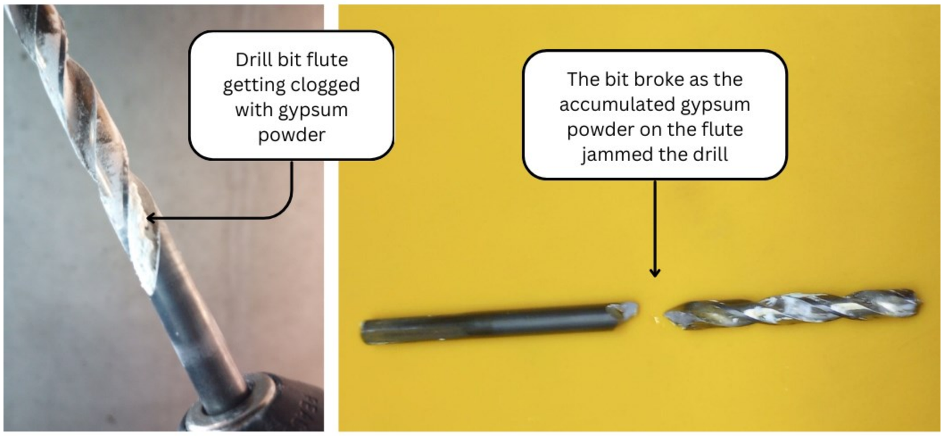

Figure 12. Broken drill bit due to the flute being clogged with gypsum powder

In agriculture, gypsum is used as a fertilizer to enhance crop growth (Gomes Araújo et al., 2018), reduce soil salinity (José de Andrade et al., 2018; Xu et al., 2023), and recover phosphate from wastewater (Jaromír Klemeš et al., 2017). It can also be combined with other fertilizers to increase its effectiveness (Beesigamukama et al., 2020). In our studio, I mixed ground gypsum with vermicompost in a vermicompost bin, adding small amounts of the mixture at a time. I added nearly 100 grams of ground gypsum to the bin over the past month. To test the compost quality, I used a "rapitest soil testing kit"[4] to measure pH, Nitrogen, Phosphorus, and Potash levels. The results showed that the pH level was suitable for most plants, the Nitrogen level appeared to be in surplus, and the Phosphorus and Potash levels were adequate. The test indicated that the addition of ground gypsum had no negative impact on the compost levels. However, the test kit may not be as reliable as a standard laboratory test. We have also been adding various organic materials to the compost, which has contributed to its nutrient-rich composition. If we were to continue to use gypsum, we would conduct a standard laboratory test to assess the calcium and sulphate levels in the compost.

4.2.2. Corn based

With the growing interest in bio-degradable materials, there has been some exploration in food-based materials, especially for 3D printing and electronics enclosures. Recently, the work of Buechley and her colleague has inspired us to delve into a few recipes for homemade play-dough (Buechley & Ta, 2023). They utilized a ceramic printer and various versions of corn-based dough to document the properties, possibilities, and challenges of 3D printing play-dough. I followed Buechley and Ta’s corn and wheat-based recipe, combining 150g of corn flour with 50g of wheat flour, 30g of vegetable oil, and 150g of vinegar to create a soft, clay-like consistency.

I first printed sample cups to experience the materiality and identify potential printing issues. One challenge I encountered, as mentioned in Buechley’s work, was the lack of a drying or heating system with the ceramic printer. Since the extruded materials were soft and wet, when one layer was printed on top of another, the softness and

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[4] http://www.lusterleaf.com/img/instruction/1601-soiltestkit_instructions.pdf

wetness could cause sagging and instability. To address this, Buechley recommended using a heater during ceramic printing. While this solution worked well for small printings, I still faced difficulties with this issue when working on larger printings.

After printing small samples, many of our curious colleagues wanted to touch and feel the objects to better understand the material. Some even noticed the faint scent of vinegar. However, a significant number of cups were accidentally broken by those who were unaware of their fragility. This led me to reconsider the thickness of the prints. In order to achieve thicker layers, I 3D printed a 3mm diameter nozzle, allowing for layers to be extended to 2.5mm. However, adjusting the nozzle size presented unexpected challenges, leading to a complex interplay between material, hardware, and software elements in the printing process.

I adjusted the G-code settings of the 3d print using a slicer software, relying on trial and error to find the appropriate settings for corn printing. One key difference with plastic printers I discovered was the need to ensure that the extruder was continuously printing without stopping from one point to another, using a spiral direction to reduce the number of pauses in a single path (Figure 13). Otherwise, there could be improper printing on the surface (Figure 13) due to material dragging when the extruder paused and moved back. Figure 13 also demonstrates how printing in a spiral direction actually reduces the number of pauses in a single print. In the case of ceramic printing, the fewer the starting and ending points, the better the print result.

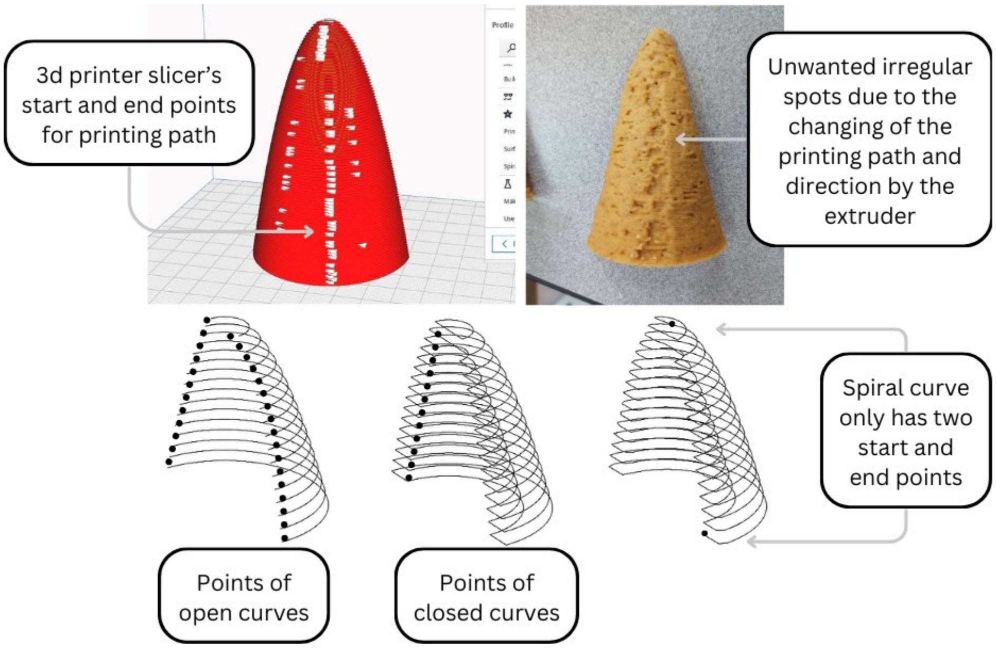

Figure 13. The start and end point of the print path can make unwanted surface result (top); An annotated diagram showing how spiralized how printing path can reduce the points (bottom)

Unfortunately, the success I achieved with smaller-scale printing projects did not carry over to a larger, real-scale project. By increasing the vertical height of the cone, challenges arose in the form of instability and sagging due to the weight of the structure (Figure 14). In Figure 14, we can see how the excessive weight of the upper layers caused the print profile to bend. Despite incorporating a heat air drying process for the lower layers in the larger-scale print, the weight of the upper layers caused them to crack and lose their structural integrity (Figure 14).

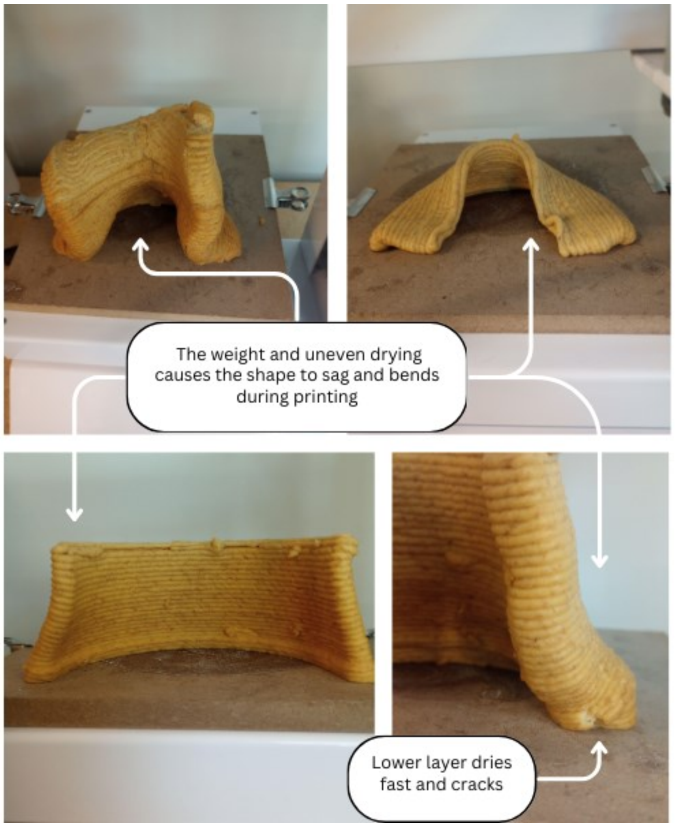

Figure 14. Annotations of instability and sagging due to the weight and uneven drying during multiple attempt.

There are several potential solutions to address this challenge. One approach is to adjust the wall thickness of the print thick enough to provide sufficient strength without adding excessive weight. This would require further experimentation with different print flow rates, nozzle diameters, and wall thicknesses to find the optimal balance. Another solution is to print the shape in multiple parts and then assemble them using glue (Figure 15). Alternatively, we could print a separate support structure before printing the main cone shape and use it to hold the cone in place during the print process, distributing the weight and preventing sagging or bending. However, this would still require printing the support structure in parts, from bottom to top, to avoid any collision between the 3D printer's extruder arm.

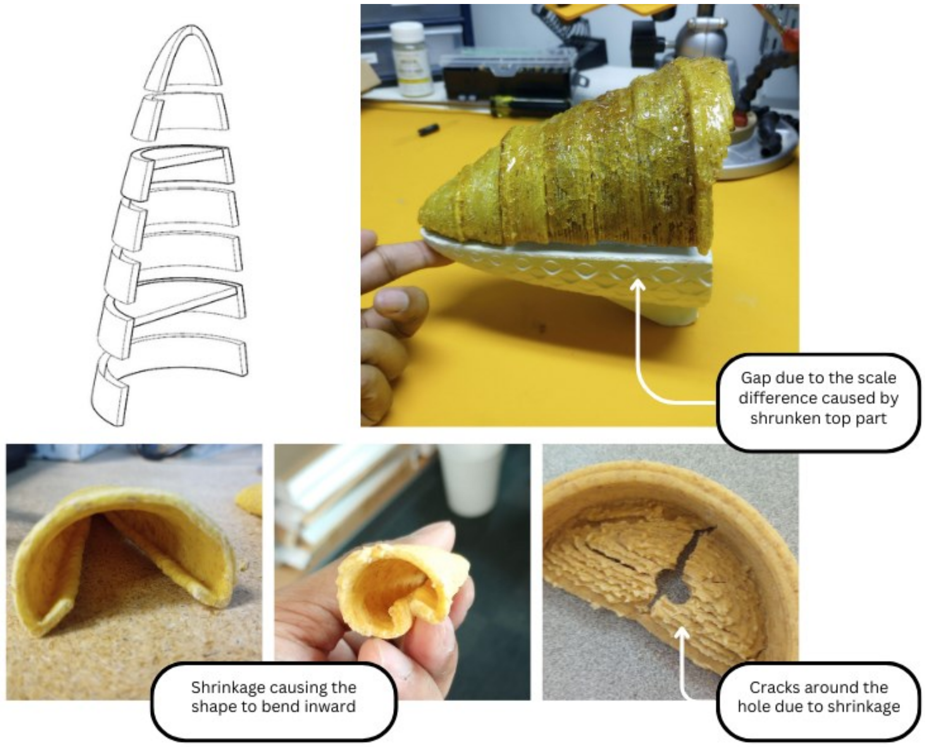

Figure 15. Printing the shape with multiple parts (top left) and gluing them together and applying pine resin coating (top right); Annotations of shrinking effects over a month (bottom)

During the process of printing the cone shape in multiple parts, I encountered a challenge where the edges of the corn-based material did not seamlessly merge when the parts were assembled with the bottom gypsum cavity nest (Figure 15). I discovered that the corn-based material had experienced some degree of shrinkage, causing the edges to not align perfectly. This shrinkage, which was not initially considered, can lead to bending or cracking in different shapes and openings.

Buechley and Ta (2023) mentioned a 10% shrinkage rate in their work on corn-based materials, but did not elaborate on how this would affect the shape of printed objects. Through my investigation, I observed that the effects of shrinkage may vary depending on the specific shape and asymmetry of the object, with symmetrical round objects being less affected than irregular shapes (Figure 15). Additionally, the presence of any holes or gaps on the surface may intensify the presence of shrinkage-induced cracks (Figure 15).

Finally, since the corn-based material is not water-resistant, I decided to apply a coating of pine resin to the surface to make it waterproof. During a degradation test in the backyard, the cone attracted a small animal, likely a squirrel or raccoon, and was eventually devoured (Figure 16). This incident highlighted the potential attraction of the corn-based material to animals due to its organic nature. The dried corn from the cone can also be reused by grinding it and mixing it with a new batch of dough, allowing for a sustainable and eco-friendly approach to material reuse.

Figure 16. Animals leaving traces of their interaction to no traces at all within a week.

4.2.3. Reflection from Phase 2

I have described the second phase of my first-hand material exploration, detailing my experimentation with Gypsum and a corn based recipe. These materials embody distinct temporal dimensions within the Turner Boxes. In this section, I present the reflections that occurred during this hands-on exploration. Subsequently, these reflections will undergo analysis alongside those from the other phases presenting the common reflective lessons in Chapter 6.

Material vs Machine

In this phase, I encountered a unique interaction between the material and the fabrication tool. While attempting to drill into a large gypsum block, I experienced the external manifestation of material resistance. As the drill bit repeatedly got stuck in the dense gypsum block, the resulting friction caused the block's fine powder, clogging in the flutes of the drill bit. Moreover, when I tried to adjust the drill's clutch to remove the stuck bit, it failed to do so and instead broke the bit in half. This unexpected outcome taught us the importance of being more cautious when using machinery.

There was no difference in the nature of the corn-based material. The ceramic printer would only be capable of proper printing when the corn material achieved the right consistency. Otherwise, due to the material's hardness, the ceramic printer's plunger would fail to extrude it. On the other hand, if the material's density was too low, the printer would struggle to maintain the proper layer thickness. To address these challenges, I employed another machine in the ceramic printing process: a heat gun.

Another aspect that I haven't mentioned yet is the maintenance of the ceramic printer and its materials after use. It is not appropriate to leave the printer's tube, material chamber, and extruder filled with the material overnight. This can lead to the material drying up and causing various parts of the machine, including the motor, to malfunction, which can be even more challenging to clean later on. This is one of the differences between a normal 3D printer and a ceramic printer. The latter requires proper maintenance at the end of each session, which may take another few hours. In conclusion, both the material and the machine are very demanding and require a lot of attention and care from the maker.

Sensitivity of Material

The complex nature of the corn-based material becomes evident during the printing process. Even with the correct consistency, challenges may arise in extruding the corn paste. Using a heat gun to dry the layers from below, causes the entire print often face uneven dryness. This results in the lower layers being cracked due to heating for a longer period of time under the weight of the upper layers at times. Thus, it was difficult to successfully print objects with significant vertical height. In section 5.2.2, insights are gained into how the printed object starts to deform due to the material's wetness and softness. Finally, the characteristic shrinkage of the material is uncovered, a factor overlooked in the exploration.

In addition to its complex behavior, the corn-based material is also fragile. While its shrinkage nature causes cracking, the material's susceptibility to human handling can lead to it easily breaking or deforming. Moreover, the corn-based material is not water-resistant. Even if it becomes strong and cookie-like through proper heating and drying, it can still easily absorb water and moisture, causing it to lose its structural integrity. To address this issue, I used a thin coating of pine resin as a protective layer for the printed objects. This helps to enhance their water resistance and overall durability.

Back to the Ecology

Placing materials in vermicompost or leaving them in the background sparked uncertainty within me. As a novice explorer (Oogjes & Wakkary, 2022), I was unsure of the outcomes. Yet, upon testing the vermicompost, I discovered positive results in pH levels, nitrogen, phosphorus, and potash content. It remains inconclusive whether these results are solely attributed to gypsum. To determine this, comprehensive laboratory tests and a deeper quantitative analysis would be necessary, exceeding the scope of this current research. Nevertheless, I am satisfied with the absence of any negative results.

A similar case can be observed with the corn material. I initially expected that the conical shape made from corn would start to break down in the presence of heat and rain. However, I was surprised to find that within just a week, the corn material had fallen prey to some non-human species. Since I did not have a camera set up in my backyard, I could not specifically identify the species responsible for this. However, based on the bite marks and its regular visits, I speculate that a raccoon might be the culprit. When I discovered the remnants, I assumed that the raccoon probably did not like the corn, which were covered in pine resin coating. However, when the entire form was completely gone the following night, it became evident that this material composition could potentially function as a food source for specific species, thereby influencing the ecological dynamics of our environment.

4.3. Phase 3: wi-fi-no-tifier

In this phase, I immerse in working on a different project called wi-fi-no-tifier. An alternative concept of wi-fi-no-wi-fi project, wi-fi-no-tifier repurposes uses salvaged parts from its predecessor to detect and physically notify Wi-Fi networks. It is designed for outdoor use in areas with limited Wi-Fi awareness, with a rectangular form and two-sided colored paddles rotating only in the presence of Wi-Fi. In creating the electronic enclosure, we kept it simple. We simply ensured that the enclosure had just enough space for the electronics and included thin slits for the flaps on both sides (Figure 17).

Given that the location of the enclosure was determined to be outdoors, I designed its upper side with a pyramidal shape to prevent rainwater accumulation.

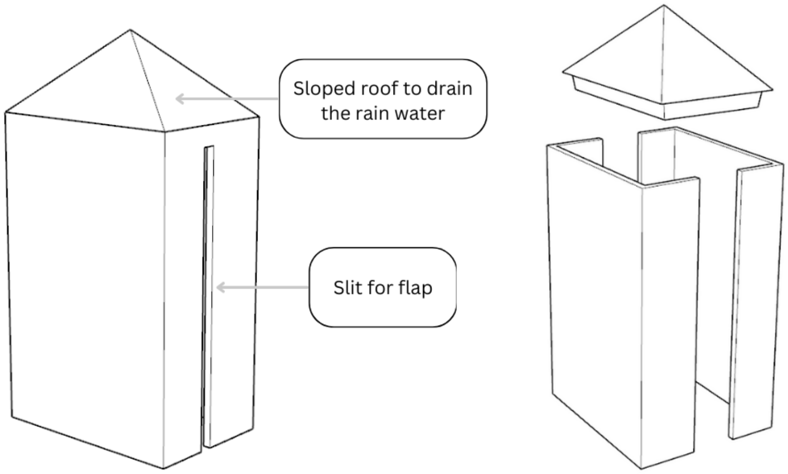

Figure 17. The wi-fi-no-tifier electronic enclosure (left); Three divided parts for mold press (right)

The wi-fi-no-tifier was our attempt to engage with the more-than-human world. Therefore, for the housing, I used an organic composite of corn, wheat, and sand, which will be describe in the next section along with my reflections.

4.3.1. Corn and Sand

I explored a corn-based material for the wi-fi-no-tifier project, following a recipe that incorporates 150g of corn flour, 50g of wheat flour, and 200g of sand. This combination increases the material's structural integrity and reduces the shrinkage factor to 5% (Buechley & Ta, 2023).

For the wi-fi-no-tifier enclosure design, I noticed that the slits on the sides would make it difficult to print the shape continuously in a spiral pattern using a 3D ceramic printer. Therefore, I decided to use a mold press to create a rectangular box shape, dividing the enclosure into three simple parts (Figure 18). The process involved filling the outer section of the mold with corn-sand material and subsequently applying pressure with the inner part of the mold. Following this, I carefully removed the inner mold to allow one side of the material to dry (Figure 18). After 4-5 hours of drying, once the inner side of the material was dry enough, it was easier to slide the shape out of the mold. I air-dried the wet side for another 5 hours (Figure 18).

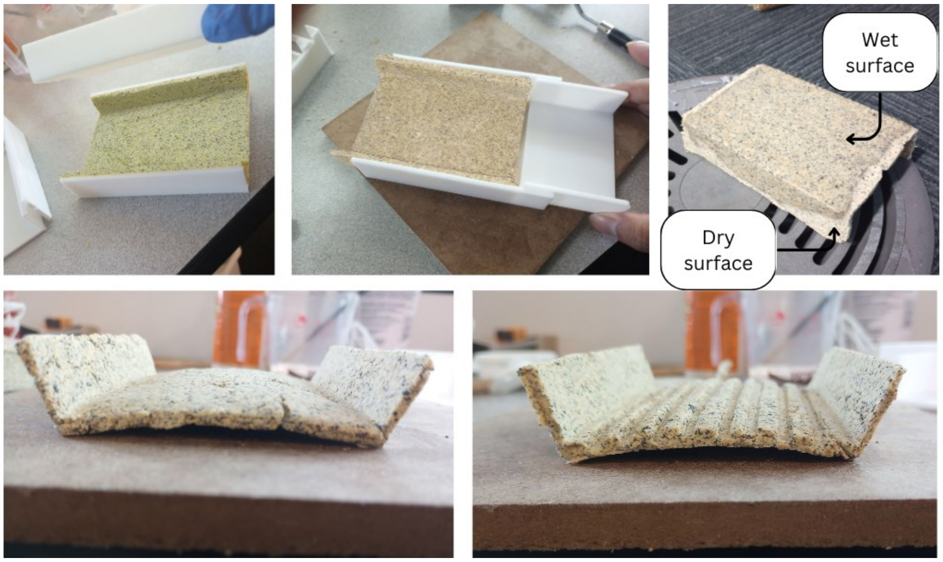

Figure 18. Press molding and air drying the corn shape (top); Bending due to shrinkage with and without scorching pattern (bottom).

Despite molding with a 5% allowance, I had struggle to control the bending in the inner direction after air drying (Figure 18). Since the electronics would be placed on the inner side, the direction of the bending became a concern for us. I tried various positions during the drying process, such as standing or upside down, and concluded that it was not bending toward the gravity. Regardless of the position during drying, the material always bent inward.

I tried adding a vertical scorching pattern, which reduced the bending but didn't eliminate it (Figure 18). When the vertical scorching didn't work out, I realized that uneven drying might be causing this. Since the outer surface dries later, it shrinks on that side, causing the material to bend inward. Figure 19 can help us visualize how uneven drying impacts the shape of the material.

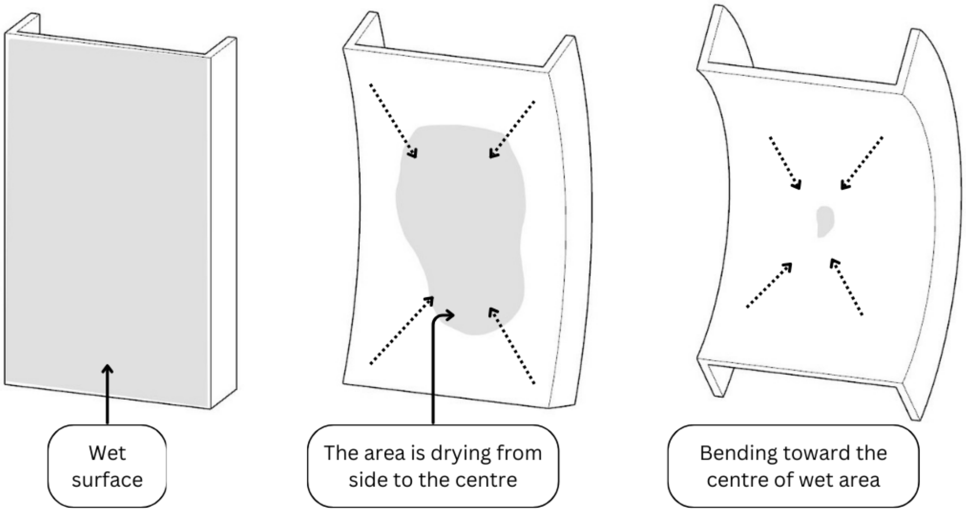

Figure 19. Illustration of how uneven drying can bend the shape

To address the issue of uneven drying, I remodeled the outer side mold to allow the outer surface to be open to the air while still keeping the material in shape using side arms of the new frame (Figure 20). This allows the material to dry evenly from both sides of the surface. As a result, I was able to achieve a promising outcome with no bending at all (Figure 20).

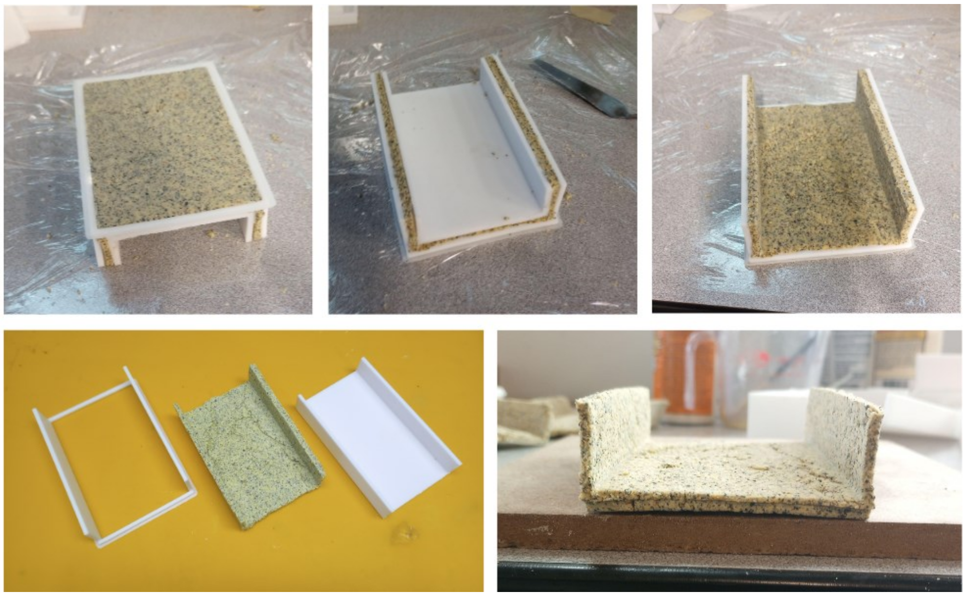

Figure 20. New mold design that allows to air dry from the both side after pressing that shows no bending after drying.

Once the three parts are properly dried, I use white glue to join them together. Finally, to ensure robustness and waterproofing, I apply a layer of pine resin (Figure 21). To understand the end-of-life scenario for the corn-sand material, we placed the wi-fi-no-tifier without any electronics inside our garden (Figure 21). However, we also attached paddles to the side of the box to see how it works. The paddles were made of basswood and coated with aesculin from the horse chestnut tree for coloration, which is visible in the UV spectrum for many species, including bees, but not the human eye.

Figure 21. wi-fi-no-tifier enclosure with the paddle placed in garden (left); Damaged remains of wi-fi-no-tifier after about a month (right).

For the first few weeks, despite the cracks in the pine resin due to temperature fluctuations from sun and rain, the wi-fi-no-tifier's enclosure seemed to blend in with the garden landscape. However, almost a month later, the material was targeted by a raccoon or squirrel, but they didn't completely devour it but was damaged (Figure 21). Since the recipe included sand, the wi-fi-no-tifier, while attracting them, didn't make it to their dinner menu. We left the remnants of the corn-sand material in the garden to observe how it degrades over time in the garden soil. After another month, we found the rest of the pieces missing, possibly picked up by crows.

4.3.2. Reflections from Phase 3

I have described the third phase of my first-hand material exploration, detailing my experimentation with a corn and sand based recipe. This material is a continuation of the corn based material exploration in the preceding phase, as the addition of sand imparts a certain robustness. However, this new ingredient also introduces fresh reflections, which I detail in this section. Subsequently, these reflections will undergo analysis alongside those from the previous phases presenting the common reflective lessons in Chapter 6.

Atmospheric factors

Working with the corn-sand based material, I encountered challenges related to its material properties. I expected issues such as shrinkage and bending with this type of material. However, during this phase of exploration, I became aware of several other factors. Factors like air circulation, room temperature, and gravity also became part of the design constituency. They seemed to signal their existence and importance through the bending of the material.

Temporality and uneven dryness can open up playful design opportunities as well. As we can see by applying different approaches, I managed to reduce the bend. However, this opens up the possibility for further exploration at different levels. For example, what if I dry the outer surface first and then the inner surface? Or what if I dry one side of the material first and then the other side? What if I apply a vertical scorching pattern to the outer surface or a horizontal, diagonal, or wavy pattern? Although I did not explore all of these possibilities further, different atmospheric, temporal, and drying factors can shape the material differently, making them an important key player in the design.

Multispecies Damage

The inclusion of 50% sand with corn and wheat in the material did not deter interactions with other non-human species. The aesculin on the paddles might have attracted the squirrel as well. However, unlike the previous exploration with the full corn and wheat-based material, the majority of the wi-fi-no-tifier enclosure was left intact, even though it was destroyed and some small parts went missing.

Nevertheless, it's interesting to see that the material invites multispecies activity and interaction. However, such multispecies vandalism creates a frictional scenario when the material is used as an enclosure for electronics. While we are trying to explore multispecies interaction through projects like the wi-fi-no-tifier, this interaction often results in the destruction of the material. This can eventually lead us to reflect on theories like unmaking (Song & Paulos, 2021) and material speculation (Wakkary et al., 2016), but from a more-than-human perspective.

In the context of material speculation, the interaction of non-human species with the material can provide insights into how different materials might behave or be perceived for a more-than-human world. This can lead to new understandings and speculations about material properties, their agency and potential uses. It challenges our human-centric assumptions about how materials should behave and be used. This can lead to a more nuanced understanding of materials and their interactions with the more-than-human world.

Chapter 5. Reflective Lessons

In this chapter I present the lessons I learnt from the three phases of material exploration. I engage in a rigorous reflection of each of our steps, design decisions, and the resulting consequences, employing an annotated portfolio to give rise to six overarching lessons.

5.1. Beware of Greenwash

At the very beginning of the exploration, I found ourselves tangled in the web of greenwashing. The market is flooded with numerous biomaterials, which manufacturers often advertise as renewable, environmentally sustainable, compostable, and/or recyclable. When I was searching for biobased epoxy, I came across a plethora of products named Naturepoxy, Ecopoxy, Entropy Resin, Bio Epoxy, and Fairpoxy. Ecopoxy claims to be "developing high bio-content epoxies, made from annually renewable resources"[5] . Naturepoxy boasts of being the "Worlds Highest Performance Bio-Epoxy" [6]. Similar advertisements are seen for the rest of the products, which seem too good to be true.

Designers and makers are often misled by the deceptive descriptions of many biomaterials. One such example is the PLA filament. For instance, eSun describes their filament as "environment friendly"[7]. Power tool corporation and filament producer Dremel labels their PLA as "biodegradable"[8]. Another major 3D printing brand, Flashforge, claims that their filament is "extracted from corn starch" and thus is "environmentally friendly for use"[9]

Typically, the biopolymers derived from plant starch originate from high-yield Genetically Modified Organism (GMO) crops (Kabir et al., 2020). There exist concerns about whether these GMO crops alter the toxin levels in the soil (Arcieri, 2016;

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[5] https://www.ecopoxy.com/pages/about-us

[6] https://www.naturepoxy.com/

[7] https://www.esun3d.com/pla-pro-product/

[8] https://www.dremel.com/us/en/digilab/support/3d45-series-3d-printer/filament/pla-filament

[9] https://flashforgeshop.com/product/flashforge-pla-standard-filament-1-75-mm-1kg-spool?cID=29

Zimmermann et al., 2020). Similarly, there are apprehensions about how the use of farmland to grow biomass for bioplastics impacts human food production, animal feed production, and areas suitable for animal pasture (Kabir et al., 2020).

This misconception will only be dispelled when producers and manufacturers specify in their product information the aerobic or anaerobic conditions required for their biomaterials to break down. Technically, all materials break down in nature over a certain period. However, plastics become fragmented into microplastics long before they decompose (Kabir et al., 2020). For any plastic to decompose, specific environmental conditions must be met, including proper humidity, temperature and pH level, and the presence of microorganisms (Borowicz et al., 2019; Kjeldsen et al., n.d.; Kreutzbruck et al., 2021).

Greenwashing can occur not only in material properties but also in material practices. Recycling has emerged as a greenwash practice. The petrochemical company is perceived to be diverting the public’s environmental concerns about plastic with a hollow promise of recyclability since its inception in the early 1970s (Laura, 2020). Almost 25 years later, executives from the plastic industry confessed that recycling was merely a public relations exercise to deflect the public’s environmental concerns about plastic. Recycling technology is also costly and the system is complex. Consequently, less than 10% of plastic has ever been recycled, a fact that has been concealed from the public (Laura, 2020).

Whether it be the cultivation of GMO crops, the unsustainable harvesting of jute, the extraction of pine resin, recycling practice or even the beekeeping practices that led to conceptualize our Turner Boxes project, all are the result of anthropocentric intervention upon our ecology. It’s crucial for designers to educate themselves about the environmental impacts of various biomaterials and to critically evaluate claims of greenwashing. Prioritizing transparency and honesty in their design practices is key, and they should strive to use materials and processes that have been independently verified as environmentally sustainable. This approach not only enhances the credibility of their work but also contributes to the larger goal of environmental conservation.

5.2. Considering Imperfection

In urban planning and design, it is often the overlooked, the fractured, and the forsaken elements of the city that unexpectedly become a sanctuary of biodiversity. The path to reconciliation with materials is paved with the acceptance of impermanence, incompleteness and imperfection. This acceptance allows the material to unveil its inherent worth or even enhance its value over time, through a continuous renegotiation of incompleteness and imperfection among the artifact, the maker, the material, and the environment in which it resides.

In the initial phase of material exploration, I observed this with jute fiber and pine resin. I initially wondered how I could join the fragile parts of the turner box, but the scorching sunny day softened the pine resin and bonded the two parts. I also noticed ants capitalizing on the imperfect, uneven surface to store their mud balls for their colony. Such examples can be found in our city infrastructure as well. Cracks in the asphalt capture water and expose soil, often creating the conditions for life to flourish; abandoned buildings and infrastructure become sanctuaries for bats and birds, much like dead trees. On a broader level, employing this design principle requires the interaction designer to invite potential non-human participants to take action and engage in the design process, appropriating the artifact through use and over time, completing the incomplete design.

By accepting impermanence in design, we also embrace fragility, and thus, longevity and durability may not necessarily be the primary targets of design. It allows a temporality within design thinking. The inherent fragility and impermanence of various materials might inspire new directions, techniques, and practices in design. Other design research has considered such expressions in the work of wabi-sabi (Tsaknaki & Fernaeus, 2016), impermanence (Tsaknaki et al., 2016) and unmaking practice (Liu et al., 2019; Murer et al., 2017; Wu & Devendorf, 2020) in interaction design research.

5.3. Hustling with the Machine

The consideration of imperfection extends to the machine, tools, and techniques as well. Crafting is a process that unfolds through continuous negotiations among the craftsperson, the materials, and the tools in use, which necessitates time and skill. Just as exploring material qualities is essential for the designer, so is exploring form-giving tools. Through this process, the designer or craftsperson develop their individual skillsets over time to harmonize with the machine for specific materials. In this context, the designer often relies on their personal judgment and tacit knowledge, proceeding with whatever resources they have at their disposal at that moment.

This bears a striking resemblance to what Deepa Butoliya terms as ‘Critical Jugaad’ (Butoliya Deepa, 2018). The Punjabi word ‘Jugaad’ encapsulates the essence of finding solutions, hacking, trickery, or simply making the most of what one possesses. Echoing this sentiment, Butoliya identifies a range of critical making practices in the global south, underpinned by a resilient culture and a potent desire to merely survive and resist. Consequently, there exists no ‘perfect’ or definitive path to becoming a proficient maker.

Such hustle and hacking were necessary during our Phase 2 exploration with the 3D ceramic printer. No matter how simple the 3D printing process may seem, it is, in reality, complex and prone to failure. This dual nature can be quite deceptive, as it provides easy access for fabrication, but the material and machine demand a more integral involvement throughout. During Phase 2 of printing with corn-based material, I had to ensure the printability of the material at the start of the print. Similarly, during the ongoing printing process, I had to dry the layers of material with a heat gun. Even after the print was complete, I had to constantly adjust the hardware and software based on the properties and characteristics of the material to achieve better results. But that’s not all. Cleaning the ceramic printer after the print turned out to be an important part of the process. All these activities serve as evidence of how the practice of 3D ceramic printing involves a complex interplay of human action, machine, and material contingencies.

Not to mention, employing the ceramic printer as an organic material printer was also an exercise in Critical Jugaad. I drew inspiration from the work of Buechley (Buechley & Ta, 2023). Much like Buechley, design researchers perceive the machine as a type of malleable material, which opens up possibilities to reshape the machine to align with their needs and requirements. Anderson and her colleagues also view the machine as a material in itself, offering an intriguing and useful reimagining of what a machine can potentially be (Andersen et al., 2019).

The dialogue with the machine is not merely confined to the 3D printer. I also perceive the concept as being directly applicable to other fabrication machinery, such as laser cutters and CNC mills, as well as to other physical computational devices. In all these instances, the maker’s expectations and predictions need to be continuously harmonized with and adapted to the machine’s behavior.

5.4. Considering Non-human Agency

Jane Bennett challenges the traditional binary of animate/inanimate in her concept of Vibrant Matter (Bennett, 2010). She argues against the common belief that 'matter' is passive and inert, which prevents humans from recognizing the vitality of matter. To illustrate the vitality of matter, she shares a personal experience involving a glove, a mat of oak pollen, a dead rat, a plastic bottle cap, and a stick of wood on a sunny Tuesday morning.

> *“When the materiality of the glove, the rat, the pollen, the bottle cap, and the stick started to shimmer and spark, it was in part because of the contingent tableau that they formed with each other, with the street, with the weather that morning, with me. For had the sun not glinted on the black glove, I might not have seen the rat; had the rat not been there, I might not have noted the bottle cap, and so on.”* (Bennett, 2010, p. 5)

In this scenario, each actor played a vital role. This experience helped Bennett to understand the vitality of the objects and subjects around her, as well as the interconnected movements among them. She realized that everything surrounding her was not inanimate, but rather possessed the power to change the world. The absence of any one actor would have shifted the outcome differently.

During my second and third phases of material exploration, I witnessed the potency of vibrant matters while utilizing a ceramic printer and corn-based materials. The behavior of the materials, such as shrinkage and bending, was molded with the aid of the printer, heat gun, and surrounding environment (e.g., temperature, moisture, air flow, and drying conditions). It is not my intention to imply that these qualities can be effortlessly translated into design; instead, I emphasize the significance of considering such non-human elements in the more-than-human design processes.

This offers a shift from anthropocentric perspectives of designing technologies that sculpt our environments and daily lives, echoing Wakkary's theory of 'designing-with' (Wakkary, 2021). 'Designing-with' signifies a relational and expansive practice of design where humans are not at the center nor exceptional, but rather exist in ecological interdependence with the nonhuman world. One of the primary insights gleaned from designing with nonhumans, illuminated through material explorations, is the act of reconciliation. The designer, no longer the sole form-giver, does not wield complete control over the matter. Instead, it is often the nonhumans that dictate the creation of the world.

5.5. Meeting Multispecies

There are works in ACI (Animal Computer Interaction), mainly concentrating on pets, which often build on an owner's intimate knowledge of their animal (Hauser et al., 2014; Mankoff et al., 2005; Zamansky et al., 2017). However, designing for wild animal species has been studied less than that of companion species. Designing for multispecies interactions are complex and do not often fall under one specific field of study, which tends to result in them being under-studied or oversimplified. Nevertheless, they are often the most intriguing from a design perspective and help to connect the social, technical, and ecological aspects.

I experimented with various materials in our exploration: jute fibre, pine resin, bamboo culms and corn derivatives. As I shaped these materials to house electronics, they became homes and food sources for spiders, fungi and racoons. This is where the skill of seeing the world from the eyes of other species becomes vital in the design process; it enables designers to consider the design from both human and multispecies perspectives, where they encounter different realities. For instance, in a vermicompost bin, earthworms and microbes are essential agents in breaking down gypsum powder. This process, though invisible to the naked eye, can be revealed through explorative interaction. The core of reconciliation is to hold together divergent views.

Even when not designing directly for multispecies, it is beneficial to consider how the material would impact other species interacting with it. This does not mean that every feature in an interactive environment should be enhanced for ecological value or made into a habitat for nonhuman species. The effects on other species should be comprehended and taken into account, even if the goal is to minimize wildlife interaction. There are many instances in which the presence of multispecies is not welcomed. In our design cases, we have observed such contestations, where we aim to create enclosures for electronics that are traditionally weatherproof and animal-proof, but we encounter spiders and fungi, which are not necessarily favorable to bee habitats.

Feeding is perhaps the most extensively studied aspect of such competitive interactions and remains a topic of much debate. In many cases, animal feeding is the primary cause of aggression towards humans and poses health risks to the fed animals. The Stanley Park Ecology Society warns about the dangers of feeding coyotes. Although in my exploration phase 2, I unintentionally used corn-based materials that could be considered raccoon food, I do not necessarily suggest feeding multispecies with material design. Instead, we must be mindful of these aspects and view them as an opportunity to learn about their ways of interaction. As we invite more species to share interactive systems with humans, acts of reconciliation should be maintained in these multispecies encounters.

5.6. Material Recomposition

The idea that this world is a treasure trove at our command from which we can take resources at our whim has turned out to be a vain hope. Now we have to look for new materials and resources. We have to seek resources in waste, which is the outcome of current many production methods, discover new ways of farming with algae cultivation and cooperate with microorganisms to produce new organic materials and dyes.

Reconciliation arrives through the allowance of materials to decompose and recompose. Microorganisms do nothing but transform given substances into new matter. Even for non biodegradable materials this is true. They die and transform anyway but in way much longer timeframes, it just happens on a time scale far from our perception. Consider the example of plastic, which requires anywhere from a century to a millennium to degrade. When employed for products with short or negligible usage time, the result is the accumulation of towering heaps of waste. In addition, the manufacturing and disposal processes of such materials release toxic substances into the environment.

In the second phase of the exploration, we have shifted the design direction of Turner Box to consider the temporal scale of materials. While the bee cavity nesting part is intended for long-term use, the camera part will only be deployed for a brief three-month period. As such, we have opted to explore the use of organic, degradable materials such as corn and sand. Even gypsum is ground into a fine powder and mixed into a vermicompost bin for future use. We observe earthworms consuming and breaking down the material into smaller pieces, which they then mix with their own excrement, or "castings." This mixture is transformed into vermicompost through the action of microorganisms present in the worms' digestive system and surrounding environment (Anand & Sinha, 2020; Insam et al., 2010). Vermicomposting has the potential to serve as a suitable means for waste remediation and recomposition. Recognizing this cyclical nature of energy and matter, we must align our practices with these natural processes.

Chapter 6. Discussion

In this chapter, I will answer my research question by presenting the lessons into guidelines for material designers. To reiterate, my main research question is as follows: **How can designing-with material reconciliation provide guidance for material practice toward more-than-human interaction design?** I then reflect on the methods I used and justify my approach. Finally, I acknowledge the challenges and limitations of the study.

6.1. Guidance for the Material Designers

Throughout this thesis, I have attempted to explore materials and their fabrication techniques for two design cases that employs designing-with and reconciliation with ecology. I believe that the lessons I have uncovered can provide guidance to HCI material practitioners specially in the field of more-than-human design. As I discussed in Chapter 2, a shift in materiality is becoming evident in HCI practice. Yet, there is a lack of tools and methodologies to navigate this shift. We observe that electronic components can create friction and pose challenges when interfacing with organic material enclosures and multispecies interactions. Especially when deploying such electronic devices outdoors, HCI designers often opt for plastic enclosures as their initial choice, owing to their durability and ease of prototyping - a proof to our anthropocentric design thinking. The two design cases present an opportune moment to challenge these human-centric assumptions.

The lessons I offer will aid HCI designers to transcend these assumptions and foster a more practical consideration of designing with more-than-human worlds. In doing so, I hope that our designing-with material reconciliation can inspire future work and serve as an analytical framework to underscore situated and embodied practices in the context of material and multispecies interaction. Although I have delved into the six reflective lessons extensively in the earlier section, the following table presents the primary insights for designers.

Beware of Greenwash	**Emphasizing the need for designers to educate themselves about the environmental impacts of various biomaterials and to critically evaluate claims of greenwashing.**
Considering Imperfection	Accepting of impermanence, incompleteness, and imperfection in design. These elements can enhance the value of a material over time and might inspire new directions in design.
Hustling with the Machine	Understanding that improvising, hacking into, and adapting to the machine are essential aspects of making.
Considering Non-human Agency	Considering the behavior of materials and the impact of non-human elements such as tools, machines, and environmental conditions in the design process.
Meeting Multispecies	Recognizing that materials may end up as homes and food sources for various species, and considering the impact on other species interacting with the designed environment.
Material Recomposition	Looking for resources in waste, algae cultivation, and microorganism cooperation as alternative solutions. It is important to align material practices with natural processes, such as decomposition and recomposition.

6.2. Methodological Reflection

In design research, researchers do not seek universal truths as one might in the natural sciences. Instead, they delve into the unique, the specific, the "ultimate particular" of a design context (Stolterman, 2008). Following this line of thought, my research journey was not a quest for a single solution, a definitive truth, or a clear-cut answer to my research questions. Rather, it was an exploration of a specific design context, defined by material practices, to contribute new insights and knowledge in the domain of more than human interaction design research. Thus, the “wicked problem” (W. Gaver, 2012) I grappled with was a broad question: How can designing-with material reconciliation provide guidance for material practice toward more-than-human interaction design?

Therefore, I prototyped for two design cases to generate the deeper insights which otherwise would not be attainable. Each phase involved not only the main craft materials but also fabrication technology and multispecies ecology. These explorations helped me to uncover new phenomena and embrace necessary modifications. Through experimentation, I stumbled upon unexpected results, which led to novel interpretations. Through a cycle of feedback and observations, the design could be periodically reframed in an iterative process.

This research would have remained incomplete had I not placed materials in the backyard. Before I knew it, the backyard had become an integral part of my research. The backyard represented the more-than-human world, providing the materials I was fabricating in the studio with an opportunity to recompose and meet with multispecies. The backyard became a site of revelation, where the materials I worked with shed their rigid forms. Here, the boundaries between the human and the more-than-human blurred, allowing for a deeper understanding of the world's complex system where everything is connected. This mode of thinking could enlighten material scientists or HCI practitioners in their laboratories, helping them to comprehend the intricate and interconnected world we inhabit.

As the first-person design researcher, I provided a detailed description of each material and address the challenges and setbacks encountered through reflections in each phase of exploration. It is important to critically reflect on the processes and outcomes in first-person approach. The finalization of this study was the synthesis of the reflections gathered from the annotated portfolio. The portfolio allowed me to organize the messy exploration into phases. By annotating them with sticky notes and classifying them I managed to extract themes over my reflections across different material and techniques that came out as lessons and guidance for me and the HCI material practitioners.

First-person research prioritizes the researchers’ first-hand experiences, where the researcher’s own experiences serve as the compass guiding the inquiry. Yet, it raises questions of the human-centric nature of our understanding, of the dominance of the human voice in data collection, analysis, and documentation. It requires a careful balancing act to ensure the inclusion of the nonhuman, the voiceless, the silent actors in our world.

I became a “speaking subject”, as Wakkary (2021, Chapter 6) calls it, giving voice to the nonhuman actors that participated in the design process. Wakkary outlined two approaches for speaking subject: not-knowing things and generosity (Wakkary, 2021, Chapter 8). I started from a position of not knowing, opening up possibilities for learning and noticing unexpected material expressions. However, this approach came with risks, such as deception by greenwashing and unexpected encounters with multispecies. My position of generosity emerged from interacting with nonhuman agencies. With materials like pine resin and corn-based ones, I abandoned the full control of the designer over matter, marking the end of the designer as the sole form giver. Instead, I constantly had to align and collaborate with the nonhumans who had a say in shaping the material.

Other methodologies, such as case study (Yin, 2018), could be applied to address the research question. However, its application would necessitate the selection of design cases in which my direct participation in the design process is absent. Similarly, the grounded theory (Charmaz, 2014) approach holds promise. Yet, it is important to acknowledge that such an approach may constrain the performative and embodied aspects of my exploration.

6.3. Limitations

In this thesis, I offer insights tailored to practitioners interested in experimenting with organic or biomaterials for more-than-human design projects. It is important to note that these insights may not directly apply to individuals focused on areas like electronics or programming within the HCI community. As we continue to develop our design cases, further study will undoubtedly yield additional insights across various aspects e.g. electronics, power consumption, wireless network consumption, etc.

The design cases of this thesis, being material speculation are not intended for direct comparison with commercially available products. The functionality and purpose of these designs differ, thus constraining my exploration and understanding to fabrication techniques suited for small-scale prototype production. Scaling up to larger batch production may unveil new nuances and reflections absent from this thesis.

I also acknowledge that one of the design cases is ongoing, while the other is an extension of a separate project. Our current phase involves shaping the nests of the Turner Boxes using reclaimed douglas fir wood, with the assistance of a woodturner. This has led to a reduced level of hands-on experimentation on my part. Furthermore, the Turner Boxes have yet to be deployed during the proper bee season, limiting the insights contributed to this thesis.

Furthermore, different degrees of multispecies interaction unfold in many ways, each with its own unique impact on the lives of both humans and nonhumans. For example, while I designed the cavity nests of the Turner Boxes for bee habitation, they were infested by other species, potentially impacting the desired habitation for bees. However, understanding nonhuman participation enables designers to pursue collaborative efforts with nonhumans, equipping them to comprehend the long-term and multi-relational effects of their designs.

Finally, bias is an inevitable downside of the first-person approach. Yet, continuous reflections, peer reviews, and discussions mitigated such consequences. The first-person approach also limits the work's generalizability. Even with Wakkary's Speaking Subject in consideration, tensions persist in first-person approaches when exploring research questions focusing on the nonhuman. The tension lies in the use of human language. How can I speak for those who cannot speak, or even understand?

Chapter 7. Conclusion and Future Work

In this thesis, I have delved into the exploration of transitioning towards a material practice that teaches us to reconcile with the more-than-human world. I start by addressing the theories and concepts of desiging-with and reconciliation, approaches that aim to cultivate a harmonious coexistence between humans and nonhumans. I present the two design cases that is informed by designing-with theory and present the materials explored that advocate for an approach of reconciliation. Utilizing first-person narrative and annotated portfolio, I illuminate the obstacles that led me to identify the lessons I have learned: 1) beware of greenwash, 2) considering imperfection, 3) hustling with the machine, 4) considering nonhuman agency 5) meeting multispecies, and 6) material recomposition.

The contribution of this research offers these lessons as a starting point to consider designing-with material reconciliation in HCI material practice and future research. My aim is to continue exploring more organic materials as I step into phase 4. To generalize the study more to the community I intend to arrange co-design workshops and invite more material designers to contribute to future study. As we stride forward in the realms of fabrication and digitization, we are presented with a new conundrum - how does material interaction weave itself into the tapestry of the technological and virtual world? Or what role does it play in the digital landscape? I hope that my research will inspire others to further study and to explore the design space of material things, environments and multispecies systems from a perspective that would account for more sustainable, reconcilable and rich biographies.

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