BLENDING VIRTUAL AND ORGANIC WORLDS

Unpacking mutualistic care with DNA data storage in microalgae

TU Delft

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PREFACE

I started my master in Delft with a vague perception of designers being able to make complicated processes and systems feel easy and seamless for people, and that that is mostly a good thing in an increasingly complex world. When starting to dive into More-than-human design through an elective course at the faculty, I became more mindful of the wider possible implications of abstracting, simplifying and making things feel smooth, which is that it can contribute to create a sense of disconnect to where things we use come from and make humans feel very detached from the natural systems we're dependent on. This, in turn, made me curious about how to design to not just obscure these complexities, but to see how to engage people with them in meaningful ways.

I am very glad that I was able to dive more into this with this masters thesis. I would like to especially thank my supervisors, Himanshu and Jiwei! Your help, kind support and engagement throughout the process was not only helpful but also very inspirational for helping me navigate a very broad and sometimes vague topic. Also, thank you to everyone else who also contributed to this project, by joining focus groups, workshops and interviews. I would also like to thank Iohanna, Elvin, Raphael, Shruthi and Melissa for taking the time to meet to give very helpful feedback along the way. Also thank you to the nice people in Applied labs for the help and for letting me sit there. Thank you to my parents and friends who were there for emotional support and for the fun times in-between, and thank you to the coffee group who made the days at uni very nice.

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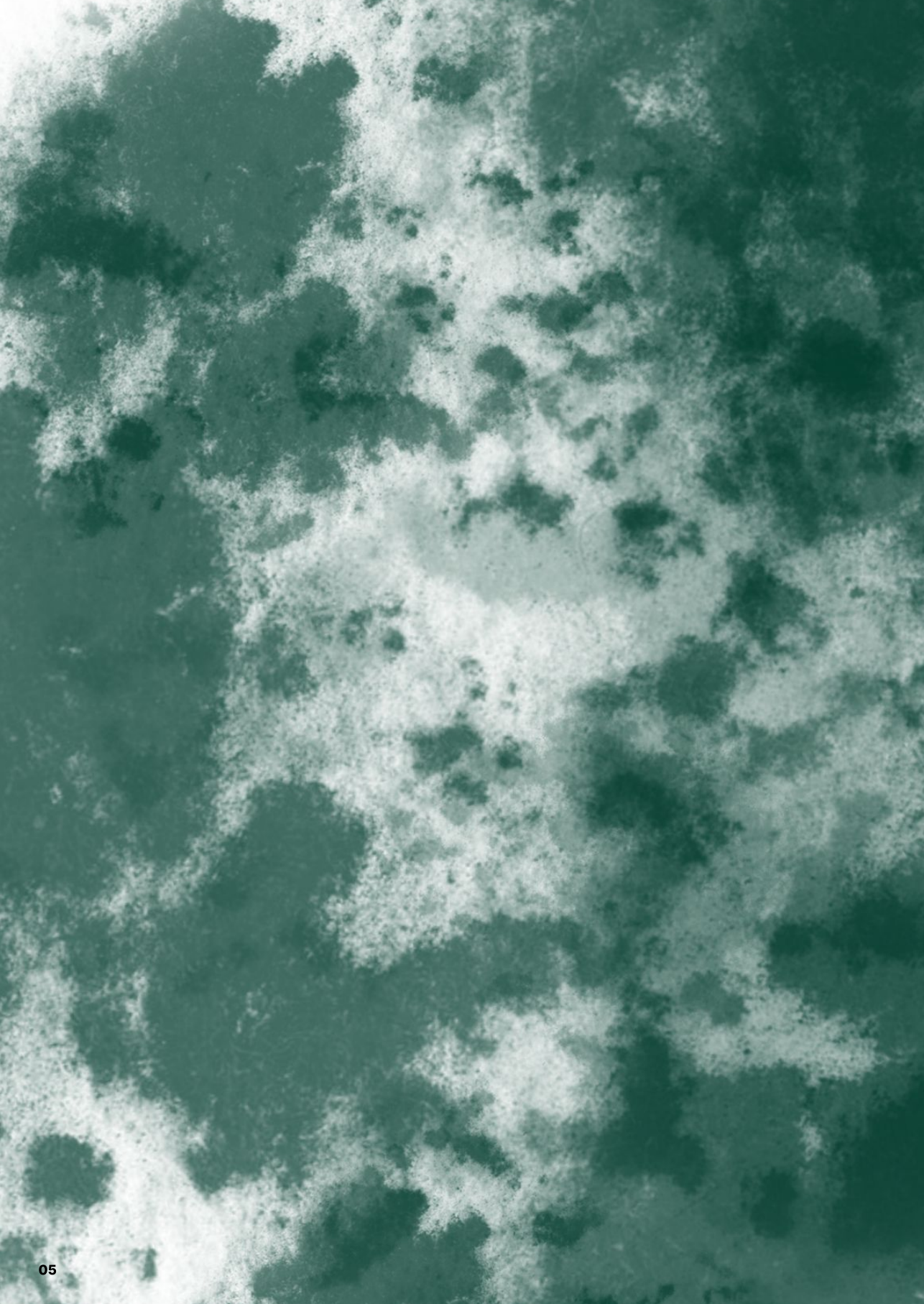


ABSTRACT

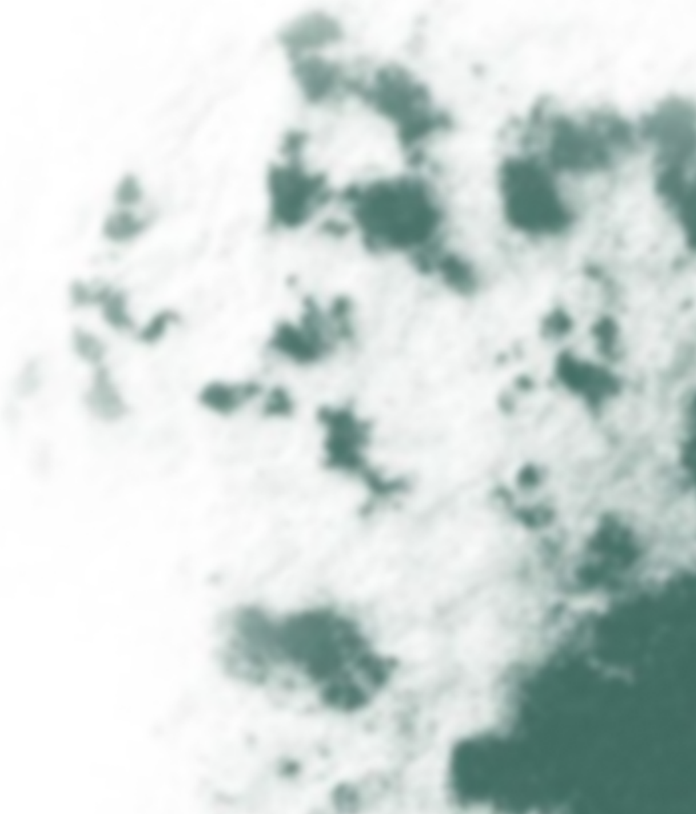
In complex and distributed human-made-systems, the intimate co-dependency between humans and non-humans can feel distant and vague. A novel approach for fostering a sense mutual care between people and living organisms can be found within biodesign, where living artefacts provide human users with functional benefits, like lighting, air purifying and unique material qualities in exchange for care.

Emerging bio-technologies bring new opportunities for mutualistic care. Recent research has, for instance, demonstrated the ability to engineer bioluminescent plants with inbuilt switches, and electrosynbiotics have demonstrated that trees can generate electricity. Other projects are experimenting with the feasibility of storing data in living plants.

Using speculative design as a tool, this thesis starts unpacking how storing data in microalgae might facilitate mutualistic care, and how this might implicate care. The final speculative research artefact, “Algae Cloud,” imagines a personal cloud-storing system as a series of algae cultures; a relation of mutualistic care where data storage is traded for sunlight, nutrients, and regular attention.

Algae Cloud is a contribution of this project as a speculative design provocation that intends to inspire designers to think of novel ways to design for mutualistic care. It was presented and discussed in a focus group format with researchers from bio-design, more-than-human design, and data-centric design. The results from the discussions suggests that storing data in algae might bring new opportunities for mutualistic care that blend what it means to care for algae and data. The discussions also highlighted implications of care, like who should care, and what do people actually care for when they care for algae with data inside.

Bridging results from the discussions with previous work in HCI, the thesis presents opportunities for designers to further explore what could emerge in the intersection of virtual and biological worlds.



Terminology

PAIRING TECHNOLOGY AND LIVING ORGANISMS

Bio-digital hybrid
In this project, bio-digital hybrid refers broadly to systems where inbuilt capacities of alive living organisms are paired with digital technologies to do something, for example, function as an exhibition peace, an object for the home, or something that translates plant needs to actionable human steps.

Living Artefact
Living artifacts, as defined by Karana et al. (2020), are artefacts that fulfil functional human goals by using inbuilt qualities of living organism, such as microalgae, bacteria, fungi, or plants. Since the living component is kept alive during use-time, the livingness of the artefact becomes an essential part of the design.

TERMS FOR CLASSIFYING TYPES OF LIVING ORGANISMS

Living Organisms
In this project, we use “living organisms” as a general term to refer to plants, microbes, and fungi; practically all living things, not including animals or insects.

Microorganism, microbe
A microorganism, also known as a microbe, is an organism that is too small to be seen with the naked eye and can only be observed through a microscope. While some microbes, such as Spirulina, share some characteristics with plants, like being able to photosynthesise, they are not classified as plants.

Microalgae
Microalgae is a type of microbe that is typically found in aquatic environments and can photosynthesize. Spirulina is a type of microalgae and was used in this project.

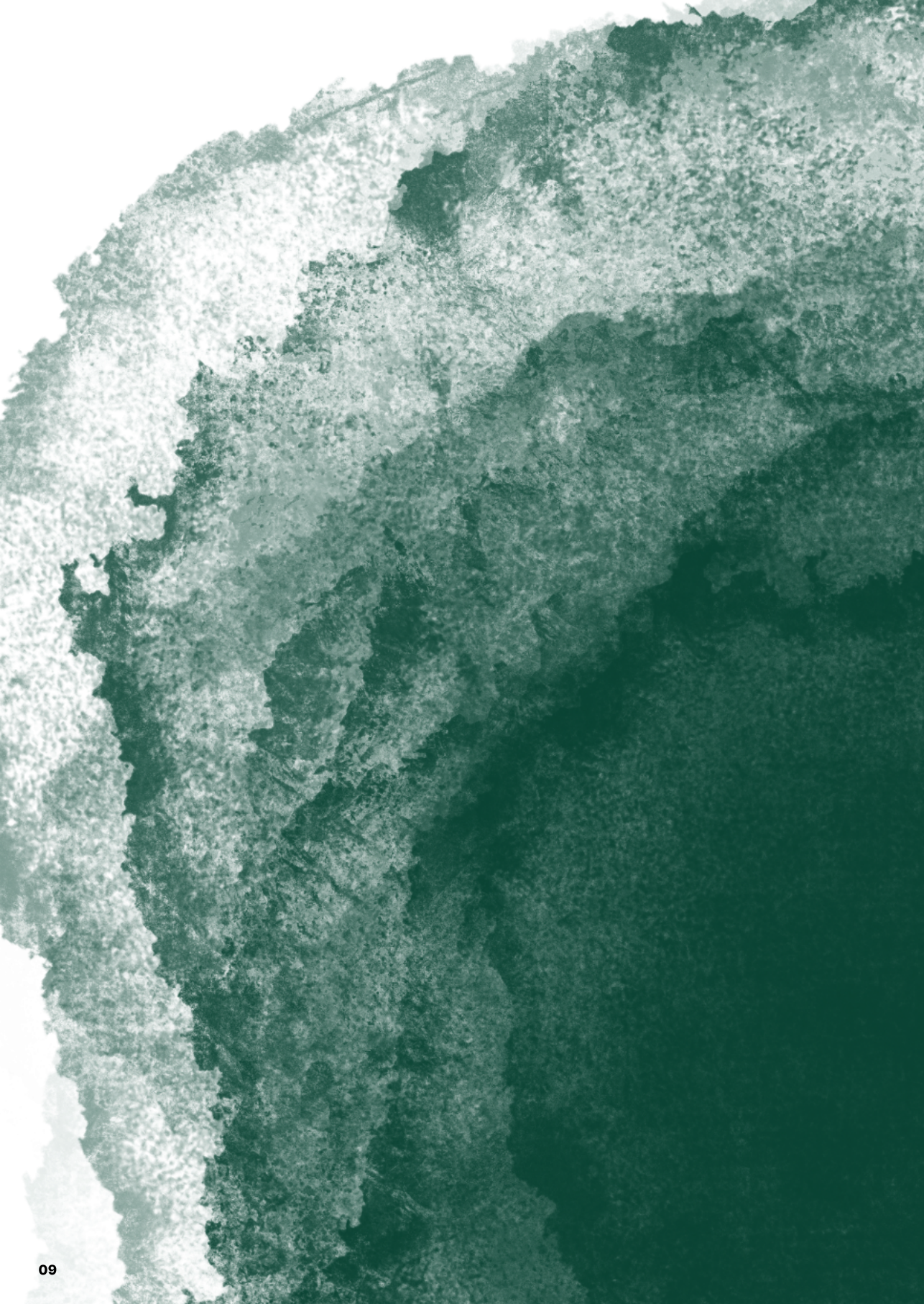
Plant
Plants are living organisms that produce their own food through photosynthesis, have a complex cellular structure, and play a crucial role in ecosystems and human societies.

WAYS OF RELATING TO LIVING ORGANISMS

Interspecies empathy
The term “interspecies empathy” in this project refers to the general ability to notice, consider, and feel empathy towards living organisms. This project used interspecies empathy as a lens in the exploration phase to understand how people can feel empathy towards plants, but later focused on mutualistic care between humans and microalgae.

Care
Care includes *“everything that we do to maintain, continue and repair ‘our world’ so that we can live in it as well as possible. That world includes our bodies, our selves and our environment, all of which we seek to interweave in a complex, life-sustaining web”* (Tronto, 1993, 103). De la Bellacasa emphasises that care is not limited to human-to-human interactions, but includes the care of non-human entities such as animals, plants, and ecosystems (Puig de la Bellacasa, 2017).

Mutualistic care
Mutualistic care is defined by Karana et al. and refers to the relation of care between a human and a living artefact within bio-design. This is a reciprocal and evolving relationship, where humans act upon the living artefact in order for it to survive and flourish. In return, the artefact continues to provide humans with (functional) benefits. (Karana et al., 2020)



ch. 1

INTRODUCTION

"Ultimately there is a growing sense that, without fast action at every level of society, we cannot outrun crisis. In the Anthropocene age, shocks of all kinds are raising questions about the future and value of humankind."

(Light et al., 2017)

Introduction

Like all living things, humans are tightly interwoven and dependent on their surrounding natural ecosystems. Although this co-dependency exists, our current era (referred to as the Anthropocene) prioritises short-term human needs over those of other living things and ecosystems and artificially divides humans from nature. Scholars like Anna Tsing, Donna Haraway, and Maria Puig de la Bellacasa argue that current anthropocentric ways of understanding the world, such as the distinction between nature and culture, need to be revised in the face of recent social, technological, and environmental change. These thoughts have contributed to the emerging more-than-human design field, which critiques fundamentals of human-centered design and encourages sensing, noticing, and experiencing non-humans as partners in an ecosystem rather than only resources (Forlano, 2017) and embodying this into design solutions. Some examples of more-than-human design, design things that are meant to benefit non-humans instead of the traditional human user. An example is Wildlife Crossings in Canada, bridges over highways that let other animals cross the roads more safely (Smith et al., 2017). Another approach to more-than-human design is making living artefacts, which can align human and non-human needs by encouraging human users to help a living organism flourish for practical benefits in return (Karana et al., 2020). In the face of a global existential crisis, designing for multi species flourishment rather than only one species (humans) could unlock new and symbiotic ways of relating to the world.

Examples of existing living artefacts suggest how including living organisms such as fungi, plants, bacteria, and algae in functional designs could encourage new more-than-human bonds. "Ambio" uses bioluminescent bacteria's ability to produce light in a lamp, shaping home lighting practices that require care for microorganisms (Hobson & van Dongen, 2015). Another example embedded a slime mold, a living organism, as a functional component in a smart-watch, probing users to care for the slime in as a practice of caring for the smart-watch. The study found that participants testing the watch felt a sense of responsibility towards the device, experienced the livingness of the organism as a source of affect, and formed a reciprocal relationship with it (Lu & Lopes, 2022). In other words, integrating living components into functional, everyday things could foster new inter-species relationships between humans and non-humans.

Emerging fields of bio-design, biotechnology, synthetic biology, and biological computing are opening doors for new types of future caring relationships between humans and living things. Recent research has, for instance, demonstrated the ability to engineer bioluminescent plants with inbuilt switches, and electrosynbiotics have shown that trees can generate electricity. Projects like "Living Bits" demonstrate how living microorganisms can be integrated into human-computer interaction. Other projects like Grow Your Own Cloud are experimenting with the feasibility of storing data in plants (Chang et al., 2022). Solutions like these have the advantage of being green alternatives to, for instance, data storage and generating electricity today. Still, they suggest that we could interact differently with our light, computers, and data-storing options in the future, moving from "smooth" practices to ones that foster mutualistic care (Karana et al., 2020) between humans and living organisms.

This project looks specifically at DNA data storage in microorganisms as a practice for imagining reciprocal relationships between people and microalgae. What types of relationships could we have with microalgae if we felt directly dependent on them for data storage? How might we treat data storage if it needs care and eventually dies?

Approach

RESEARCH THROUGH DESIGN

Research through design (RtD) is explained as *".. an approach to scientific inquiry that takes advantage of the unique insights gained through design practice to provide a better understanding of complex and future-oriented issues in the design field."* (Godin & Zahed, 2014). In other words, RtD utilises the design process to create new knowledge in complex areas. In their work, Stappers et al. (2017) provide an insightful examination of the various interpretations and applications of Research through Design (RtD) across multiple scholarly perspectives. RtD does not fit into a single mold, and other arts and engineering disciplines apply similar approaches under different labels and with slightly different values and emphasis on different aspects.

This project uses the commonly cited framework for RtD in the HCI community by Zimmerman et al. (2020) as a guiding approach. Zimmerman et al. mention that RtD, among other things as a way to engage with "wicked problems"; complex and systemic problems that are difficult to define, has multiple causes and effects, and lacks a clear and straightforward solution. RtD also makes room for exploring opportunities and consequences of emerging technologies before they arrive (Zimmerman et al., 2007). At the heart of this approach lies the notion of design as a way to ask questions instead of solely providing solutions. Unexpected things that were not a part of the initial problem can emerge through the design process and be further addressed through iterative design and play.

Given the intricate and multifaceted nature of the "wicked problem" at hand, namely, the absence of mutualistic care between humans and living organisms, this thesis adopts a Research through Design (RtD) approach. Since RtD particularly fits for unpacking opportunities and consequences of emerging technologies, it is also helpful in exploring how bio-digital futures might take shape.

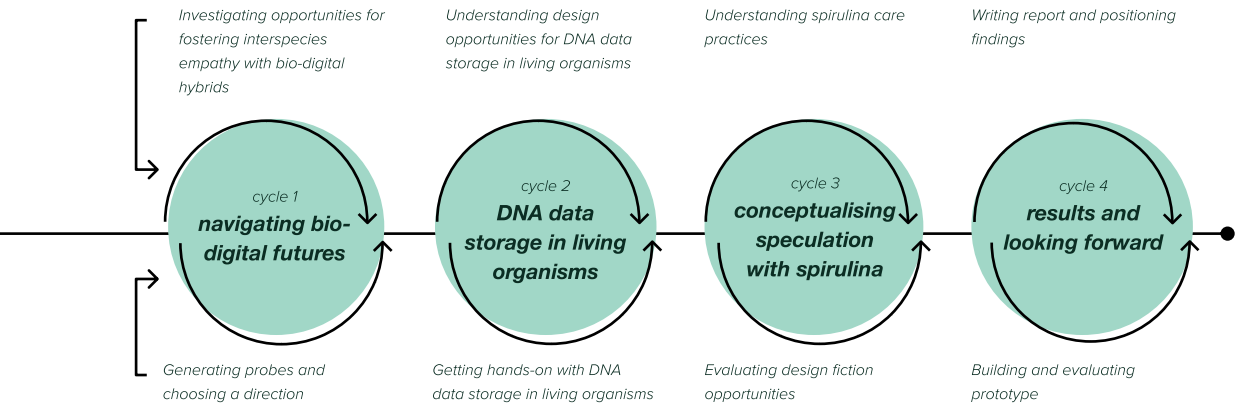
RESEARCH FOR DESIGN
Exploring design space

RESEARCH THROUGH DESIGN
Engaging with design space

FOUR CYCLE APPROACH

The underlying structure of the project has four pivotal cycles that suggest specific focus areas. A circular format is preferred instead of a diamond structure to ensure an open and iterative approach to each focus area.

Each cycle is divided into two sections; research for design and research through design. Although the project followed a research through design approach, research for design activities also helped inform the design process.



Research for design, as explained by Stappers et al. (2017) refers to research activities that inform the design process. In this project this is largely explained as expert interviews and literature research, but also to other activities like a co-speculation session (pg. 51), growing spirulina at home (pg. 67) and understanding how others experience growing spirulina (pg. 69). In general, these research activities were deployed to learn about the design space before (and sometimes while) engaging with it.

Research through design refers to making designs and evaluating peoples responses to them as a way of gathering information. In other words, engaging with the design space through making. This mainly involved building prototypes and seeing how people reacted to them.

Grounding methodologies

This project combines methodologies from more-than-human design and speculative design within a Research through Design (RtD) approach. Perspectives from speculative design are deployed in crafting design artifacts that help people imagine alternative future relationships with living organisms mediated by DNA data storage. Thus, the research outcome of the project, and findings on the way were identified by analysing what questions and discussions a speculative artefact provoke. More-than-human design perspectives informed the development of the prototypes and the alternative futures they represent

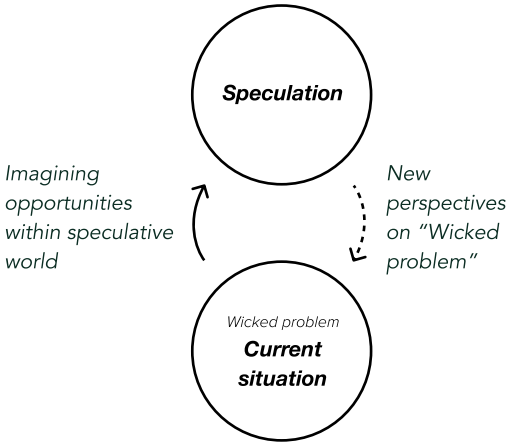
SPECULATIVE DESIGN

Speculative design *"thrives on imagination and aims to open up new perspectives on what are sometimes called wicked problems, to create spaces for discussion and debate about alternative ways of being, and to inspire and encourage people's imaginations to flow freely"* (Raby & Dunne, 2013). Unlike producing designs for industrial purposes, speculative design artifacts and research methods are intentionally provocative, simplified, and fictional to help people imagine and engage with possible futures while critically reflecting on current practices (Auger, 2013). It is similar to research through design in the sense that both look towards imaginary futures. Speculative design focuses more on the fictional artifact, while research through design is concerned with what we can learn from the artifact.

Outcomes of speculative design do not typically lead to concrete solutions or measurable results but provide a starting point for asking more questions, sometimes making it difficult to measure what speculative design leads to. Some scholars have positioned Speculative Design as more of a research tool rather than providing specific results. Galloway & Caudwell discuss, *"We believe that speculative design offers much promise as a form of "undesign" that requires a shift from viewing it solely as a form of research output or possible solutions to possible problems, to a method of research, or means of asking questions and generating new connections"* (2018).

Within RtD, speculative design methods are often deployed to engage with a problem and identify opportunities for a research community. Lawson et al. (2015), for example, made speculative products for tracking the movements and emotions of pets. The prototypes were presented and discussed in focus groups with pet owners and animal behavioural experts, which further informed a broader debate regarding quantification technology.

This project uses speculative design to prompt imagination, ideas, and reflection around relationships with living organisms and digital data storage. In this design process, it was applied concretely during co-speculation (pg.51), a focus group with a research artefact (pg. 53), a design fiction evaluation workshop (pg. 71) and in analysing the final research artefact (ch. 7). All research activities involved making fictional artefacts, either with participants or discussing them with participants, and using the generated questions and connections as starting points for further research opportunities.



The figure illustrates how speculative design was used in this project to imagine opportunities while critically reflecting back on the current situation

An example that overlaps with speculative design and more-than-human design. Lui et al. (2018) made speculative tools to inspire designers to think about how interactive technologies could invite people to notice non-humans in their environments.

MORE-THAN-HUMAN DESIGN

Although there are overlapping definitions, more-than-human design is, in essence, to incorporate the needs of other species and non-humans in design considerations while challenging anthropocentric ways of designing. Examples of projects that fall under the more-than-human category use design to bring humans closer to other species, either by caring and engaging with them or just by noticing that they are there. Related projects also look at how technologies can be utilised in alternative ways to achieve this. Lui et al. discuss that *"Because technologies play a critical role in shaping how humans relate to their environments, investigating design strategies to support multispecies resilience are of critical importance."* (2018). Existing more-than-human design projects can also often fall under the category of speculative design since they involve imagining multispecies futures.

A dilemma of more-than-human design is that humans, no matter how hard they try, will always be humans, making it impossible to understand other species fully. Still, more-than-human design encourages designers to acknowledge this while taking humble steps.

This thesis builds on background literature from more-than-human design and explores how technology can be utilized in shaping interactions that bring humans closer to microalgae. It was applied as a perspective that guided the design process rather than a specific set of methods. For instance, in the early exploration phase, a more-than-human design perspective motivated interviews with "plant sensing experts" to understand what people can do to form interspecies empathy towards plants. It also informed the decision to work with DNA data storage in microalgae since it involved exploring what might happen if humans feel directly dependent on a living organism in a relationship with them.

Research methods

Various methods were applied in the process of engaging with the research questions. These are the most dominant ones.

Literature research
Literature research was applied at various stages to find a research gap and understand mutualistic care within HCI, DNA data storage, and spirulina.

Qualitative research (expert interviews)
Interviews with various experts: “plant sensing experts,” design students experienced with bio-digital hybrids, DNA data storage experts, and “Spirulina growing experts” helped inform and deepen the findings from the literature at various stages in the project.

Creative facilitation
Creative facilitation is applied to facilitate processes where people feel free to be creative, inspire each other, and generate ideas and opportunities that inform the design process (Heijne & Meer, 2019). Principles from creative facilitation were used concretely during a co-speculation session (pg. 51) and a design fiction evaluation workshop (pg. 71).

Focus groups with speculative research artifacts
Focus groups were conducted to let participants bounce ideas off each other and engage in subjects on a deeper interpersonal level. This is also a strength of the focus group format (Freeman, 2006). Focus groups were conducted first to understand how people related to storing data in trees (pg. 53) and later when evaluating the final prototype (ch. 7). In both focus groups, speculative research artefacts were presented as a starting point for discussion.

Prototyping as a way of engaging with the design space
Design theorists discuss how engaging with the design space of a problem by making things is in itself a way to ask questions and find connections in the design space (e.g. Schon & Wiggins, 1992; Cardoso, Badike-Schaub & Eris, 2016). In this project, probes were made to explore opportunities with bio-digital hybrids (pg. 42) and DNA data storage (Appendix D). Prototypes were also built to explore the design space between gene editing and plant care (Appendix H) and to iterate toward the final prototype.

Video sketching
Speculative video sketches were made to help participants imagine possible scenarios with DNA data storage in the focus groups. Video sketches can be used to illustrate concepts, prototype interactions, and test user feedback in a relatively low-fidelity way, saving time and resources compared to, for instance, making a detailed prototype. Additionally, video sketches can help convey the dynamics of a design scenario, which can be challenging to communicate through static images or wireframes.

Sensitising assignments
Sensitising involves giving research participants space to reflect and explore a topic by themselves before engaging with it in a co-design process to form deeper insights (Visser et al., 2005). Here, research participants completed sensitising assignments before the first focus group (pg. 53) and before the spirulina design fiction workshop (pg. 71), to reflect on data storage practices and experience caring for spirulina.

Example of a method used: probes for interviews with DNA data storage experts (ch. 4)

Initial brief and project goals

PROJECT GOAL

The initial goal of this project is to explore how bio-digital hybrids, a thing consisting of a digital component and a living organism, might be tools for fostering interspecies empathy. This addresses the general issue that, in many industrialised societies, there is a tendency to neither notice nor value our entanglements with the ecosystems we live in, even though they are present and crucial for life and well-being.

Since the general issue is significant, and the potentials for bio-digital hybrids are many, a part of the assignment is to investigate and define the problem to address a specific use case for bio-digital hybrids. The project started by looking broadly at approaches for fostering interspecies empathy towards plants in an exploration phase and then narrowed the focus to practices of mutualistic care between people and microalgae mediated by DNA data storage.

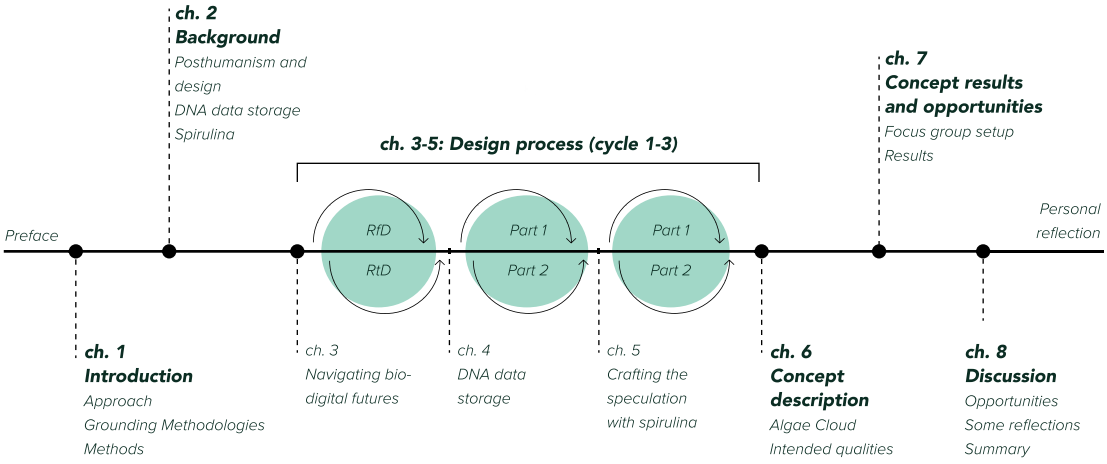
The project's end goal is to develop one (or more) prototypes that explore what mutualistic care between people and living organisms, mediated by DNA data storage, could look like.

INITIAL QUESTIONS AND PROJECT GOALS

The project started with a set of questions to guide the initial literature review and first research activities. Since the project scope was quite broad, the questions and initial plan were expected to change throughout the process.

1. What does it mean to have interspecies empathy towards living organisms? What do people who notice living organisms see in them?
2. How can bio-digital hybrids help foster interspecies empathy?
3. What qualities does DNA data storage offer in a bio-digital hybrid?
4. What opportunities for mutualistic care could DNA data storage in microalgae bring?

Report structure



This report has seven chapters, a preface, and a conclusion. After introducing the project and background in chapters 1 and 2, chapter 3-5 gives an overview of the design process. Chapters 3-5 are divided into “Research for Design” and “Research through Design.” Chapter 6 presents Algae Cloud, the research artefact outcome, and Chapter 7 presents results from a focus group discussion. In Chapter 8, the results are discussed and summarised.

CHAPTER SUMMARY

In this chapter, we introduced the project brief, grounding methodologies, and methods. It follows a Research through Design approach while applying methodologies from Speculative design and more-than-human design. The project starts by looking broadly at bio-digital hybrids for fostering interspecies empathy and eventually steered towards mutualistic care between people and living organisms mediated by DNA data storage.

ch. 2

BACKGROUND

Posthumanism and design

This section briefly presents relevant posthumanist theories and how it relates to bio-digital hybrids and mutualistic care. This is included to bring an idea of what type of terrain this project is situated in.

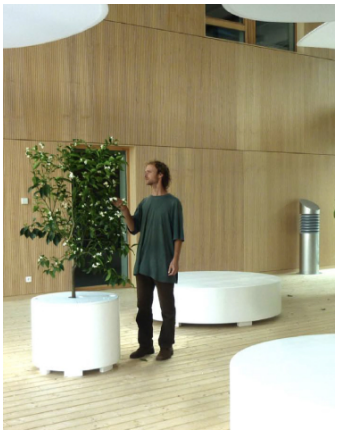
Since the onset of the industrial revolution, humans - primarily in Europe and North America - have been extracting resources, emitting more and more greenhouse gases, and causing disturbances to ecosystems at an escalating rate. This has led to the current era being labeled the Anthropocene, where human actions are the primary catalysts for alterations in the planet's geology, ecology, and climate (Ruddiman, 2013). The name suggests that the current climate situation is both the fault of humans and that our faith is entangled with its development. Although there are efforts to halt this progress by gradually transitioning to green energy forms, the transition is currently not fast enough to stop catastrophe (United Nations, n.d.). At the same time, the green energy transition requires minerals and resources that seriously threaten indigenous communities and the many local ecosystems they help maintain. (Hafner & Tagliapietra, 2020).

Post-anthropocentric ways of thinking have evolved and call for fundamentally rethinking what roles humans should play when we inevitably have to stop doing “business as usual” and find new ways of relating to and being in the world. Although there are different lineages of post-anthropocentric thought, key characteristics include rejecting the human as divine or supernatural, decentering and viewing humans as part of an ecosystem rather than on top of it, and resisting binary categories (Forlano, 2017). Fundamental thinkers in this field are Donna Haraway, Anna Tsing, and Maria Puig de la Bellacasa. Haraway emphasizes the interconnectedness of all living beings, de la Bellacasa advocates for a more caring approach to nature, and Tsing explores the interdependence between humans and non-humans in capitalist ruins. (Haraway, 2008; Tsing, 2019; de la Bellacasa, 2017)

More-than-human design and technology

Post-anthropocentric lines of thought also acknowledge the power of technology to impact humans' relationships with their environment and other living organisms. Light et al. call for designers to avoid “Bovine technology, or tools that encourage passivity, rote behaviour and a blinkered existence at a time of great uncertainty and change” (2017). De la Bellacasa advocates designing more caring relationships with non-human entanglements in an aching world (Puig de la Bellacasa, 2017). HCI researchers adopting viewpoints from Anna Tsing and Donna Haraway talk about how interactive technologies could enhance humans' abilities to notice and respond (“response-abilities”) to more-than-human entanglements around them (Liu et al., 2018). Gough et al. discuss how “Biodesign is a field that will extend beyond human-centred design, to a form of human-organism symbiotic design” (2020)—suggesting that living with living things in everyday practices could create new human-non-human partnerships.

Photo by Maksim Shutov on Unsplash



Listentree (Portocarrero et al., 2015)

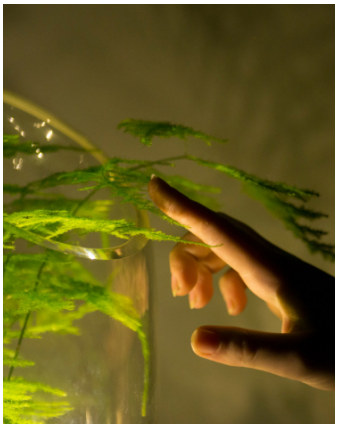
BIO-DIGITAL HYBRIDS

Areas of HCI have applied post-anthropocentric theory into practice in different ways, many of which fall within the bio-digital hybrid category, which in this project is broadly referred to as systems where living organisms are paired with digital technologies to do something. Some have studied how care as defined by Maria Puig de la Bellacasa could manifest into everyday products embedded with living organisms. An example is Nukabot; a technological enhanced traditional Japanese wooden bucket used to pickle vegetables in a fermentation process, which engages people in the fermentation process by having conversations with them and inviting them to care (Chen et al., 2021). Human-Plant-Interaction (HPI) is a research area within HCI that examines how plants' natural abilities to sense and respond to stimuli from the environment can be applied as components in design, offering novel interactions, sustainable degradable components, and opportunities for aligning the needs of humans and plants through technology (Chang et al, 2022). Chang et al. provide a comprehensive framework of opportunities and use cases for HPI, ranging from bio-integrated city technologies to fostering human well-being and interspecies empathy. An example here is Listentree, an installation that connects audiences to the environment while interacting with the tree through the sonification of ecological data (Chang et al, 2022). Another example showed that Engineered spinach plants could concentrate and collect certain chemicals in groundwater and then transmit data about these chemicals via infrared communication to a smartphone, acting as a kind of living smart sensor for city infrastructures. Most existing examples of combining living organisms with technology are small-scale research experiments and art installations; still, they hint at what interactions with living organisms could look like in future everyday products or even larger infrastructures.

Speculating on posthuman, bio-digital futures

Drawing the lines back to post-anthropocentric philosophies, bio-digital hybrids present opportunities for rethinking current anthropocentric ways of relating to the world. Obviously, we are far away from a society where the needs of living organisms and humans are perfectly aligned, and many current bio-digital hybrid systems need electronic components and a lot of resources to function. Still, bio-digital hybrids can help imagine opportunities and iterate towards preferable futures. While technologies we use have been discussed as contributing to a feeling of artificial divide between humans and non-humans (Haraway, 2008), we could design them in a way that helps humans notice and care for living organisms, learn more about them, and foster symbiotic relationships between people, living organisms, and technology.

Nukabot (Chen et al., 2021)



(Living Light, n.d.)

CARE

Care ethicist Maria Puig de la Bellacasa explains care as a relational and situated practice that extends to more-than-human worlds, including animals, plants, and the environment. Care is also described as tensions and relations between three dimensions; labor/work, affect/affections, and obligation. Labor, or doing care, refers to the physical, practical acts of caring. Affect is more emotional, bodily, and intimate, which also impacts how people care. Affect doesn't necessarily have to be positive feelings and emotions, but can also be harmful or more complex. Obligation refers to ethical, moral, or socially influenced reasons for why someone feels they should care. De la Bellacasa also emphasises that care doesn't always involve a perfect distribution of the three pillars but that there are often unsolved tension and contradictions between them. The traditional notion of care as connected to love and affection, for example, gives paid care workers a moral obligation to also emotionally invest in the work they are doing, who might rightfully want to preserve their affective engagement. As mentioned earlier, previous HCI work has applied care as a lens to design with, engaging people to not only to design things to be used, but *"engage with their becoming"* (Puig de la Bellacasa, 2017).

MUTUALISTIC CARE IN LIVING ARTEFACTS

Biodesign suggests that living organisms can be embedded into functional artefacts while still alive. Living artefacts is a framework for this type of bio-design that highlights the artefacts' livingness after it is assembled in the design process. This framework propose three principles for designing for livingness: Living Aesthetics, Habitabilities and Mutualistic Care (Karana et al., 2020).

Mutualistic care is the care between a human and a living artefact that is situated in everyday practice. It highlights that humans not only care for the artefact but receive care, in the form of functional benefits, in return. The novel actions that caring for the artefact entail are embedded in the notion of mutualistic care. For example, Living Light generates electricity from a plant pot and turns this into light, making watering the plant and occasionally adding nutrients a part of the care. Living light also includes a symbolic care action, which is caressing the leaves to generate light. Mutualistic care also highlights that the relationship is evolving and developing.

DNA data storage in living organisms

This section introduces DNA data storage in living organisms as a use-case for bio-digital hybrids. A basic understanding of what DNA data storage is and why it's becoming relevant is included. How the technology has been explored within HCI is also discussed to give an idea of what opportunities the technology represents, in particular, for fostering more-than-human relationships, which is relevant for this project.

DNA DATA STORAGE AS A POTENTIAL COMMERCIAL TECHNOLOGY

What is DNA data storage

DNA data storage is a way of storing digital data using synthetic DNA, and in theory, the process is quite simple. Digital data on a base level is a sequence of 0s and 1s. This can be converted to lines of nucleobase code (A,C G,T) which form the basis of DNA, and can be synthesized into strings of DNA molecules. The machine-made DNA string can be stored in vivo (inside of a living cell) or in vitro (not in a cell). The DNA strings representing data files can be sequenced, decoded, and read back into a file later (Alliance, 2021).

The promise of DNA data storage as a commercial technology

Storing data in strands of synthetic (manufactured) DNA has been an idea since the 1960s and hailed as "the ultimate data storage solution" (DNA: The Ultimate Data-Storage Solution, 2021). The molecular structure of DNA is extremely dense, durable, easy to replicate, and requires little energy and resources to maintain. In theory, DNA data storage could fit all the information on the internet in a shoe box (Bear-McGuinness, 2017), and keep it stable for up to a million years with few maintenance costs (Kim et al., 2022). Although major technological developments are needed to make DNA data storage viable, many large collaborations and research institutes are racing to make it happen. 2020 saw the formation of the DNA Data Storage Alliance, comprising Illumina, Microsoft, Twist Bioscience, and Western Digital. There are 43 official members in the form of academic institutions, collaborations, and government-sponsored organizations across various fields and industries at the time of writing.

Why it's relevant

We are in a global information era characterised by hoarding, buying, and selling data. Data volumes are becoming more extensive than we can store, manage and analyse, making "Big data" a big problem (Alliance, 2021). It is predicted that current data storage options won't be able to cover the exponential storage demand, so alternative data storage methods like 5D optical storage, helium hard drives, and DNA data storage are becoming increasingly relevant. Current data storage methods also require a lot of energy and resources. Data warming is a term coined by Grow your Own Cloud referring to the increasing amount of greenhouse gasses emitted to store and maintain data with current data storage methods (GYOC, n.d.), which is currently more than the aviation industry.

DNA DATA STORAGE IN HCI

Beyond commercial applications, artists, designers and HCI researchers have explored DNA data storage in various formats. Microvenus, published in 1996, is a genetically modified E.coli bacteria encoded with a line drawing of an ancient Germanic rune used to represent life (Mendell et al., 2022). Microvenus was conceptualised as a message to be sent into outer space to communicate with extraterrestrial life forms. The National Film and Sound Archive of Australia also stored a film of athlete Cathy Freeman winning the 400-meter race at the 2000 Sydney Olympic Games, stating *"an iconic moment which has metaphorically become part of Australia's DNA is now stored on actual DNA"* (Mendell et al., 2022). Other work has, for instance, stored data in paintings, spray paint, and wine (Hamidi et al., 2021), adding more profound, symbolic meanings to physical items. These examples actually translate digital data into DNA and in some cases genetically engineer it into a living organism. Some of the examples within HCI also reflect on how using DNA as a living interface with data could bring new interaction opportunities. Alistar & Pevere discuss that tangible interfaces from living matter are more relatable for users compared to non-living media (computers, etc.) because life is a shared experience (2020).

DNA data storage has also been explored on a more conceptual, speculative level of imagining opportunities it could bring for everyday interactions and societal change. Artist and designer Qin[2] made *Living Harddrive*, imagining a houseplant as a hard drive (DNA Living Hard Drive, n.d), and *Skin Database*, imagining humans being able to store their data in their own skin (DNA Living Hard Drive, n.d.). *Symbiosis* also imagines a symbiosis between plants and data in the home (Jang, 2022). Previous work by Kim et al. (2022) examines opportunities for DNA data storage within HCI. A series of workshops with participants who engaged with grounded speculations on possible futures of DNA data storage, resulted in an initial set of design opportunities and challenges, namely, *"1) facilitate meaningful interactions that are intangible and molecular, and 2) foster better human relationship with more-than-human entities."* In summary, DNA data storage has enabled the storage of small amounts of data in symbolic and artistic formats. Furthermore, various design examples and studies in HCI highlight the potential for new and interesting interactions with data embedded in materials or living organisms.

Semina Aeternitatis (Allstar & Pevere, 2020): a story is hidden in bacterial biofilm and can be experienced through touch and smell.

Spirulina

Spirulina is a type of microalgae that was used in this project. This section briefly introduces its biology and projects that have applied its qualities to photosynthesise, produce oxygen and provide food in HCI, design and architecture. Insights from growing spirulina are in chapter 5.

(Our Algae — Nāmaka Algae, n.d.)

SPIRULINA BIOLOGY

Spirulina is a cyanobacteria or blue-green algae that grows in water and thrives with plenty of light and under high temperatures. It's one of the earliest forms of life on earth, being around for approximately 3,5 billion years, and is characterized by its spiral form when viewed under a microscope. Spirulina thrives in alkaline lakes, where other microorganisms find it challenging or even impossible to survive (Wan et al., 2021). This was also the case during its early days when there was limited life on Earth, and the waters were more alkaline. Spirulina can also grow quite fast compared to other living organisms like most plants. The quick growth, which involves converting CO2 to oxygen, means that spirulina produces a lot of oxygen when it grows.

"Living Things" (Living Things Spirulina Lamps « Inhabitat – Green Design, Innovation, Architecture, Green Building, 2015)

"Algae Dome" (The Algae Dome: A Food-Producing Pavilion | SPACE10, 2017)

"Algae Dome" (The Algae Dome: A Food-Producing Pavilion | SPACE10, 2017)

SPIRULINA IN ARCHITECTURE AND DESIGN

Cultivating microalgae like spirulina as a future self-sustaining food, oxygen, or electricity resource has been explored in architecture and bio-design. EcoLogicStudios Urban Algae Canopy (Hobson, 2015) and SPACE10s "Algae Dome" (The Algae Dome: A Food-Producing Pavilion | SPACE10, 2017) both raise awareness about the potential of microalgae and imagine it integrated into future urban architecture. "Living Things" generates electricity from the photosynthesising spirulina and use this for ambient lighting. (Living Things Spirulina Lamps « Inhabitat – Green Design, Innovation, Architecture, Green Building, 2015) "Elements" use qualities of spirulina as a home oxygen generator. Other projects like "Choral" (McNulty, 2021) and Spirulina Society (Spirulina Society, n.d.) make tools for helping people grow spirulina at home. Spirulina's ability to rapidly convert CO_2 and nutrients into superfoods and oxygen has generated interest in its potential role as a component in envisioning future symbiotic interactions in public spaces and households.

CHAPTER SUMMARY

In this chapter, we introduced more-than-human design and technology, its relation to bio-digital hybrids, DNA data storage in living organisms, and spirulina, a type of microalgae. This project examines how storing data in microalgae might impact mutualistic care between humans and microalgae.

Although everything is introduced together here, a large part of the project included exploring opportunities scoping it towards mutualistic care, DNA data storage, and spirulina. This is explained in the following chapters (ch.3, 4, and 5) about the design process.

ch. 3 - cycle 1

NAVIGATING BIO-DIGITAL WORLDS

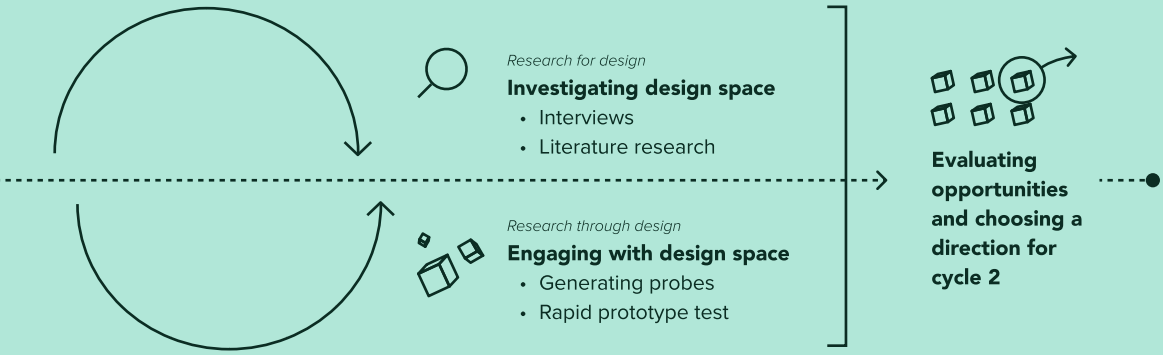
Entering cycle 1

Key terms: bio-digital hybrid, interspecies empathy

***Here we explore** opportunities for bio-digital futures and pairing living organisms with emerging technologies. Plants are examined as a specific use case for looking at options with bio-digital hybrids to provoke interspecies empathy.*

Guiding questions:
The research had two goals: identify design opportunities for bio-digital hybrids and to understand the factors that contribute to interspecies empathy. This understanding could potentially be applied to creating bio-digital hybrids that promote interspecies empathy.

1. How do people who have empathy towards plants experience them?
2. What are the design opportunities with bio-digital hybrids for provoking interspecies empathy?



Research activities

INTERVIEWS WITH "PLANT SENSING EXPERTS" AND DESIGNERS PREVIOUSLY WORKING WITH INTERSPECIES EMPATHY PROJECTS

Why

The interviews were conducted to get a sense of what it means to experience empathy towards plants and how this can be approached in design.

How

The interview participants were a mix of people researching and working hands-on with plants and promoting the value of plants to the public in various ways. Students who had worked on projects involving interspecies empathy towards plants were also interviewed to understand their research outcomes and in what ways design interventions can help shape interspecies empathy.

More information about the interviews are in appendix A.

"Plant sensing" experts

	Profession	Expertise	Organisation
PE1	*Gardener and architect*	*Gardening practices, urban planning, teaching*	*Freelance architect and workshop facilitator*
PE2	*Gardener*	*Gardening practices, urban planning, teaching*	*Botanical garden in the Netherlands*
PE3	*Biologist*	*Gardening practices, urban planning, teaching*	*Research institution*
PE4	*Botanist*	*Gardening practices, urban planning, teaching*	*Botanical garden in the Netherlands*
PE5	*Biologist*	*Plants, mycoheterotropic plants, fungi*	*Research institution*
PE6	*Botanist*	*Gardening practices, urban planning, teaching*	*Botanical garden in the Netherlands*
PE7	*Exhibition content developer*	*Exhibition deisgn*	*Natural history museum in the Netherlands*

Designers with interspecies empathy project experience

	Type of project	University
D1	*Speculative project involving interspecies empathy with urban trees*	*Masters student, TU Delft*
D2	*Project involving interspecies empathy in forests by sonification of trees*	*Masters student, TU Delft*
D3	*Project involving interspecies empathy in parks by sonification of trees*	*Masters student, TU Delft*
D4	*Project involving interspecies empathy with houseplants*	*Masters student, TU Delft*
D5	*Project involving interspecies empathy with sonification of houseplants*	*Masters student, TU Eindhoven*

LITERATURE RESEARCH ON EXAMPLES OF DESIGNING BIO-DIGITAL HYBRIDS

The goal of the literature search was to see how bio-digital hybrids have already been used to foster interspecies empathy. Some research and interesting areas to look to were also inspired by recommendations from some of the interview subjects.

WHY IS INTERSPECIES EMPATHY IMPORTANT?

WHY ARE PLANTS IGNORED?

The issue of “plant blindness” was often mentioned in the interviews, and broadly refers to people’s natural “disability” to notice plants and relate to plants over, for instance, animals or other humans, and the standard notion of thinking of plants as “background elements.” From an evolutionary standpoint, this makes sense; we are naturally attuned to notice things that can be a potential threat, like other animals and things that move. Plant blindness, though, is not something that all social groups or people acquire.

Balding & Williams (2016) argue that cultural processes such as language and practices also affect the ability to notice plants. *“If immersed in a plant-affiliated culture, the individual will experience language and practices that enhance capacity to detect, recall, and value plants, something less likely to occur in zoocentric societies.”* Plants tend to be ignored because of evolutionary reasons but also of how cultures and practices treat and relate to them.

WHAT ARE POTENTIAL EFFECTS OF HAVING INTERSPECIES EMPATHY?

When asked why feeling empathy towards plants is important, a common theme in the interviews suggested that learning about how crucial plants are to our local and global environments will promote a feeling or need to protect them.

> *"Maybe you just see a dandelion on your sidewalk. but then if you learn a bit more, you understand that a dandelion is a food source for lots of bees species, not just honey bees, but hundreds of other bee species in the Netherlands. And maybe then you're like, oh, maybe I should leave it and protect it. And maybe it's even pretty." - PE3*

Participants who worked hands-on with gardening also mentioned how working with plants and learning to attune to their needs made them more sensitive to the climate around them and how different organisms are entangled with each other, and in turn, with humans.

> *"It's humbling. you get into contact with all these little creatures and all these little processes and all these mushrooms popping up. There's so much going on [..] I feel more in contact with the seasons and weather from gardening. That's another thing… I can be really happy when it rains." - PE1*

Participants who worked hands-on with gardening also mentioned how working with plants and learning to attune to their needs made them more sensitive to the climate around them and how different organisms are entangled with each other, and in turn, with humans.

> *"We see that plants that come from other places now stay alive here and grow very well." -PE2*

On the other hand, in contexts where the particular plant is isolated from the local ecosystem, such as houseplants and plants in greenhouses, the practice of seeing the plants as part of an ecosystem isn't that relevant. Still, learning to attune to and cooperate with a living organism that is unpredictable could foster respect and fascination towards plants that can extend beyond the isolated context later.

> *"Growing plants is a dance with nature. Nature doesn't always do what you want to do, and letting go of the control - and learning from the unexpected instead. That's when it gets interesting" -PE1*

The idea of "becoming with" or coexisting with other living beings, is closely linked to posthumanist ideology. Instead of striving to dominate and control living organisms, humans could learn to observe and attune to them, accepting a certain degree of loss of control. This way, both humans and other living beings could thrive alongside each other without neglecting the needs of non-human life for the sake of human interests.

Summary:

People's (dis)ability to notice plants around them is partly evolutional but also connected with culture and practices. Feeling interspecies empathy can involve accepting a certain loss of control and shifting towards cohabitating with other species instead of controlling them. It can also make people feel a stronger need to protect other species around them.

IN WHAT WAYS COULD BIO-DIGITAL HYBRIDS HELP INTERSPECIES EMPATHY?

Themes from plant-sensing interviews

Theme 1: **Enhancing noticing and caring**

Getting closer to and being attentive toward plants is a helpful tool for fostering interspecies empathy. From the interviews with people working to educating the public about plants, a common tool is to give people magnifying glasses and encourage them to look closer at plants. Another method is making people draw plants since drawing encourages people to look closely at something to replicate it on paper. Getting hands-on and caring for plants can also encourage noticing as it helps people learn and attend to plant needs while watching the plant develop and grow. Learning to notice plants also consents to more-than-human design approaches and examples, and practicing noticing is promoted by Anna Tsing as a tool to respect the agency of other species (Liu et al., 2018).

Theme 2: **Mutualistic care**

Humans are dependent on plants for oxygen, food and life. Still, in many technocentric societies, people are far from connected to where what they eat and use comes from. Practices like growing plants to eat or for medicinal purposes, for example, or learning about where what we eat comes from, can install a sense of dependency and mutual connection towards plants. Research shows that plant blindness is less of a problem in areas where people grow their own crops and engage more with the land and soil (Jose et al., 2019), which is also something that was mentioned in the interviews.

Theme 3: **Novel and situated plant experiences**

Strong experiences that instill awe and surprise can also be a tool for making people curious about plants. Shaping experiences that detach people from the familiar notion of plants as background elements to fascinating creatures that move and make decisions can spark interest and motivation to learn and engage more. This was also stressed by some of the plant-sensing experts:

> *"As long as I can spark a visitor's interest, I'm happy. People are so blind to plants, and it's about opening the eyes."*
> *-PE 6*

Theme 4: **Learning about plants (education)**

Learning plant names and their peculiar traits can draw people towards them and be a tool for engaging people with plants around them. An experiment conducted by Jose et al. suggested that learning plant names can be a tool to help defeat "plant blindness" ((Wandersee & Schussler, 1999), and this is also something interview participants emphasized. Several plant-sensing experts working with education also mentioned the importance of getting children interested in plants from an early age and are working closely with schools across the Netherlands.

> *"When the leaves fall in autumn, people remove them because it's trash. It's dirty, but basically this is essential for the nutrient cycling of the system, right? I think if people learn this, they are maybe more open to changing their behavior." -PE5*

Design opportunities with bio-digital hybrids

Example(s)

Technology and design can enhance plant expressions and draw humans closer to them. For example:

1. Sensor technologies can be paired with plants to articulate “hidden” plant states and make humans aware of them.
2. Some designs also explored how things humans wear or already use can be designed in a way that brings people closer to the living organism and, in that way, encourages noticing. An example is from Lui et al (2018) who explores design for collaborative survival

A moisture sensor is embedded into a glove to draw people closer to the soil while using the tool (Liu et al., 2018)

This pot monitors heat, sun level and moisture to express the state of the plant to humans as a pet (Stewart, 2019).

1. Living artifacts facilitate mutualistic care between humans and living organisms. Humans care for living organisms and receive functional benefits in return.
2. Some speculative designs explore futures where plants are given more power, and thus mutualistic care happens on a larger scale.

Living light: humans care for a plant and get light in return (Living Light, n.d.)

This student project imagines that citizens pay or care for public trees as infrastructure

1. Examples from art and design have explored new ways of relating and doing with living organisms with bio-digital hybrids. These artifacts ask fundamental questions about our relationships with non-humans and embody them into something.
2. Bio-digital hybrids can show people surprising things that plants do and facilitate engaging interactions with them. Three design students who were interviewed explored alternative ways of sensing plant presence through bio-sonification approaches.

The concept of play being an ontological characteristic of all living organisms, including plants, is embraced by PL’AI (Petrič, n.d.)

This student project, “musical trees” explored how to make people curious about trees in the park with interactive technology.

Technology and design can help people learn about plants by helping them see plants differently, remember plant names, or teach them about plant anatomy and life.

“Magic Flowerpot” is an AR game that promotes learning about plants in local, home environments (zarraonandia, 2019)

Some botanical gardens have added QR codes so that people can learn more about plants they see ((Experiences at the Gardens, n.d.)

DILEMMAS WITH BIO-DIGITAL HYBRIDS

The dilemmas were printed into "dilemma cards" and used to ideate (see pg. 41)

1. Using technology to come closer to plants
How humans design their technologies influences how we relate to ecosystems around us, so thinking of new ways of designing technologies to come closer to non-humans is a relevant approach. Still, one could argue that designing technologies meant to bring us closer to nature contradicts itself. As stressed by, for instance, Watsons' project Naturepod (n.d.); Why can't nature just be experienced as it is on its own terms?

2. Not understanding what plants express vs. not noticing plants enough
Some examples of bio-digital hybrids highlight plant expressions for people to notice them.
On the one hand, you could say that it's hard for people to relate to plants because they are different from us. However, people who take the time to engage with plants notice them differently. Is the problem that we can't understand them or don't take the time to learn to understand them?

4. Domesticating plants
More-than-human design evolves around noticing and joining entanglements in the ecosystem that humans inevitably are a part of. While this is a strong principle in more-than-human design, several examples involving plants and technology take plants out of their natural environments and into the unnatural and isolated environment we give them in plant pots. On the one hand, there is room for engaging with and feeling empathy towards plants in an isolated context, while, on the other hand, this is far from their preferred natural habitat in the first place.

3. Anthropomorphism vs. otherware needs otherness
On the one hand; anthropomorphising plants can make them easier to relate to for humans, which can, in turn, make more people empathetic toward plants. On the other hand, plants should be seen as intelligent on their terms (Bridle, 2022) and respected as the complex organism they are instead of a simplified human. If plant expressions are enhanced through technology, what forms should they take?

5. Interspecies empathy vs. capitalism
It is easy to get discouraged and pessimistic by attempts to foster interspecies empathy in an industrialized society that functions by putting the needs of humans and plants at odds with each other. Projects like More-than-human citizen sensing (More-Than-Human Citizen Sensing, n.d.) show how noticing can help us respect local ecologies, but what could make us motivated to notice in the first place if our economy or way of living doesn't depend on us doing it?

6. Mutual dependency vs. increased feeling of complexity
In our (western, technocentric) practices, we are far from connected to where what we eat and use comes from. Many indigenous practices promote a direct dependency and interaction with non-humans to live. How do we install this sense of mutual dependency in a world that is growing in complexity?

SUMMARY OF INSIGHTS FROM RESEARCHING DESIGN SPACE

1. Potential effects of interspecies empathy
People's (dis)ability to notice plants around them is partly evolutional but also connected with culture and practices. Feeling interspecies empathy can involve accepting a certain loss of control and shifting towards cohabitating with other species instead of controlling them. It can also make people feel a stronger need to protect other species around them.

2. Bio-digital opportunities for interspecies empathy
There are several ways to approach designing for interspecies empathy with bio-digital hybrids. It can help people notice and care for plants, make them feel directly dependent on plants, help them learn about plants, and create novel and situated experiences.

3. Dilemmas
From this, a lot of dilemmas emerge around whether mixing technology is right, and how to approach interspecies empathy in a society that puts the needs of humans and plants at odds with each other

DESIGN ACTIVITIES

QUICK GUERRILLA TEST

Why

An early assumption was that using technology to show "hidden" plant expressions can be a tool to foster interspecies empathy.

RQ:

How might showing plant expressions influence empathy towards a plant?

How

Basic plant expressions related to a particular plant were displayed in a low-fidelity exhibition-like context, namely: Microscope images of photosynthesis in leaves, Electrical signals from the plant and Images of warning signals being triggered in plants by touch. Participants were later given a form that was meant to assess their feeling of empathy towards the plant. A short interview was conducted after they filled out the form. The test lasted 15-20 minutes, and four participants joined. More information about the experiment can be found in appendix B.

Key takeaways

Participants touched the plant to see if it affected the electrical signal graph (which was a mockup), and three of them said they gained a new perspective on their houseplants. The other parts of the exhibit demonstrated how plants have "nervous systems," but participants found it difficult to connect this to the plant in front of them. After filling out a form and discussing plant empathy, it was clear that moving from brief experiences to changing plant perceptions is challenging.

The test revealed that experiencing plant expression can spark curiosity and play, but developing long-lasting empathy is complex and difficult to measure.

Guerrilla test setup

THEME CARDS AND DESIGN PROVOCATIONS

Why

Explore design space within different approaches of designing bio-digital hybrids for interspecies empathy.

How

Insights from theme exploration 1 were gathered into "theme cards," which were used for ideation. The theme cards were the categories: "*technology opportunities," "plant expressions," "dilemmas," "practices for fostering interspecies empathy,"* and *"approaches with bio-digital hybrids."* Inspired by creative facilitation (Heijne et al., 2019), force-fitting different themes was used to spark novel ideas and think outside the box. All theme cards and provocations can be found in appendix C.

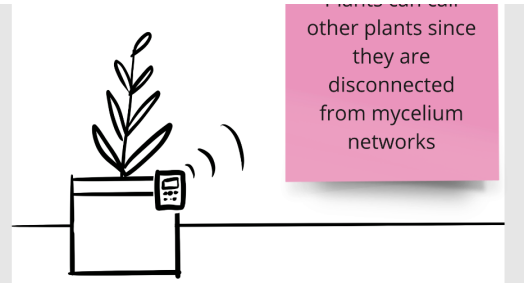
Miro board with probes

Results - options for project direction

"Plant-centered design"

Theme: 3. Novel and situated plant experiences.

This theme looked at how interactive technologies could work in the interest of plants and designing for plants as social agents. One example was a "plant cell phone," making it possible for plants disconnected from their mycelium networks to communicate. Even though Plant-centered design is supposed to work in the interest of plants, but would probably work better as an exhibition piece for humans to discuss.

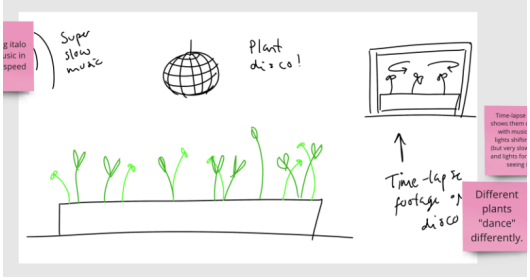


"Plant cell phone"

Make people fascinated about plants by seeing them in a different light

Theme: 3. Novel and situated plant experiences.

This theme relates to "novel and situated plant experiences," and looked at how bio-digital hybrids could create exhibition experiences that would make people experience plants in a different light. This direction could have been further explored as an exhibition piece. An example is "plant disco," which highlights that plants move and respond to the world, but on a different timescale.

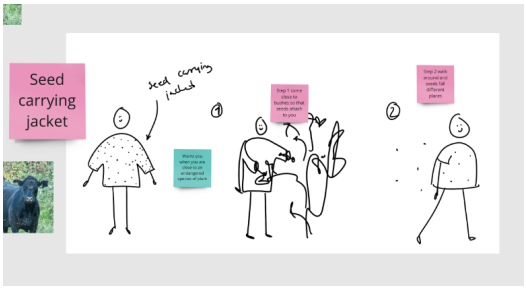


"Plant disco"

Design for humans to help plants around them

Theme: 1. Noticing and caring.

This theme looked at how humans could help plants around them through design. Examples were "seed carrying jacket" and "burglar alarm," which recognize when tomato plants send natural "danger signals," which they send to other tomato plants in the wild, and communicate it as an attack alarm to humans. This direction could be further explored to see if interventions like these impact interspecies empathy over time.

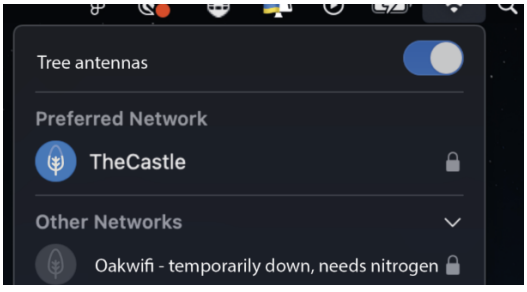


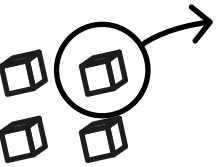
"Seed carrying jacket"

(Chosen direction) Posthuman scenarios of mutualistic care between plants and humans with emerging technologies

Theme: mutualistic care. This direction was also inspired by the dilemmas.

This theme developed from ideating with dilemma no. 6: mutual dependency vs. increased complexity. It involves designing interventions in everyday practices that foster a mutual dependency between a human and a plant with emerging technologies. Examples were "tree wifi," based on an old technology that allows trees to function as antennas (Schilten, 2014). Another idea, "plant data storer," was that personal data could be stored in houseplants using DNA data storage technologies.





Navigating opportunities and choosing a direction

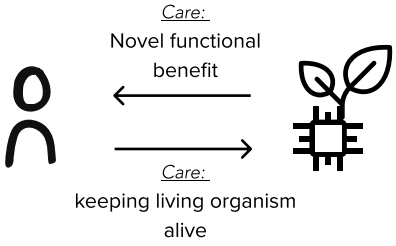
Now we have identified and engaged with opportunities on how to address interspecies empathy with bio-digital hybrids. Since we are dealing with a broad space of opportunities with no straightforward answers, exploring mutualistic care with DNA data storage in living organisms is chosen as a direction to explore further. This section explains why.

Discussion

TOWARDS POST-ANTHROPOCENTRIC SCENARIOS OF MUTUALISTIC CARE

Early in the process, an assumption was that showing people “hidden processes” in plants through technology could be an interesting approach for helping people relate to and be more attentive toward plants, which was also explored in the guerrilla test. Existing similar projects use different plant sensors to pick up a signal from a plant or its habitat, like moisture and light levels, and translate it into something else, like sound or facial expressions. In this area, multiple dilemmas and contradictions between human-centred design and more-than-human design emerge; Should plant expressions be anthropomorphic or not? Is it contradicting to use technology to understand plants? Or should we just embrace the way plants are and focus on noticing them more instead? These contradictions raise interesting questions about relationships between humans and plants and can be good fuels for thought. After learning more about existing examples of bio-digital hybrids, and various ways of feeling empathy toward plants, I learned that a large part of feeling interspecies empathy towards plants comes from attending to, noticing, and spending time with plants over time. Through working with plants in practice and feeling our sense of connection towards them, we can learn to attune to their (slower) ways of being and different expressions and needs.

Then, another dilemma is; how do we instil a sense of being dependent on plants in a world where there is an increasing sense of disconnect from where our resources, food, medicine, and materials come from? In other words, why would I need to attend to plants? Emerging opportunities within Biodesign might bring exciting answers here. How we have cooperated with nature throughout centuries has evolved with how we interact with it through technology; what symbiotic relationships between plants and humans could occur when biotechnology opens new doors to collaborations between humans and plants?



Discussion:

SOME TECHNOLOGY OPPORTUNITIES

There are a lot of technologies that could have been interesting to explore further within this area. Because of time constraints, a few were evaluated and DNA data storage in plants was chosen to move forward with. These were some options that were considered based on examples found in the literature research.

The options that involved caring directly for plants were preferred over those that included plants connected to larger ecosystems since this would make mutualistic care more explicit.

Trees as antennas
This direction was based on a project by BioArt Labs, which used an invention from 1904 to turn a tree into a radio antenna (Schilten, 2014).
Initial opportunities and challenges for further exploration:
+ This could perhaps make listening to the radio or using wifi a practice that involves taking care of trees
- Care is a bit complicated in this scenario, since the tree is self-sustained.

Electricity generated by living organisms
This direction is based on a technology that makes it possible to generate electricity from photosynthesis in living organisms.
Initial opportunities and challenges for further exploration:
+ We interact with electricity every day, so this direction could be quite versatile. It would also be interesting to relate to electricity as something that changes with light and weather outside, which makes the living organism photosynthesise.
- Not necessarily negative, but there are a lot of examples using this technology to generate light, like Living Light (Living Light, n.d.) and Living things ((Living Things Spirulina Lamps « Inhabitat – Green Design, Innovation, Architecture, Green Building, 2015).

Chosen direction: data storage in living organisms
This direction was inspired by Grow Your Own Cloud, which experiments with storing data in plants with DNA data storage technologies (GYOC, n.d.).
Initial opportunities and challenges for further exploration:
+ This represented a kind of interesting symbiosis opportunity. Data storage is something humans have become dependent on relatively recently, and something most people can relate to. Simultaneously, this area blends virtual and biological technologies, which is a step further away from the other options. DNA data storage as an emerging technology is also interesting because of the attention and development that is going into making it happen.
- The technology is far from being feasible.

Key takeaways from cycle 1

RESEARCHING THE DESIGN SPACE

1. Potential effects of interspecies empathy

People's (dis)ability to notice plants around them is partly evolutional but also connected with culture and practices. Feeling interspecies empathy involves accepting an inevitable loss of control and shifting towards cohabitating with other species instead of controlling them. It can also make people feel a more vital need to protect other species around them.

2. Bio-digital opportunities for interspecies empathy

There are several ways to approach designing for interspecies empathy with bio-digital hybrids. It can help people notice and care for plants, make them feel directly dependent on plants, help them learn about plants, and create novel and situated experiences.

3. Dilemmas

From this, many dilemmas emerge around whether mixing technology is right and how to approach interspecies empathy in a society that puts the needs of humans and plants at odds with each other.

ENGAGING WITH THE DESIGN SPACE AND MOVING FORWARD

1. Interspecies empathy is connected to practice

Single, situated experiences with plants can cause fascination and awe, but Interspecies empathy is a process that happens through time and regular practice.

2. Mutual dependency vs. increased feeling of complexity

Although people depend on plants to survive, few practices in technocentric societies foster this in everyday practice.

3. Opportunities in new technologies for mutual care

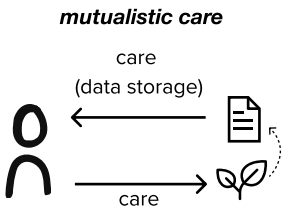
Emerging forms of biotechnologies bring new opportunities for mutualistic care between humans and living organisms, and these are explored further as "posthumanist scenarios of mutualistic care."

4. DNA data storage in living organisms

DNA data storage in plants is chosen as an interesting area to explore further.

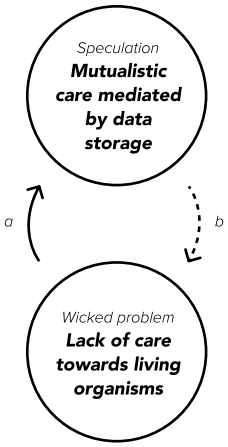
FOCUS ENTERING CYCLE 2

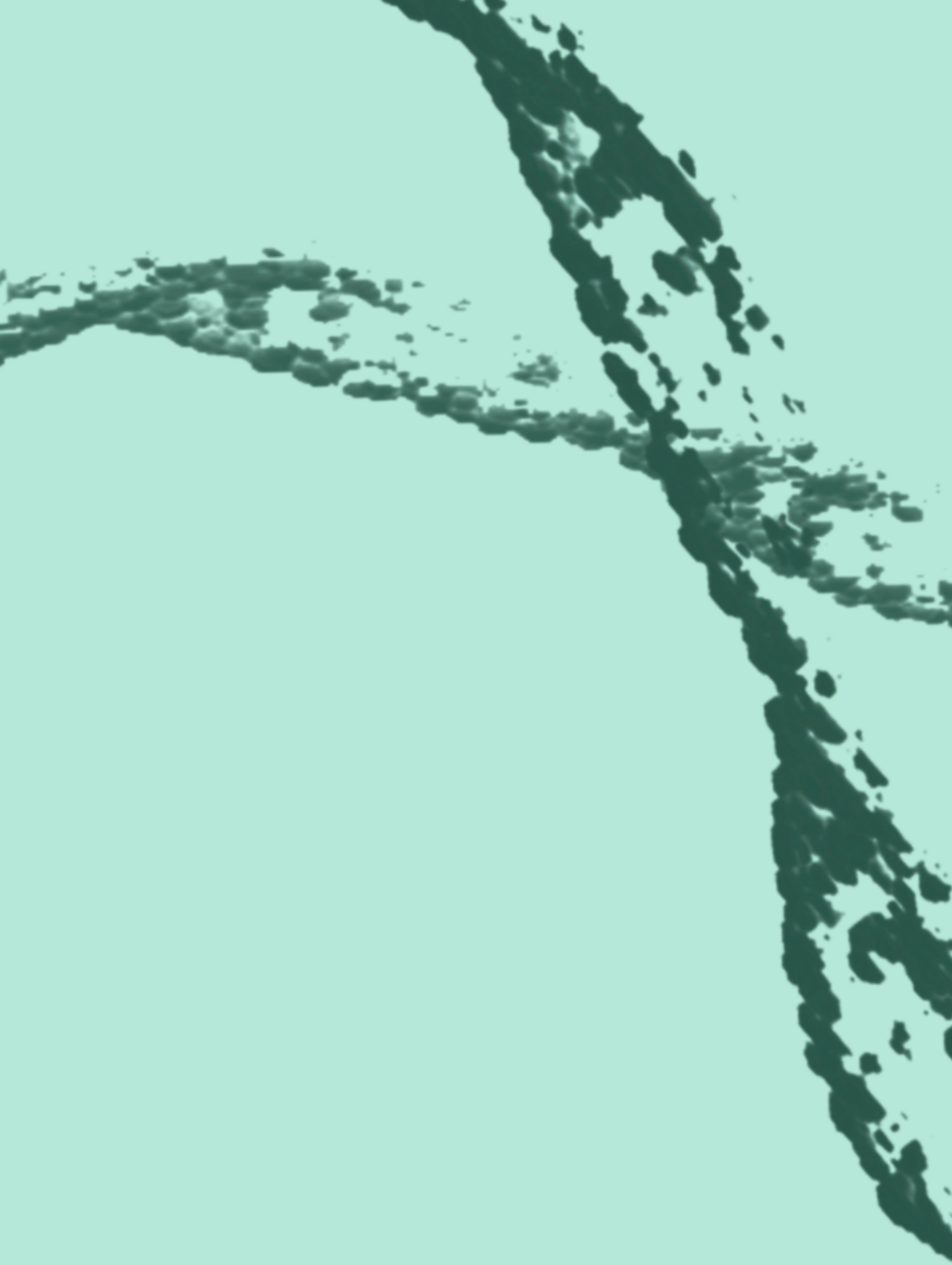
Explore how DNA data storage in living organisms might impact mutualistic care between humans and living organisms



CURRENT DESIGN GOAL:

Design a speculative artefact that encourages people to (a) imagine new relationships of mutualistic care between people and plants while (b) critically reflecting on current practices





ch. 4 - cycle 2

DNA DATA STORAGE IN LIVING ORGANISMS

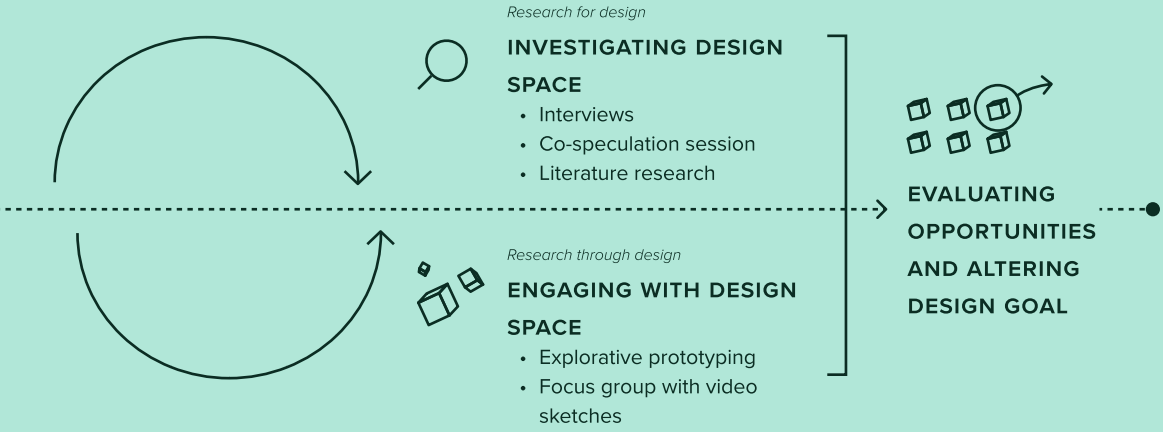
Entering cycle 2

Key terms: mutualistic care

***Here we explore** design opportunities for DNA data storage in living organisms, and engage with the design space by making prototypes and discussing them with people.*

Guiding questions:

1. What are design opportunities of storing data in living organisms?
2. How do people engage with DNA data storage in living organisms?



RESEARCH ACTIVITIES

INTERVIEWS WITH DNA DATA STORAGE EXPERTS

Why

Questions that were harder to answer in the literature search were asked in interviews with people working with DNA data storage.

How

In the interviews, the experts discussed some questions and reacted to probes. The discussions lasted 30 minutes to 1 hour, depending on how much time the participants had. The probes were examples of world-building tools made by participants in the co-speculation sessions, examples of existing projects such as Living hard drive (DNA Living Hard Drive, n.d.), and some ideas from the co-speculation session that were re-drawn for clarity.

DNA data storage experts

	Expertise	*Organisation*
DE1	*CTO and associate professor*	*DNA data storage company*
DE2	*PhD candidate and Co-founder*	*DNA data storage company*
DE3	*Biomolecular Engineer*	*DNA data storage company*

Key takeaways

- Basic understanding implications and technical challenges of the technology that surfaced in the co-speculation sessions.
- Understanding the technological state of DNA data storage and what people who work with it think. All experts were at least 50% certain it would be the next big data storage solution.
- Showing probes to the experts didn't help much. The interviewed experts work on making DNA data storage commercially feasible, so they mainly said what could actually work and what is technically very hard to do.

CO-SPECULATION SESSIONS

Why

The goal of having a co-speculation workshop was to open up the theme and investigate people's concerns, ideas, and thoughts about what society could look like if data was stored in plants.

How

The co-speculation workshop structure was inspired by the workshop structure used by Kim et al. (2022) and methods from creative facilitation to investigate imaginaries and possible scenarios with DNA data storage in plants. The workshop combined methods from creative facilitation (Heijne et al., 2019) with a futuring exercise (Joshi, 2021).

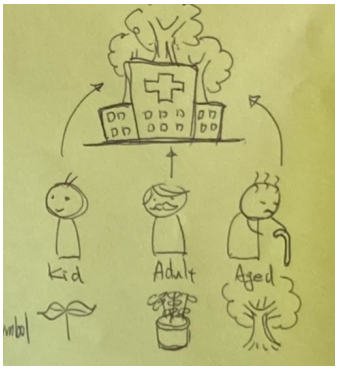
Two co-speculation sessions were conducted with seven design student participants in total. More information about the sessions is in appendix D.

LITERATURE RESEARCH ON DNA DATA STORAGE IN HCI

The aim of the literature research was to get inspiration from projects that also use DNA data storage. A brief overview of the findings can be found in the background section (pg. 27).

INSPIRATION FOR DESIGN OPPORTUNITIES

The co-speculation sessions were mainly a good source of inspiration and helped in imagining the width of opportunities available for storing data in living organisms. Drawing inspiration from previous work in HCI, previous examples of DNA data storage, and outcomes of the co-speculation sessions, the following design opportunities were identified for this project relating to DNA data storage in living organisms. A lot of the results are similar to previous work examining opportunities for DNA data storage (Alistar & Pevere, 2020; Kim, 2020; Kim et al,. 2022;).



"Forest hospital" imagines that a person gets a tree where personal medical information is added through the years.

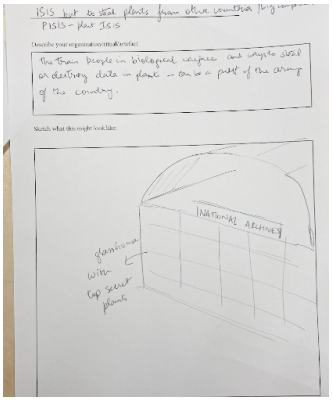
"Grow together": wedding vows encrypted into an engagement ring.

Multi-lifespan information management
Storing data in DNA offers opportunities to retrieve and respond to information over multiple generations. This theme is also explored by Kim (2020) and was frequently occurring in the co-speculation sessions. Many previous examples of data stored in DNA also store things meant to last a long time; information with monumental or political value for a country; for instance, the Declaration of Independence, . In the co-speculation sessions, some of the ideas evolved around storing long-lasting information in trees.

Fear of societal side-effects
Storing data in living things instead of closed servers could have huge implications for what role data storage could play. This theme was also present in Kim et al., study about possibilities with DNA data storage. Fears were expressed during the co-speculation session about DNA data storage in plats, mainly linked to ways data could potentially spread, be hacked, and how it might impact class distinctions. For instance, discussions evolved around who would own forests if they were data centres and that houseplants might become expensive, rare and represent status.

Symbolic, more-than-human connections
Many ideas from the co-speculation sessions had a high level of symbolic meaning. For example, one participant imagined marriage vows being embedded into engagement rings.

New Interactions
This theme relates to how blending living organisms and data storage brings ideas for new types of interactions. Participants discussed how people could eat data, and how reading data would involve physically going to plants.



"pISIS" trains people in biological warfare and wants to steal or destroy data in plants.

DILEMMAS AND IMPLICATIONS

Disjointed nature relationship vs. bridge to nature
Storing data in trees and plants could suggest that future interactions invite us closer to nature. Participants also discussed whether storing data in plants was decentering humans, or just represented another way of exploiting living organisms for human benefits.

Technological confusion and worry
Participants expressed confusion and worry about the technical implications of the technology. For example, what would happen if the plant died? Does the technology harm the plant? Could GMOs spread and ruin ecosystems? How does the data live inside the organism?

Key takeaways that influenced the design process:

1. The co-speculation format gave room for imagining a lot of different opportunities and concepts, but the hands-on feeling of mutualistic care was missing a bit, which was taken into account when planning the next focus groups.
2. The introduction to DNA data storage was too brief, which caused some confusion. Future activities should give a feel for what it is or explain it.
3. "Data" can be a bit abstract. In the next focus group activity, the sensitising assignment included thinking about what data storage means for people.

DESIGN ACTIVITIES

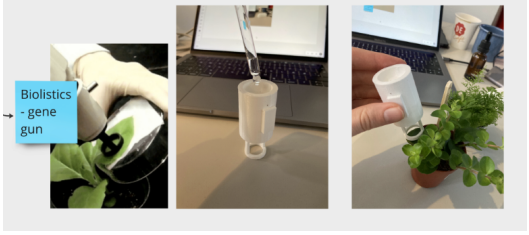
EXPLORATIVE PROTOTYPING

Why

Prototypes were built to look at interaction opportunities for how gene editing practices could influence storing, retrieving, and reading data from plants.

Key takeaways

This mainly helped for getting inspiration on how to build the prototypes later and getting a feel for gene-editing practices. Photos of protoypes are in appendix H.



One of the early prototypes took inspiration from a "gene gun"

FOCUS GROUP WITH SPECULATIVE RESEARCH ARTIFACTS

Why

The overall goal was to get inspiration and insights into how DNA data storage in plants might affect relationships of care with plants and data, and possible side effects, and implications.

How

The focus groups were conducted in two rounds to include various perspectives. More information is in Appendix E.

Focus group

Considering the un-accessibility of the DNA data storage in plants, and that thinking about possible use-cases requires some imagination and speculation, a focus group was conducted to let participants bounce ideas off each other, and engaging in subjects on a deeper interpersonal level. This is also a strength of the focus group format (Freeman, 2006)

Sensitising booklet

Sensitizing assignment

Participants were given a booklet with a three-day sensitising assignment before the focus group. This aimed to help them get used to the concept of DNA data storage and start thinking about how it could relate to how they store their data. The sensitising assignment included exercises in starting to think about what personal data means to people, how DNA data storage works and imaginaries depicting four possible scenarios with the technology. The imaginaries were inspired by the bespoke booklet method for situated co-speculation (Desjardins et al., 2019). The booklet is in Appendix E.

Tinkering materials

Tinkering materials such as leaves and branches were provided to the focus group to offer a tactile experience of what it feels like to touch a tree.

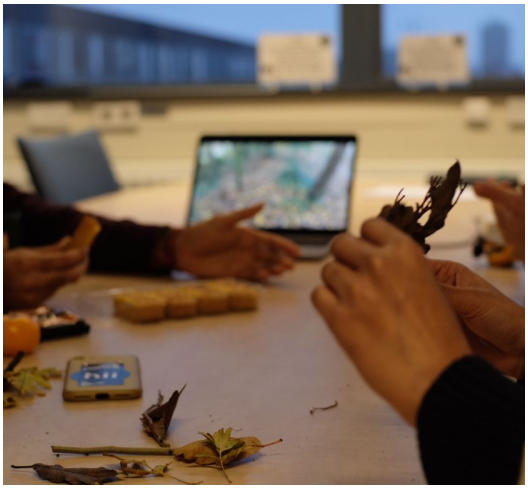


Photo from one of the focus groups

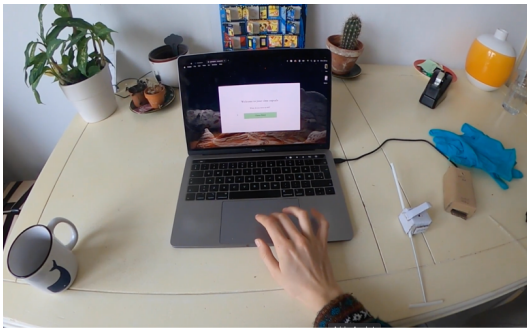
Speculative video sketches

Speculative video sketches were made to help participants imagine possible scenarios with DNA data storage.

Storing data in a tree was chosen as a scenario to see how people would relate to the living organism being "in the wild," having to give up some control in the reciprocal relationship.

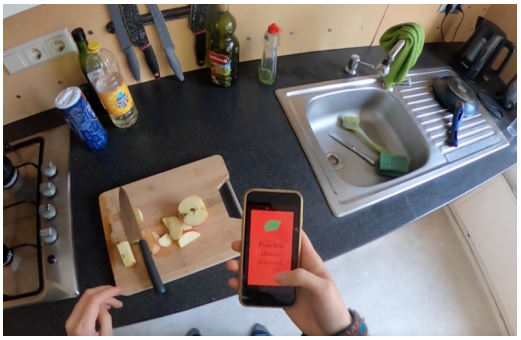
The video sketches depict two scenarios:

1. A person uploads a file to their DNA synthesising program on their computer. The synthesised DNA is placed in a syringe and injected or "uploaded" to a tree.



screenshots from video sketch 1

2. The same user gets interrupted while cutting apples by the DNA storage program, which informs her that there is a possible threat to the tree she stores data in. The user bikes to the tree, checks what is wrong with a device, and cares for it.



screenshots from video sketch 2

Participants

Design students were invited since they were easier to access for the study. One PhD researcher who works with microbiology was also invited to get feedback from someone familiar with bioengineering. Three people were in the first focus group, and four in the second one.

Analysis

Audio recordings along with notes from the sensitizing assignments were analyzed using open and axial coding to surface and organize themes. Themes related to how data is and might be cared for with DNA data storage emerged from this.

FOCUS GROUP RESULTS

The provocation showing data stored in a tree seemed to trigger thoughts about how people relate to their current storage systems, comparing and discussing practices around the immortal “cloud” compared to a living tree. Three main themes related to data storage and care were defined, along with some additional themes

DATA CLUTTER AND NEGLECT

This theme relates to how, within current data storage practices, data storage can feel quite cluttered and messy.Participants knew they could go through their files and clean up, but things are also designed to make this difficult.

“There's so much decision making. If you're talking about like pictures on WhatsApp and on your phone, there's so much that you need to categorise. In theory, you would have to take like 10 minutes every day to go through the new pictures that are on your phone.” - P3

Participants generally expressed that it was overwhelming for them to think about the amounts of data they produce and how its stored in the sensitising assignment prior to the workshop. It also takes time and labor to go through and decide what data is essential and what is not, so it is something they typically do not do. One participant compared it to moving houses:

“It’s not like … moving houses. Like, when you’re starting over again and you have to go through all of your stuff and decide what stays and what doesn’t” - P2

Some participants expressed that deliberately choosing what data to store in a tree, would require carefully considering what is valuable information and what isn’t. Simultaneously, themes around the already overwhelming amount of data existing in the world, and questions of whether more storage space is the best solution to this problem emerged.

“Maybe it would be better if we were like more frugal with what we saved and we actually like, maybe it's good that we have some restrictions to how much data we can store, because it prevents us from storing even more.” - p1

While DNA data storage could provide a more sustainable storage method, the technology might give excuses to keep cluttering clouds with data.
Concerning storing data in plants, maybe deciding what files to store and maintain in a plant could provide an incentive to decide what is worth keeping and caring for.

DATA IMMORTALITY

This theme refers to digital data's ability to feel immortal. It does not have a way of expressing that it needs maintenance and care to keep existing. Participants did not feel the same bodily and intimate affect towards digital files as towards material things. Still, P4 expressed an underlying feeling of digital data always having a timeline or, at some point, just disappearing.
“With data, I feel like there's a time limit on it. [..] I'm always a bit like worried is this going to stay here forever?” - P4

In other words, data is not permanent. However, simultaneously there is a feeling of it just being there and not slowly deteriorating or changing like other things. With storing data in plants, maybe perceiving data storage as something that grows and eventually dies could influence feelings of data immortality.

DATA OWNERSHIP

This theme relates to how data storage in plants might address problems related to data ownership and security. Participants were afraid of how stable the storing method is, if the data would change or be harmed in some way and if it could easily spread to other parts of the ecosystem or if someone stole it. Simultaneously, they discussed not having complete control over the digital data they have now. The video showed personal data being stored in a public, mostly self-sustaining tree, which might have affected why ownership became an apparent theme. Some participants also discussed how caring for data storage might increase a sense of ownership towards it.

"I can imagine that if I stored it in a plant at home, that I might feel a stronger sense of ownership than in a park, since then it's in my environment and it needs me to survive, and I need it for my data" - P1

There was also a tension between data feeling like it's always owned by someone, and trees belonging to the public. Raising questions about who should be able to access and own data if it also is a natural resource.
"A lot of things are public land, and nature should be for everyone, but then if you're like capitalising on it. It's ethically not cool. " - p5

Disjointed motivation to care

Some participants expressed that data storage felt like a disjointed motivation to care for trees. Trees are already an essential part of global ecosystems and crucial for life.
"Like... Do you need this personal connection, this human centered connection to respect other beings?" - P7

"Data" is a vast concept

"Data" can mean a lot of different things. "Data" is associated with "big data," and problematises the huge amount of information companies like Facebook and Google collect about their users for profit. In the way the sensitising assignment was made, participants were also probed to think of data as physical tokens like photo albums and meaningful treasures. There are also data files, which are individual photos and files that are stored in different digital spaces.

Why would you do this?

Some of the discussion was around why people would do this at all. Participants said it would be impractical and unhandy to bike to a tree to store a photo when it can easily stay on a computer or USB stick.

OTHER FINDINGS

Other findings were also noted down and helped shape the development of future prototypes.

Fear about unintended consequences; capitalising nature, harming ecosystems, GMOs, etc.

How data is stored in a plant's DNA, how it affects the plant, and how it is maintained and potentially spread within and beyond the organism is were fears that were raised. Related to digital data, participants acknowledged that they also did not fully understand how digital data storage and distribution works. There were also fears about doing gene editing.

P1: "Like you put it into an organism and then, I don't know, it probably does something there, right? Maybe it accidentally encodes a protein that would be interesting or dangerous."
P3 (microbiologist): "People do this. It's protein engineering"
P1: "oh, sick"

Key takeaways for design process

- Imagining storing data in plants can promote discussion about current data storage practices. The themes *data immortality, ownership, clutter and neglec*t were identified.

Insights for crafting future speculations:

- It's a good idea to make it more clear what type of data is stored to avoid confusion between for example data files and "big data".
- Blending the speculative artefact with current data storage technologies can cause confusion and thoughts on "why would you do this?"
- Storing data in a tree brings different types of care since it is mainly self-sustained. Storing personal data in a public tree as presented in the video also brought wider associations to privacy leaks and what would happen if companies started capitalising on public land. These are valid concerns but maybe not relevant for the design goal.

NAVIGATING OPPORTUNITIES AND CHOOSING A DIRECTION

Discussion

REFRAMING DESIGN GOAL TO INCLUDE DATA CARELESSNESS

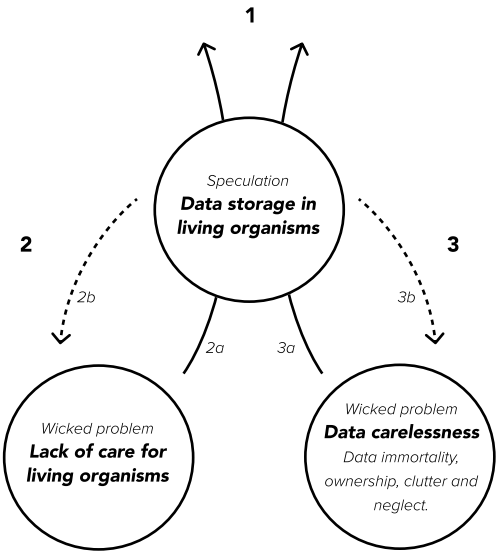
The plan before the focus group involved investigating how data storage in plants could create bonds of mutualistic care between people and plants. The speculative video sketch showing personal data being uploaded to a tree and the tree needing care to store data surfaced themes related to current data storage practices and anthropocentric relationships with data storage and plants instead. The discussions brought fears but also ideas and opportunities for how data storage in plants could create alternative ways of relating to data on a societal or personal basis. Like speculative design tends to do, the focus groups initially provided more questions than answers (Galloway & Caudwell, 2018) for where to continue with the project. Big questions for the outcome of the project became: What data, what practices, what species, and why?

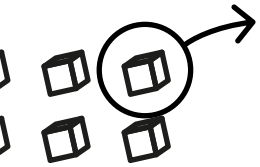
While the crafting og my particular speculation had caused fear about potential consequences and discussions about current relationships with data, other projects related to DNA data storage within HCI and design, like *Grow Your Own Cloud*, (GYOC, n.d.), *Living Harddrive* (DNA Living Hard Drive, n.d.) and *Semina Aeternitatis (Allstar & Pevere, 2020)* seemed to frame the technology in a way that provided inspiration and wonder for new ways of living symbiotically with data and living organisms.

From this, the design goal was reframed to address two wicked problems: Lack of care for living organisms, and data carelessness, while imagining opportunities for what could happen at the intersection of organic and virtual worlds.

New design goal:

1. How might the speculation help imagine new opportunities for mutualistic care between people, living organisms and data storage?
2. How might the speculation (2a)* help imagine new opportunities for mutualistic care between people and living organisms, while (2b) critically reflecting on current practices?
3. How might the speculation (3a)* help imagine new ways of relating to data storage while (3b) critically reflecting on current practices?





Discussion

OPPORTUNITIES FOR SPECIES TO EXPLORE FURTHER

Since different species require different care interactions and open up a range of opportunities for storing, sharing, and distributing data, the project was scoped further to include one species. A few living organisms were discussed as potential options:

Cactus
Qualities: lifespan is up to 10 years, but can live longer with proper care. Needs water every 2-4 weeks, likes light, repot around every 5 years, and needs nutrients every year.
Perceived opportunities and challenges for this project:
+ Spikes “protect” data, hard to kill.
- Largely self-sustaining.

Tree outside
Qualities: lifespan is between 100 and 1000 years depending on health and conditions.
Perceived opportunities and challenges for this project:
+ Stable and can live for a long time. Maybe a good option for public information.
- Self-sustaining, and out in public.

Moss in terrarium
Qualities: lifespan is 4 months - 2 years without care. It can last longer if cared for. Needs to be in indirect sunlight, and soil and nutrients should be changed about every 2 years
Perceived opportunities and challenges for this project:
+ Isolated, glass storage brings interesting prototype opportunities.
- Largely self-sustaining

Sprouts
Qualities: lifespan is 1-2 weeks, and they need relatively little care after setting it up.
Perceived opportunities and challenges for this project:
+ Good for highlighting that some data can live short-term
- Last very short

Bonsai tree
Qualities: lifespan is between 100-1000 years if cared for properly (the oldest bonsai trees are over 1000 years old). It needs water, occasional pruning and shaping, and an occasional repotting.
Perceived opportunities and challenges for this project:
+ Can live for a long time and be passed on through generations
- Care isn't that frequent

(Chosen species) Spirulina (microalgae)
Unlike the other options, spirulina is a microalga and not technically a plant. If taken care of at home, it needs to be harvested every 3-5 weeks, recharged with nutrients, and kept with plenty of light at a temperature between 19 and 35 degrees in a high alkaline level. The lifespan of a single strand of spirulina is about 3-5 weeks, but the culture can live for a long time if cared for.
Perceived opportunities and challenges for this project:
+ Microorganisms, in general, are hard to grasp and understand, which makes this interesting in the sense that people have to learn to understand it. It also requires regular care.
- There is a danger that spirulina can feel too unfamiliar for people

WHY SPIRULINA?

Spirulina was chosen for a few reasons. Firstly, microalgae aren't something most people know how to "read," perhaps creating an interaction where people must mindfully interact with and learn to understand algae to provide care. Secondly, the care practices around spirulina are novel, like measuring the PH level, checking the smell and avoiding contamination. In that way, it might be more interesting to test how people relate to caring for spirulina rather than for a houseplant since the interactions are new and unfamiliar. A spirulina culture needs care and attention every week, while a bonsai tree, for instance, needs trimming maybe once a year. Since the speculation would be about care, perhaps choosing a species requiring much care and attention could highlight the theme. Spirulina also doesn't have a specific form, which makes it a versatile prototyping companion.

Key takeaways from cycle 2

RESEARCHING THE DESIGN SPACE

1. Design opportunities

What people think of Storing data in plants presents a lot of interesting design opportunities and implications, which were explored in the co-speculation sessions and demonstrated in previous work with DNA data storage.

2. Mutualistic care wasn't addressed in ideation sessions

The co-speculation session introduced concept ideas, but mutualistic care wasn't as present. To address this, the next focus group included tinkering materials and showed hands-on interactions of caring for trees.

3. Presenting DNA data storage in the "right" way

Just saying "you can now store data in plants", which was basically the way it was done in the co-speculation, is too vague, but explaining the technology in detail is also difficult. When engaging with the technology later in the process, how it worked was introduced either through sensitising booklets (in the first focus group and workshop) or by presenting it as a convincing speculative artefact (the final focus group)

ENGAGING WITH THE DESIGN SPACE AND MOVING FORWARD

1. Data carelessness

Showing people a speculative scenario of data being stored in trees provoked wider discussion problematising current data storage practices. "data" in digital spaces feel immortal in the sense that it does not develop over time. Data clutter and neglect address how data storage does not take up physical space and how hoarding data is easy. It can also be overwhelming to think about all the data people have. Data ownership refers to how it is unclear who owns data.

2. reframing the design goal to include data

The final speculative artefact aims to make people reflect on opportunities for blending living organisms and digital data while critically reflecting on current data storage practices and relationships with living organisms.

3. Choosing spirulina

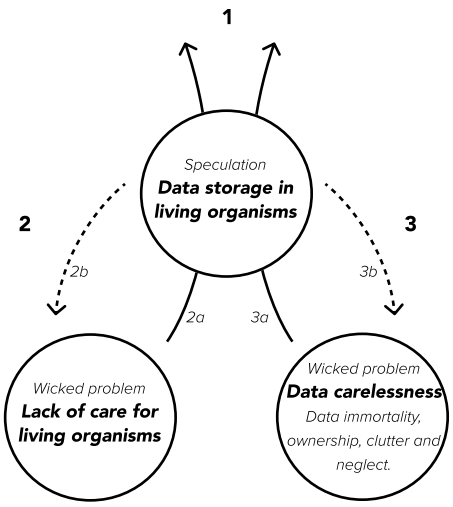
Spirulina is chosen as a specific species to craft the speculative artefact with

FOCUS ENTERING CYCLE 2

Explore spirulina care qualities and how this can manifest into a data-storing prototype.

NEW DESIGN GOAL:

1. How might the speculation help imagine new opportunities for mutualistic care between people, living organisms and data storage?
2. How might the speculation (2a)* help imagine new opportunities for mutualistic care between people and living organisms, while (2b) critically reflecting on current practices?
3. How might the speculation (3a)* help imagine new ways of relating to data storage while (3b) critically reflecting on current practices?



ch. 5 - cycle 3

CONCEPTUALISING ALGAE CLOUD

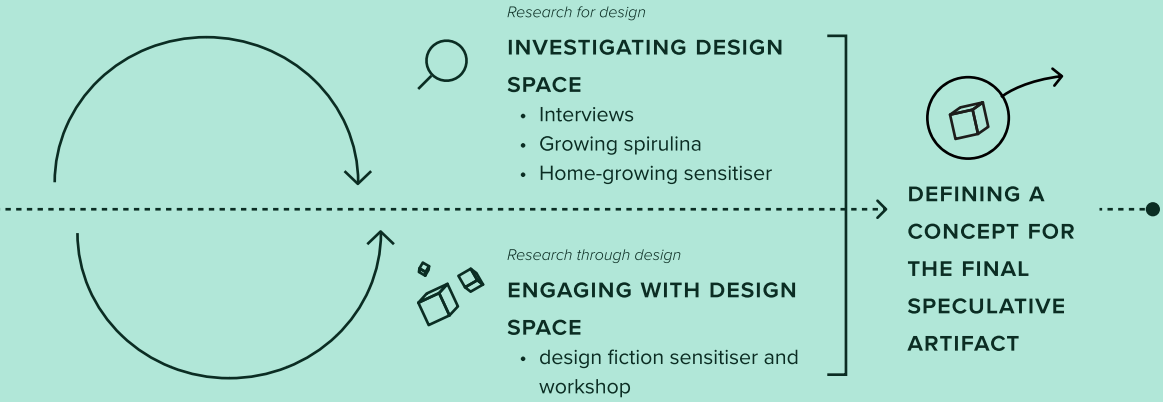
Entering cycle 3

Key terms: microalgae

***Here we explore** spirulina care practices to understand what mutualistic care with spirulina and data storage could look like on a hands-on level. It also navigates different opportunities for design fiction scenarios to embed the final speculative research artefact in.*

Guiding questions:

1. What does caring for spirulina look and feel like?
2. How to craft the speculation in a way that addresses the design goal?



RESEARCH ACTIVITIES

INTERVIEWS WITH SPIRULINA GROWERS

Why

Understand how people who know spirulina care for it and understand what type of relationship this is. How does it differ from, for example, growing houseplants?

How

Different people who grow spirulina were interviewed for 30 minutes to one hour.

Spirulina growers

	Affiliation with spirulina	*Motivation to grow*
SE1	*Founder of an online community for home spirulina growers*	*Initially for graduation project. Now for online community*
SE2	*Founder of a company selling spirulina powder and frozen spirulina*	*For growing and selling spirulina*
SE3	*Artist and designer working with spirulina and different microalgae*	*For using it in art projects*

GROWING SPIRULINA AT HOME

Why

Get hands-on experience with what growing spirulina feels like.

How

I ordered spirulina and caring equipment and set up a growing system in my bedroom based on different online tutorials. I also put some batches in closed containers to see what happens if they don't get attention. Reflections on this are in appendix H.

Photo of spirulina after harvesting some of it

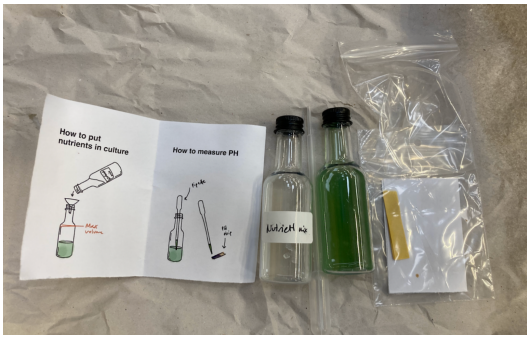
HOME-GROWING ASSIGNMENT AND WORKSHOP DISCUSSION ABOUT SPIRULINA CARE

Why

Understand how other people who don't have much knowledge of spirulina engage with it.

How

As a part of a workshop (which is described in more detail on pg. 71), participants kept and cared for spirulina for a week in their homes while documenting the experience since care is typically something that is done over time. At the workshop, their caring experiences were addressed by filling in a mind map with prompts and discussing them afterward. The aim of the workshop was twofold: to understand how participants relate to spirulina while examining their initial reactions and discussions around various design fiction scenarios. The findings from the second part of the workshop can be found on pg. 73.



Home-growing experiment

HOW TO CARE FOR SPIRULINA

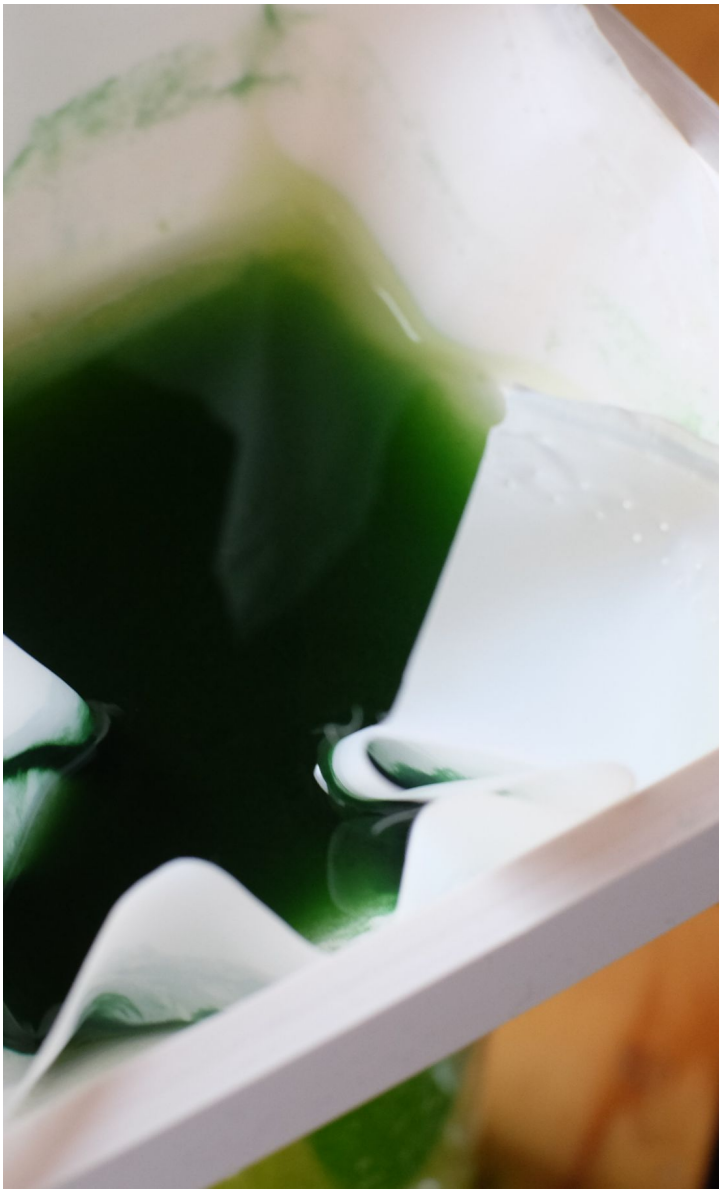


Photo from harvesting spirulina at home

These are tips and techniques that various DIY websites like spirulinasociety.com and different youtube channels give for how to get started with a spirulina culture at home.

HOW TO CARE FOR SPIRULINA:

Needs filtered tap water

Likes plently of sunlight

The culture is probably stressed when you get it and it can take some time for it to adjust to a new environment. Be extra careful during the first days

Needs to be safe against contamination: have clean hands

Spirulina like alkaline environments. The PH should be between 9-11

Smart to have backup cultures incase the main culture dies

Spirulina thrives in temperatures at around 25°C, but can survive between 15.5 and 38 °C

Spirulina cultures should be harvested regularly. You can eat the harvested spirulina.

When harvesting, you should replace the spirulina taken out with new nutrients.

Key takeaways that influenced the design process:
These insights shaped what care interactions were presented and crafted tools for in the final speculation.

SPIRULINA CARE QUALITIES

Research activities for understanding how people, new growers, and frequent growers, engaged with spirulina helped shape three care qualities.

A process of engaging with and learning to understand

It can be harder to understand how a spirulina culture is doing compared to a traditional houseplant. On one hand, not really understanding how to read the spirulina could create some distance from it.

"I understood this less. With a plant I understand that I give it water and it drinks it. With this I'm not really sure what the nutrients and light does. Is it good that it clusters? What is the white stuff? " - workshop P5

Another participant from the workshop noted that this could be a driver to care more.

"When I know it's alive and I have uncertainty that also drives my care to get to know it. So I think it can create attachment. My other plants at home I know how to care for so I don't need to pay as much attention, there's not as much curiosity in that aspect anymore." - workshop P3

This fear of failure can be very apparent in early caring stages when a culture is first introduced to the home. One of the spirulina growers remembered how she was trying to adjust to and understand the culture during the first few weeks:

"When it arrived, it was like getting a baby. I think it was very stressed and sad because it was shipped from Sweden. [..] I was observing it regularly and being really careful the first few weeks. Now it's not that hard anymore, but I still pay attention." - SE1

Formless

Unlike a plant that has a physical form and can be perceived as "one thing," microalgae looks like one liquid but consists of many small particles. Some of the workshop participants discussed the feeling of the algae when clumping together and after shaking it.

"I guess it's kind of wanting to see it as one creature... when it clumps together it's like ok now it's a living thing" - workshop P1

One of the frequent spirulina growers, on the other hand, described the spirulina states with very empathetic words like "stressed," "happy" and "shocked." The formless quality could make it harder to relate to than a plant, but some participants managed to feel this way, and frequent growers also seemed to have gotten past this. Still, one of the frequent growers expressed that she thought is hard for the general public to experience spirulina as a living and relatable thing.

"They are not visible for the naked eye so my experience is that "the general public" can't really build a relationship with something they don't see moving, growing etc. for most people it just looks like coloured water. " - SE3

Novel and frequent care routines

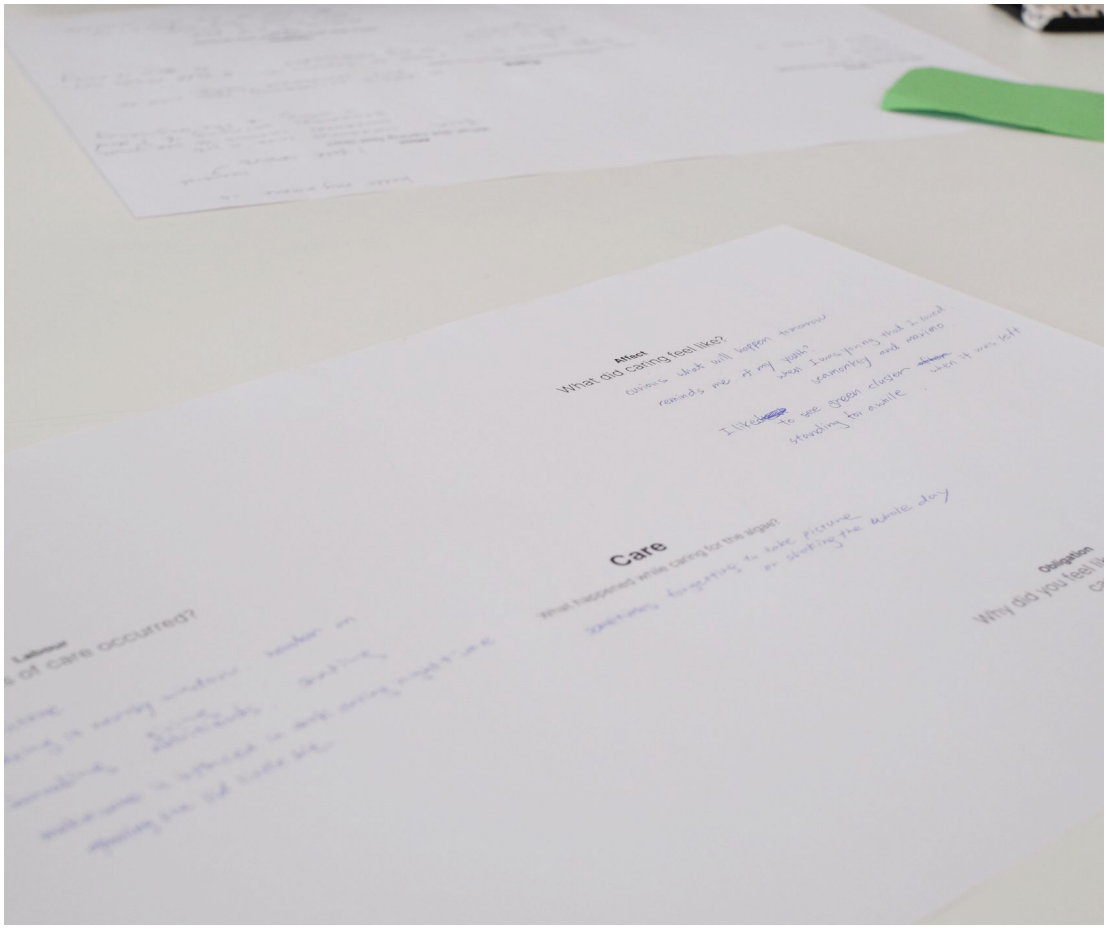
Compared to a lot of houseplants, spirulina requires more care and unconventional ways of doing care. Measuring PH value, adding a precise measure of nutrients, etc. also explained to feel a bit like a science experiment.

"The PH is more like controlling the environment, like measuring the temperature. I felt like a scientist optimising the environment" - workshop P1

Participants and growers also discussed how more frequent care routines could influence feelings of affection towards it.

"a plant you can kind of read over time. This moves and changes all day, so you have to read it several times a day. Maybe that makes you closer to it" - workshop P4

"I would say the relationship now is pretty much like having a pet. Even more a pet than a plant. The plants I have at home are quite easy to take care of, mainly just feeding them water. With the algae species its different as each one required different amount of light, different nutrients and care. You quickly see when they are not feeling well so they are much more work and pleasure for me personally. " - SE3



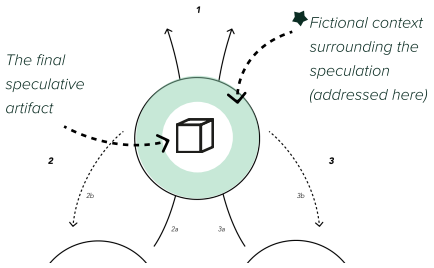
A mind-map reflecting on spirulina care from one of the workshop participants.

Key takeaways that influenced the design process:
This helped in understanding how people learn to relate to spirulina which contributed to shaping the interaction qualities for the final prototype video (pg. 91). Spirulina takes time to understand, is a different thing to relate since it is formless, and requires novel and frequent care routines.

DESIGN ACTIVITY: DESIGN FICTION WORKSHOP

Why

Understand what different design fiction scenarios make people reflect about, and how the reflections relate to the identifies themes discussed in the design goal. The workshop and sensitising assignment was conducted to help choose what specific design fiction scenario the speculative artefact should be in.



As described in the figure showing the design goal, this design activity aims to scope further what context the speculative research artefact should be in

How

Participants got a sensitising kit for 7 days, and participated in a workshop for 1,5 hours on day 8. More information about the workshop is in Appendix G and results are on the next pages.

Day 1	Day 2	Day 3	Day 4	Day 5	Day 6	Day 7
Get to know your spirulina			Introducing DNA data storage	Design fiction 1	Design fiction 2	Design fiction 3

The study description that participants recieved

<u>Algae culture care and care log sensitiser</u>

Participants cared for an algae culture for 7 days with a care log. They were encouraged to regularity shake the culture, give it enough light, open the lid to circulate new air, add nutrients and measure the PH value.

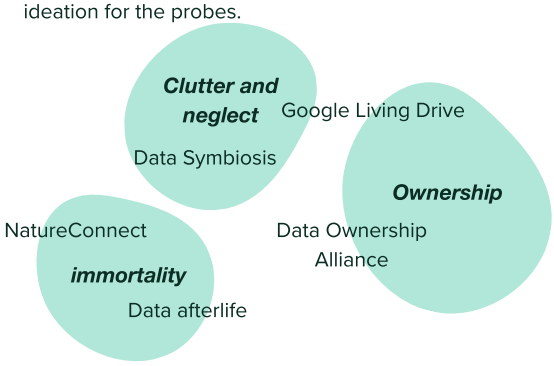
<u>DNA data storage introduction</u>

On day 4, participants were given some background information about DNA data storage, and potential opportunities the technology could bring. This was to get them used to the idea before introducing the design fictions.

Design fictions

On days 5, 6, and 7, participants got different design fictions. Some were website links and emails, while others were physical flyers and letters. The design fictions were made in simple, 2D formats and were purposely ambiguous, not describing specific products or things in detail but offering vague promises to investigate how the different design fiction scenarios helped people imagine opportunities.

The three data themes were used as starting points for ideation for the probes.



Participants

Participants were six design students in two different groups. Each group got three design fictions. Some of them differed but one (Data AfterLife) was presented for both groups.

Mind mapping about care experience

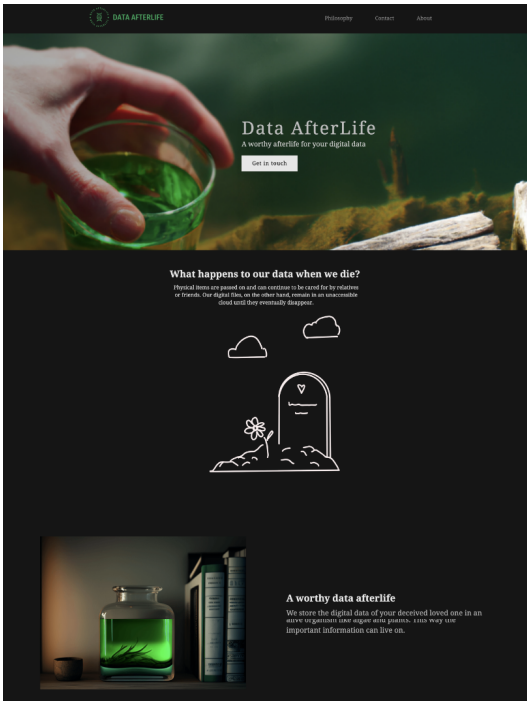
Participants wrote down their experiences with caring in a mindmap with some added prompts to help them reflect on the three dimensions of care; e.g. affect (what did caring feel like?), obligation (why care?), and labor (what did you do to care?)

Group mind mapping about design fictions

Group mind mapping (Heijne & Meer, 2019)was used to collectively open up and discuss the different design fictions that were introduced in the sensitizing assignment. Participants first quietly noted down thoughts, and then discussed them together. Mind mapping was used instead of just having an open discussion to help bring all ideas to the table and give participants room to compare and reflect.

Participants discussing design fiction scenarios in group mind mapping assignment

DESIGN FICTION WORKSHOP RESULTS



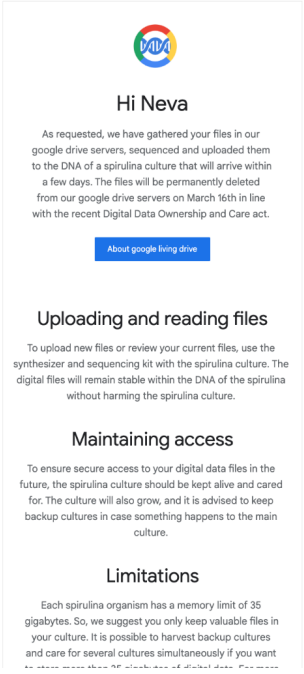
1 DATA AFTERLIFE

Group(s) who discussed this:
Group 1 and 2

Data afterlife (website link) is a fictional website and service that allows people to store data of their deceived loved ones in an algae culture. Making caring for the algae a part of a grieving process.

What people discussed:
People discussed what kind of data they would leave behind, and who gets to choose what data. They wanted to be able to choose themselves before they die. There was also a discussion about what happens with data after death, and participants were comparing it to cleaning the house of someone who died. The groups also discussed that people should let go of data when people die, and not hold on to them like this service suggests you should do. They also discussed what kind of data this would be.

Did it connect to the design goal?
Partly. People thought about how data lingers around, but what the service actually did seemed a bit vague



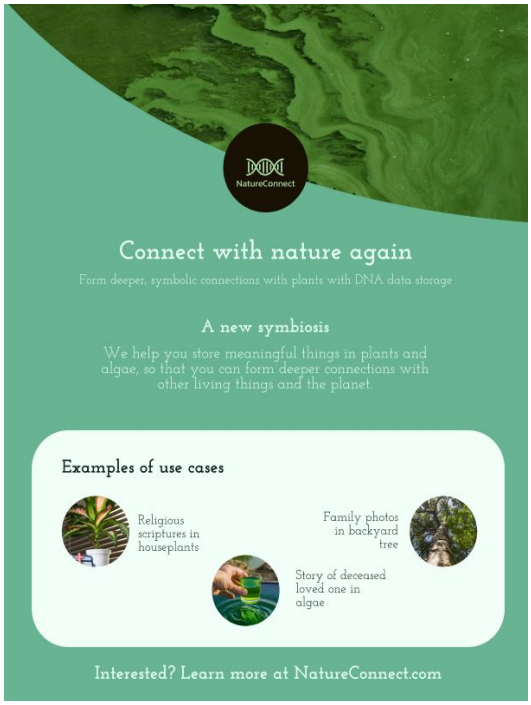
2 GOOGLE LIVING DRIVE

Group(s) who discussed this:
Group 2

Google Living Drive is a fictional email from google explaining how they are moving their cloud service to physical spirulina cultures.

What people discussed:
⅔ participants thought this email was actually from google, and felt a bit confused by it. They were discussing how it would force them to be selective about what to keep. They also discussed that it sounded quite impractical and a bit dramatic, since they could easily store 35 gigabytes (the limit from google living drive) on a USB stick.

Did it connect to the design goal?
Yes. People reflected on how they would treat their data storage more carefully, which relates to the design goal.



3 NATURECONNECT

Group(s) who discussed this:
Group 1

Natureconnect (flyer) represents a fictional service that helps people store data in plants to "connect with nature again"

What people discussed:
People connected this to spirituality and it being symbolic. They did not like the corporate vibe of the company. They were also unsure about what to put in there. One discussion revolved around what is memories and what is data.

Did it connect to the design goal?
It did help people imagine more spiritual relationships with plants, which is a new opportunity for more-than-human connections. Still, it didnt address the other themes that well.

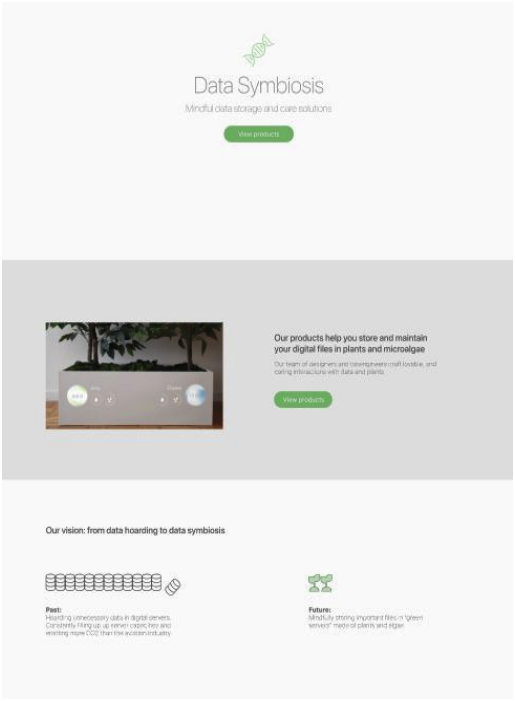
4 DATA OWNERSHIP ALLIANCE

Group(s) who discussed this:
Group 2

This letter from the data ownership alliance represents an underground movement that teaches people how they can store data in spirulina as a way to regain ownership of data

What people discussed:
The group was discussing if the community was safe to join, then thinking of the community as an underground movement that was standing up for data justice.

Did it connect to the design goal?
No.



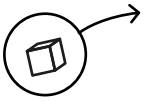
5 DATA SYMBIOSIS

Group(s) who discussed this:
Group 2

Data symbiosis is a fictional service that sells products for storing data in plants; promoting data storage as a new minimalist and mindful practice.

What people discussed:
People discussed things related to data clutter, neglect, and immortality. There was also a discussion about how it would give corporates an incentive to plant trees. The group was unsure of what data to store here, but pictured they would pick valuable data like memories. Compared to discussions around the other two design fictions for group 2, this discussion was more positive.

Did it connect to the design goal?
Yes.



TOWARDS A DESIGN CONCEPT DIRECTION

A key takeaway from the workshop analysis was that some of the design fiction scenarios seemed a bit far from what participants could relate to in terms of data storage and care. In other words, people were able to imagine what these fictions could lead to but were not able to connect it back to current practices related to plant-care and data storage. Auger, J. writes that *"One of the key factors responsible for the success of a speculative design project is the careful management of the speculation; if it strays too far into the future to present implausible concepts or alien technological habitats, the audience will not relate to the proposal resulting in a lack of engagement or connection. In effect, a design speculation requires a bridge to exist between the audience's perception of their world and the fictional element of the concept"(2013).* Data afterlife, for instance, required participants not only to imagine that data was stored in algae but also that data would be used in a grief ritual, which I realised felt quite far away from common data and algae care practices. Data ownership alliance also required that people imagine future privacy issues, reactions that might form underground movements, and using data storage in algae as a way to regain personal control, which can also be difficult to relate to current practices. Another thing I realised is that storing data in algae and learning to understand algae is by itself really new and strange for people, so adding sociopolitical consequences into this design fiction really requires a stretch of the imagination. Of course, participants were able to engage with and discuss these fictional worlds, but not all design fiction made people reflect back on their current relationships with data storage or living organisms.

Google living drive was, in this sense, the speculative scenario that I think people could relate to the most since they could directly link it to their current data-storing practices and start imagining how they would treat their google drive if they had to consciously choose and care for what to keep. Data symbiosis also sparked similar conversations, but here it was more unclear what type of data would be stored.

Based on this, I decided to make the final prototype relate more directly to common cloud storing practices. The goal of the final prototype became to help people imagine what a personal algae cloud could look like so that they can imagine further consequences and opportunities themselves.

Key takeaway for design process
The final prototype concept can include common data storage practices as a way to help people relate to it, and bridge the reflections back to current practices.

Key takeaways from cycle 3

RESEARCHING THE DESIGN SPACE

1. **Insights for care routine in final prototype video**

Caring for spirulina requires care routines such as measuring the PH value, using special water, and circulating the culture so all particles are exposed to light. These care actions were later included in the speculative scenario.

2. **Insights for care qualities in final prototype video**

Care qualities of spirulina are novel and frequent care routines, formless, and a process of engaging with and learning to understand.

ENGAGING WITH THE DESIGN SPACE AND MOVING FORWARD

1. **Relating the final prototype to a common data storage practice**

The final prototype concept should relate to common data storage practices so that people can imagine themselves in the situation of using it.

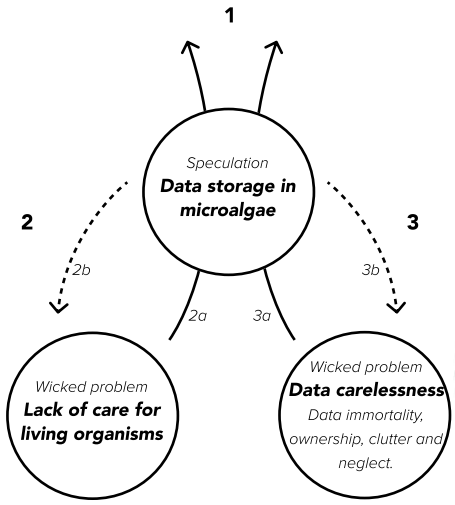
Summary of design goal and prototype concept

FOCUS WHEN LEAVING CYCLE 3

Defining concept and building prototype.

FINAL DESIGN GOAL:

1. How might the speculation help imagine new opportunities for mutualistic care between people, living organisms and data storage?
2. How might the speculation (2a)* help imagine new opportunities for mutualistic care between people and living organisms, while (2b) critically reflecting on current practices?
3. How might the speculation (3a)* help imagine new ways of relating to data storage while (3b) critically reflecting on current practices?



ch. 6

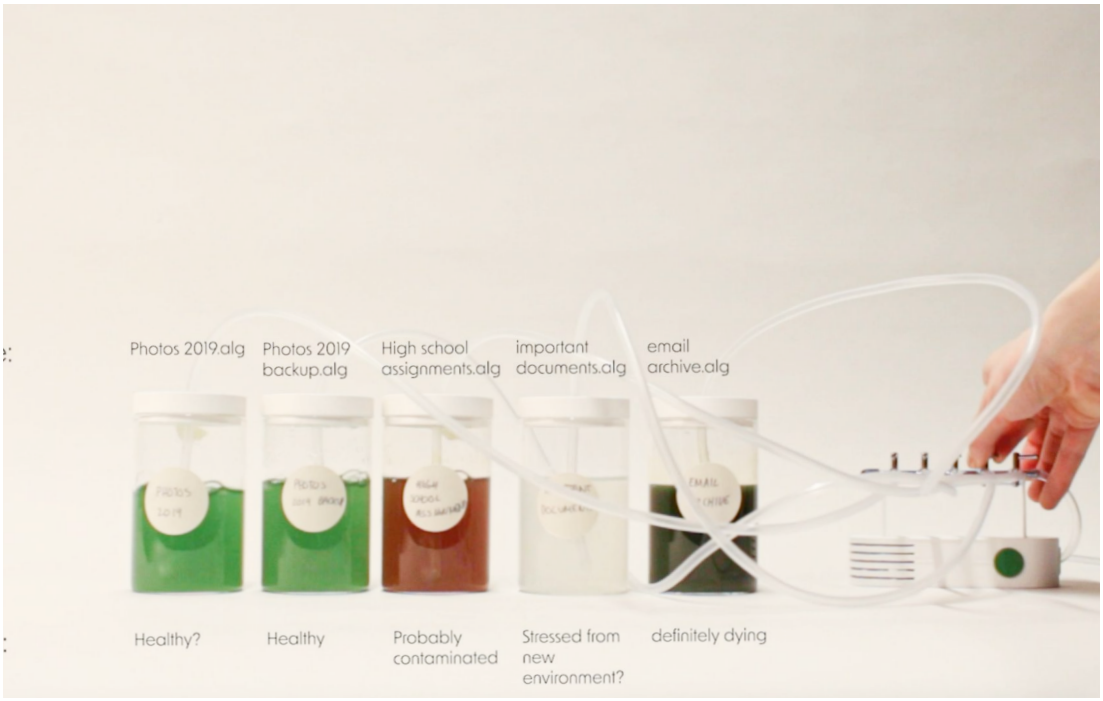
CONCEPT DESCRIPTION

Algae Cloud

"DNA data storage technologies make it possible to safely store digital data files in the DNA of living organisms. Algae cloud imagines the weightless and ethereal "cloud" as a breathing, living culture that requires and provides care. In a world where humans are increasingly disconnected from other living things, but also to how digital data hoarding takes its physical toll on the planet, what relationships could we have with non-humans and our data files if our data is stored in something that lives, grows, and eventually dies?"

Uploading data files to sample of algae culture with uploader/ downloader

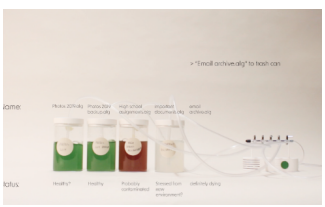
Adding algae with “Important documents.alg” to culture medium



Adding important documents to storage system

Adding important documents, throwing email archive to trashcan and checking “photos 2019” health

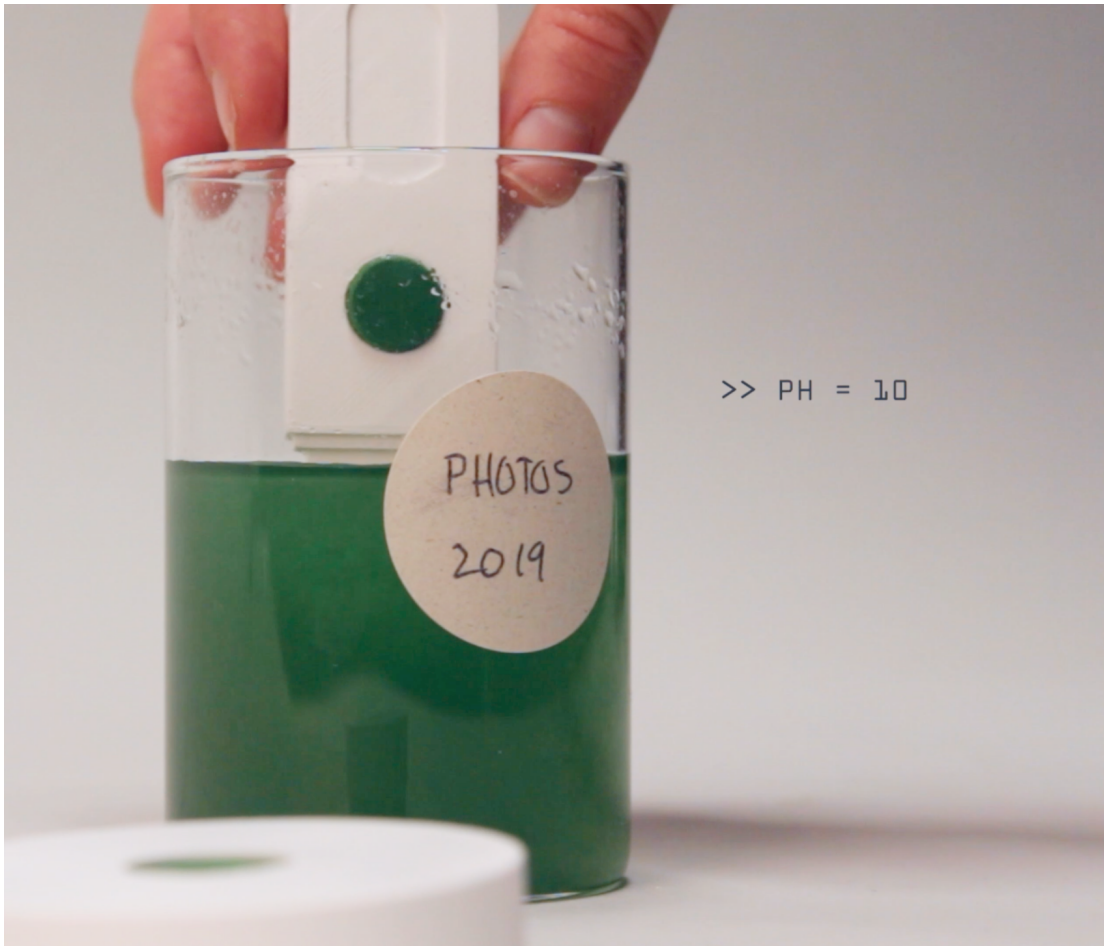




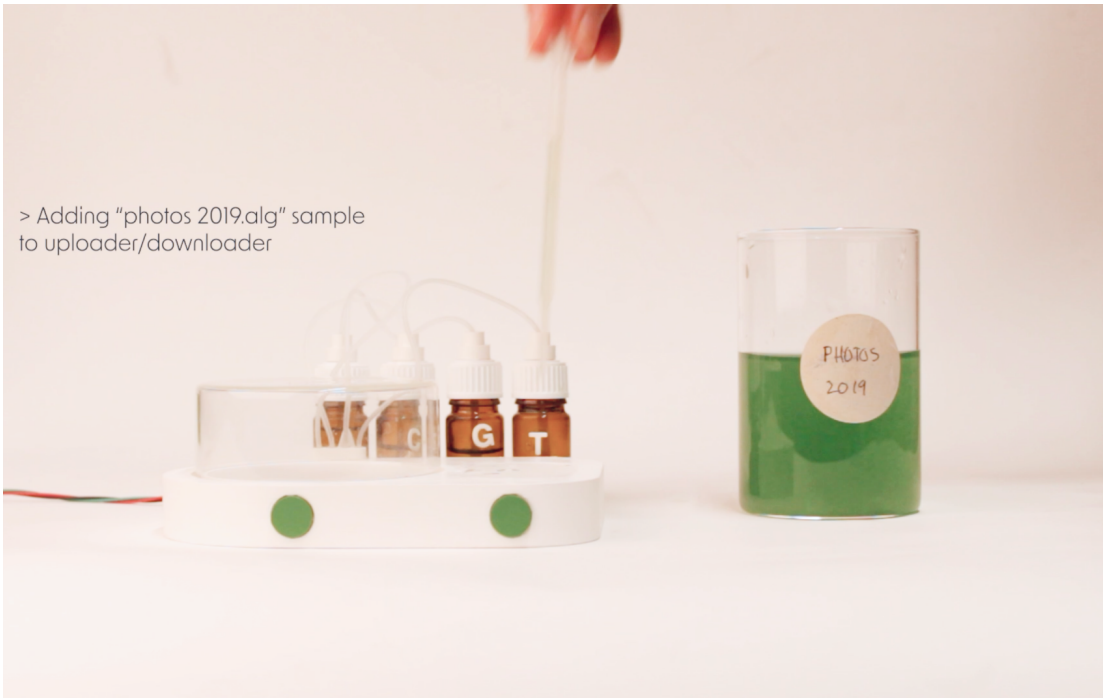

Care routine: scanning for malware bacteria

Care routine: measuring light intensity

Care routine: searching for help



Care routine: measuring PH



Downloading “Photos 2019”

Intended qualities

DESIGN INTENTION

Algae Cloud is a speculative research artefact that inspires people to imagine what it would be like if their cloud storage system was a collection of algae cultures that needs care. I hope it makes people think about how technologies like these could inspire new symbiotic practices between people and living organisms based on mutualistic care. I also hope this makes people reflect on current data storage practices and how data storage could be approached with more care.

MAKING THE PROTOTYPE AND FICTION

Before arriving at this concept and these prototypes, some prototypes were made to explore what medium to use and how to represent gene-editing and spirulina care practices on film. A video storyboard sketch was also made to get feedback from others familiar with working with speculative design. This can be found in Appendix H.

Link to video sketch:
https://youtu.be/QOz7zWBNkC8

STYLE AND FORMAT

Isolated environment
A finding from the focus group in chapter 4 (pg.53), was that directly relating current data storing methods with DNA data storing methods can be a bit confusing. Why would anyone take all the extra effort of storing a file in a tree, when hard-drives are easily accessible and storing one image is easy to do on a regular computer or in a cloud service. To avoid comments criticising practicalities, and help viewers think beyond current convenient data storage methods, the prototypes exist in an isolated environment, not affiliated with current technologies like usb-sticks, memory cards, bluetooth or hard drives.

Blending data storage and algae care
The series of prototypes were imagined to blend data care and algae care, so not necessarily separating practices of uploading and downloading data from care and data management. To do this, all prototypes were made in a similar style, and blending metaphors like “looking for malware bacteria” and “throwing email archive into trashcan” were used.

Sterile but playful
Since DNA data storage and algae care both happen in sterile environments, a sterile but tech-y feel was introduced to underline that algae cloud blends digital and biological practices.

VIDEO INTERACTION QUALITIES

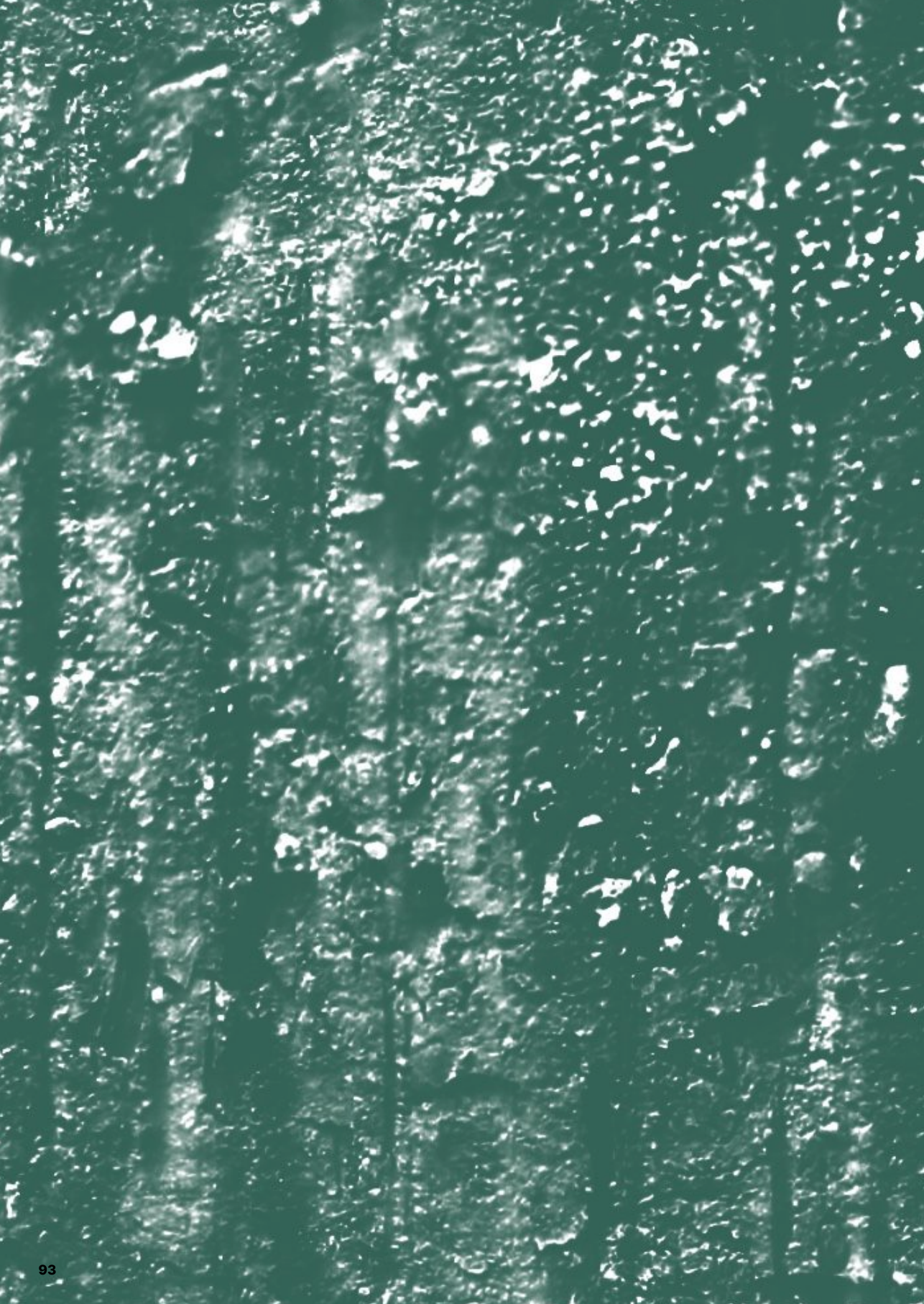
The Algae Cloud video was made with these interaction qualities in mind. The interaction qualities are inspired by the algae-interaction qualities and the three themes related to data: data immortality, ownership, and clutter and neglect.

An explanation of how this was manifested in the individual scenes is in Appendix H.

	Quality	description	Representation in video
HUMAN-ALGAE MUTUALISTIC CARE INTERACTION QUALITIES	***Dependency***	*Move from not feeling dependent on algae to a relationship of dependency.*	*Digital data like "important documents.alg" being stored in fragile algae*
	Learn to "become with	*moving from wanting to control to learning to attune to and trying to understand.*	*Situations where a person has to try to understand and read the algae.*
	Unpredictability	*Not knowing exactly what to expect and accepting a loss of control.*	*Something unpredictable happens - it smells bad.*
HUMAN-DATA MUTUALISTIC CARE INTERACTION QUALITIES	***Data mortality***	*Moving from the cloud as feeling endless and immortal to something that could deteriorate.*	*Algae cloud needs care, and non-important data can die.*
	Mindful storage	*Moving from data stuffed in a cloud and not cared for (data clutter and neglect) to sorting and caring mindfully.*	*Non-important files are discarded, and important ones remain cared for.*
	Decentralized to relational	*Moving from the feeling of disconnection to data files to one of a close relation. (data ownership)*	*A person forming a bond with the cloud through acts of care.*

Summary:

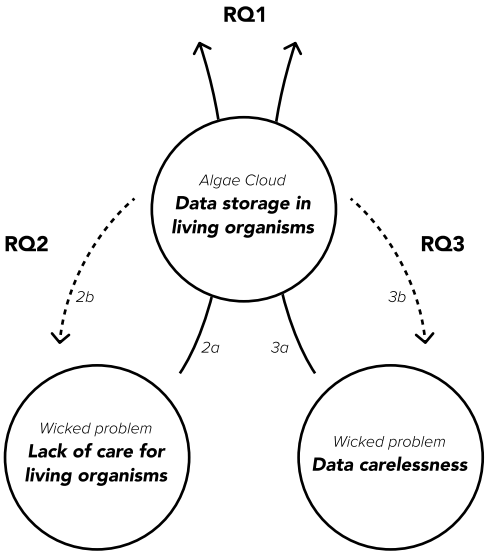
This chapter introduced Algae Cloud. More information about the tools and detailed reasoning for the storyboard are in Appendix G. The next chapter introduces how it was evaluated.



ch. 7

ALGAE CLOUD RESULTS AND OPPORTUNITIES

Evaluation setup



RESEARCH QUESTIONS

1. How might Algae Cloud help imagine new opportunities for mutualistic care between people, microalgae and data storage?
2. How might Algae Cloud (2a)* help imagine new opportunities for mutualistic care between people and living organisms, while (2b) critically reflecting on current practices?
3. How might the speculation (3a)* help imagine new ways of relating to data storage while (3b) critically reflecting on current practices?

** 2a and 3a are included in addition to RQ1 because opportunities that participants think of don't have to be exclusively linked to both algae care and data storage. For instance, if participants get other ideas on how to live with and care for algae that aren't directly connected to data storage, these will also included as insights.*

ALGAE CLOUD AS A SPECULATIVE RESEARCH ARTEFACT

Algae Cloud is a speculative research artefact and video sketch that presents an alternative future human-microalgae and human-data relationship. This takes advantage of speculative design as a tool to imagine and discuss possible futures while critically reflecting on current practices (Galloway & Caudwell, 2018). By discussing it in a focus group with qualified experts, the goal is to bring reflections and ideas related to three broad themes representing the research questions.

1. **Imagining mutualistic care between people, algae and data (RQ1)**

This category concerns opportunities for mutualistic care between people, living organisms and data storage. Here, the speculation aims to bring new ideas for what mutualistic care could look like in the intersection of algae care and data storage.

2. **Challenging current and imagining new notions of care towards living organisms (RQ2)**

The second category is related to bringing inspiration for how living organisms like algae could be given more "power" in future living artefacts, so that people have to learn to sense and care for them, which addresses how the current co-dependency can feel vague and distant.

3. **Algae Cloud as challenging current and imagining alternative notions of data storage (RQ2)**

The third area concerns how people relate to digital technology, specifically data storage. From this perspective, Algae Cloud can be described as a counterfactual artefact, which is a product or system that intentionally contradicts what would normally be logical design norms to open the possibilities for empirically investigating multiple alternative existences (Wakkary et al., 2018). This is done by imagining data storage as living and dying (contradiction) rather than immortal and infinite (the norm). This can relate to areas of more-than-human design in challenging anthropocentric ways of designing technology and treating data storage as a situated practice that requires care.

FOCUS GROUP FORMAT AND PREPARATION

Since Algae Cloud aims to inspire thought and discussion about relationships with living organisms and data storage, a focus group format was used so that participants could go deeper into implications and ideas sparked from the video through discussion. A strength of focus groups is that interpersonal communication provides space for exploring and clarifying different views. (Freeman, 2006).

The focus groups lasted for one hour in total. Participants were first introduced to the plan, watched the video sketch of Algae Cloud, and then there was a discussion with some guiding questions moderated by the author. Props from the video were also on the table to help guide the discussion to relate to the prototypes, and participants got a sheet of paper to use in case they wanted to note something down while watching the video or discussing. A detailed overview of the focus group plan and questions can be found in the appendix I. A pilot focus group was conducted two days prior to the first focus group. Some questions were adjusted from this, and some parts of the video sketch were made longer since participants said they didn't have time to read the text.

Focus group setup

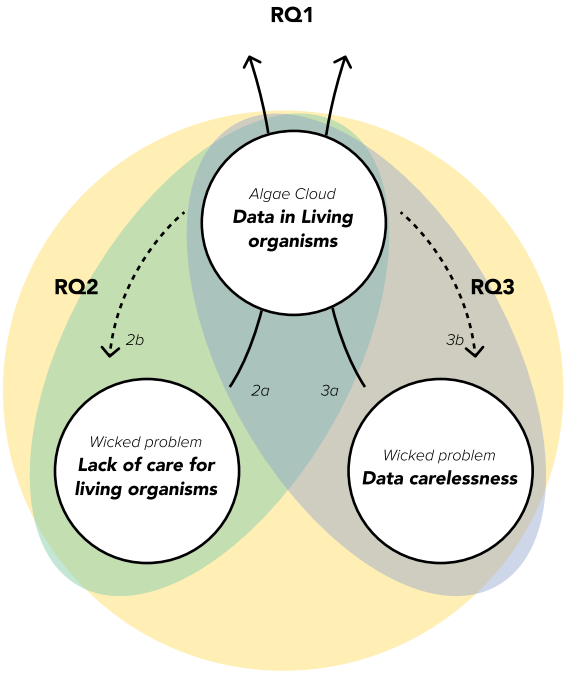


Figure 2: Researchers from bio-design (green), data-centric design (blue) and more-than-human design (yellow) were invited to hopefully bring expertise and ideas for different aspects of the research questions

PARTICIPANT SELECTION

People with expertise in three different broad research areas were contacted to join the focus groups.

1. ***Bio-designers (green)*** generally work closely with living organisms in a design process, getting a feeling for an organism's livingness through tinkering and designing with it and taking advantage of the qualities of the organism to shape an interaction. Perspectives from bio-design are included to bring ideas on how spirulina and microalgae qualities might impact interactions with Algae Cloud. The bio-designers who were contacted were also all associated with the Material Experience lab at TU Delft, and were familiar with the Living Artifacts framework, which includes Mutualistic Care as a pillar (Karana et al., 2020.
2. Designers with experience with ***data-centric design (blue)*** were included to bring perspectives on practices for storing, distributing, and using data. Both critically reflect on how it addresses current notions of data storage and imagine new opportunities.
3. Although the ***more-than-human design (yellow)*** field is broad, it generally involves designing not for isolated “users” but for users as a part of a broader ecosystem. In contrast to bio-designers, who work closely with living organisms mainly in isolation, more-than-human designers who were contacted work more broadly with rethinking technologies and systems to include non-human perspectives. Because of this, they were included to provide a holistic perspective on the implications of Algae Cloud. It should be noted that a lot of principles that relate to bio-design and more-than-human design still overlap, for example, the notion of “designing with” living organisms instead of exploiting them.

The focus group participants were found through emailing researchers at TU Delft in the three different fields. Some of the participants (P2 and P4) were previous TU Delft students with experience in the fields from the university and professionally.

Participants group 1

	Relevant expertise	Research "level"
P1	*More-than-human design*	*PhD candidate*
P2	*Experience with a design project about data warming*	*Design researcher*
P3	*Data-centric design*	*Postdoc*
P4	*Bio-design*	*Designer in a company*

Participants group 2

	Relevant expertise	Research "level"
P5	*More-than-human design*	*PhD Researcher*
P6	*Bio-design*	*PhD Researcher*
P7	*Bio-design*	*Postdoc*
P8	*Data-centric design*	*PhD Candidate*
P9	*Data-centric design*	*PhD Candidate*

ANALYSIS

Both focus groups were audio-recorded and transcribed. The transcripts were coded in a process of inductive thematic analysis by the first author, and codes were applied to each conversation fragment and used to make categories. The codes were further compiled into themes related to the research questions and additional opportunities that emerged. Additional confusion about the technology, worries about effects, and discussion for improving the prototype were also included.

The themes were first clustered into themes related to Perceived qualities, which included ***Algae Cloud Ambiguity, Algae Cloud Livingness and Algae Cloud Tangibility.*** Ideas for opportunities, implications and reflections on current practices were also added. The categories were re-structured afterwards to fit the research question better, which are presented here, but the findings from the first analysis is included in Appendix H, since they might be interesting for finding design opportunities in future work.

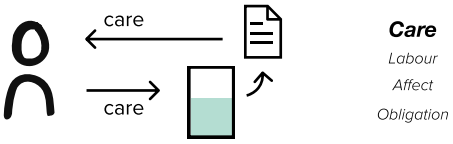
Results

The results present Mutualistic care with Algae Cloud (1), which addresses RQ1. Reflections on current practices are also presented (2), which addresses RQs 2b and 3b. Although not directly related to mutualistic care, participants shared other ideas and reflections that offer insights into how people might live with data stored in algae. These ideas are presented as Other perceived qualities (3) and Opportunities (4). Some implications are also presented (5). Participants did not discuss ideas related to just algae or data storage, so 2a and 2b are not answered here.

There were discussions about the impracticality of Algae Cloud in everyday life, which were valuable in highlighting potential opportunities. However, these comments have not been prioritized in the results because the primary goal of the Algae Cloud concept is not to be a commercially attractive device but rather to stimulate reflection.

1 MUTUALISTIC CARE WITH ALGAE CLOUD

Mutualistic care is broken down to care from a person to Algae Cloud, and care back from Algae Cloud to the person. Care is also broken down into three pillars as described by de la Bellacasa (see pg. 26); affect, labor, and obligation Puig de la Bellacasa, 2017). Since participants are imagining opportunities with a speculative artefact rather than actually using Algae Cloud, it should be noted that these are presented as opportunities and implications around the three pillars rather than how Algae Cloud “fits” the pillars. de la Bellacasa also emphasises that care doesn’t always involve a perfect distribution of the three pillars but rather tensions and contradictions between them. Here we are looking at the care from the human towards Algae Cloud since the “functional benefit” that Algae Cloud provides in return is data storage.



1.1 Labor

Labor refers to acts of doing care. These themes relate to labor in the sense that they present opportunities for how people might practically live with and maintain Algae Cloud. Since Algae Cloud is a hybrid between a storage system and algae cultures, labour in this sense involves practical aspects blending current data storage and algae care practices.

1.1.1 Sorting and deciding what to keep

Participants discussed how caring for Algae Cloud would include sorting and prioritising what algae data to keep and what to store in the first place since it’s hard to care and set aside space for everything. This was also included as a case in the video. P4 discussed this: *“Like my email inbox. I'm not sure how many emails are in there, but it's all there stored. And if you wanted to store it on the algae culture itself to keep alive, you might be a bit more critical of what you are saving and what you throw away”*

1.1.2 Labeling

Participants discussed that having Algae Cloud stored in physical containers might require different labeling and sorting methods than in the traditional cloud. *"If your whole structure is a mess, you can just "control"-find your way through the document you need. I can imagine if it's all physical, you really have some necessary structure to get the algae you need at that moment."* -P4.

1.1.3 Sensing and reacting to Algae Cloud

A part of the labor involved with using Algae Cloud, would be reading how it's doing and reacting by providing correct algae care. Participants also discussed how Algae Clouds livingness could be beneficial in grasping its state and understanding when it might fail so that algae files can be saved. P9 said, *"Sometimes my harddrive starts ticking and gives a warning, but it can also just fail. Whereas the algae, I'm hoping.. would give you a bit of warning as it changes colors slowly"*. Compared to conventional data storage methods, an Algae Cloud, being alive, can articulate its state and health. Still, participants also discussed that Algae Cloud being algae makes it more difficult to read. P5 discusses how caring for algae requires a specific approach, different from an empathetic approach *"I feel like I would be taking care of this. It wouldn't benefit our relationship if I would try to take the perspective of that algae. Like.. empathy doesn't really help. Whereas, for example, a dog or something, then you can try to a certain extent to imagine yourself in their position and think about what they would need. But then, if you have this very scientific, lab-like interaction, maybe over time you can learn to take that perspective as well. But for now, it doesn't look so much like it yet."* It should be noted that this might also be influenced by the way the algae was presented in the video as a sterile and lab-like interaction, which is discussed more in detail on page 108.

P4 discussed how learning to adjust to the needs of the Algae Cloud could bring new ways of relating to and living with algae data, having to adjust practices at home to fit the needs of the Algae Cloud as well. *"How would a house look like different types bacteria, algae, fungi that all have different functions, and all need love and care? Then you also need to decide where to put your effort in which one to keep alive for which function. [..] Maybe I want to have the curtains closed one day, or should I still let the light in if that keeps my data healthy?"* In other words, part of the labor and practical acts around Algae Cloud could be having to read and adjust to how it is doing.

1.1.4 Delegating care

Participants discussed how maintaining Algae Cloud would sometimes involve delegating care to others when, for instance, going on vacation.
"You cannot bring your algae on holiday for three weeks with you. So you have to delegate to other people probably, to take care, or some of the algae you let die because they are not really necessary or relevant for you." -P7
Participants also discussed how they would gladly pay to delegate some of the care labor to someone else instead of doing it themselves. This point is also related to fear (section 1.2.3), since mentioned that they would delegate the labor to make sure they don't do anything wrong.

1.1.5 A specific form of care

Participants in the second group expressed that maintaining Algae Cloud requires a very specific form of care that looks very scientific and formula-based. P5 compared it with caring for his houseplants, which are more familiar. *"I rather opt for storing my data in my plants, because the video it also looks quite technical, which I assume a person gets used to but then It's a new habit that you have to get into. Maybe it's easier to combine it with a habit you already have."*

1.2 Affect

Affect relates to bodily feelings and emotions around care. For this theme, Algae Cloud is a bit ambiguous since it's not clear what exactly the care is for, and individual files can entail different sources of affect. On the other hand, ambiguity and care bring opportunities for meaningful and symbolic interactions but also fear.

1.2.1 What do people care for?

On one hand, caring could feel like caring for algae, but it could also feel like caring for data files. The incentive to care could be wanting to keep data, but it could also be wanting to keep the algae alive. In other words, why would people care for Algae Cloud, and what are they caring for? This question wasn't addressed explicitly in the focus groups but emerged through analysing results and finding conflicting ideas on what care in this setting could mean. P1 and P2 discuss how people would be motivated to care to keep their data, but then there is a diffuse boundary between caring and exploiting.

P1: "I mean.. as a human you are unfortunately often motivated by self-interest and then this algae is very much serving that. So yeah, I think your average person would be more invested to care for that object."

P2: "But then is it really caring, I mean, it's still kind of exploiting."

Another note is that participants usually referred to Algae Cloud as a carrier for their data, rather than algae with data in it. Suggesting that they would maybe intuitively feel like they were caring for the algae for the data in it.

1.2.2 Emotionally profound interactions

The ambiguity of Algae Cloud, its livingness, and the care practices that are involved can also make caring a (positive) emotional experience. *"I might be able to hold by memories from 2010, etc... These kinds of collections can be a lot more romantic [..] it's like the message in a bottle" - P3.* This theme reflects how ambiguity could also bring opportunities for rituals and ceremonies. *"Maybe it performs an important part of a ritual in some way. [..] I send them a bottle, and they do a thing; maybe they'll see it together. This could be collaborated on to become part of a ritual of sharing memories." - P1*

1.2.3 Caring because of fear

Participants also discussed how Algae Cloud immediately promoted feelings of fear and worry. *"What if it dies? What happens? Where's the backup plan? What if it's important?" - P2.* Anxiety around what might happen if Algae Cloud dies could also in itself act as a strong motivation for doing care. Participants also discussed that they would gladly pay someone else to care for them because of fear of messing it up. *"if my data and the cloud would actually be stored in an Algae Cloud.. a bunch of cells, then I would gladly pay the gardener to take care of that instead of me doing it and messing it up." -P5.* In conclusion, people might care for Algae Cloud because of fear of what would happen if their files disappear.

1.3 Obligation

This theme refers to feelings of obligation around care. In other words, why people would feel like they should care.

1.3.1 Obligation to protect algae life vs data

When asked about what people felt about using algae as a carrier for data, none of the participants seemed to have moral issues with this in terms of occasionally having to "kill" some algae or using the algae as a resource. There was discussion around the ethics of manipulating DNA of living organisms which is addressed in 5.4. In other words, from the speculation, the moral obligation to care to protect life wasn't apparent. P9 remarked: *"I guess because it's an algae, not like a rabbit. I don't have any negative thoughts about hurting the algae.* On the whole, the most obvious reason to be caring for the algae seemed to be to protect the data inside it.

1.3.2 Who should care?

The second group had a discussion about who should feel obliged to care about algae data. P8 and P9 discussed this.

P8: "As I do now with my cloud, I would also like to set boundaries of when I access which information and under which conditions, in what context. So caring is also very contextual."

P9: "Yeah, I would say it's TU Delfts responsibility to care for my work algae. I'll care for my photo algae."

In other words, caring for algae data also brings wider implications of who should care and in what context.

2 OTHER PERCEIVED QUALITIES

These themes are other reflections on how people might live with and percieve Algae Cloud. They were not presented in the previous section since they were difficult to link directly to one pillar, but could also influence how and why people care.

2.1 Ownership and responsibility

Participants discussed how caring for Algae Cloud might bring a feeling of ownership towards their files. P1 discussed this as bringing more responsibility to people, but also that it feels more fragile.
"Here it's all on me, which maybe makes it more fragile because I might be clueless and not know what to do, but it does put the responsibility like completely in my hands, as opposed to the kind of distributed things that we have now." - P1

2.2 Growing and evolving over time

Some participants, including P3 expressed how experiencing data as growing on two levels could be interesting. The living organism grows, but the data files might also evolve.
"You have to take care of an evolving file in a digital space. [...] the living matter evolves, grows, and is like to parallel growing; the file and living matter. And you can go back after a while, you know, to check how it evolved." - P3. P5 reflected on how this might make it an interesting artefact over time *"I mean, like physical photos get more yellow.. [..] So maybe this is an interesting artefact over time."*

2.3 Lifetime

The fact that Algae Cloud makes it possible for unimportant data files to die and disappear was mainly discussed as something positive, although impractical at times. P2 mentioned that it would be a good way of making sure files don't just stay around unused. *"A lot of things just linger around, and with this, if you don't take care of it anymore because you don't care about it, then it disappears."*

2.4 Reflections on the overall relationship

Some reflections were related to the overall feeling of living with Algae Cloud. One participant remarked that the relationship wouldn't be far from the relationship he used to have with his old hard drive.
P7: feel like my relationship with you would not be very different from my relationship with my external hard disk. The only thing is that it's a bit more fragile, maybe.
P8: The algae or your hard disk?
P7: Both of them for different reasons. I remember once it was damaged, and I lost all the data that was collected. And then, I started collecting data on different hard disks. And every time I traveled, I used to wrap something around it to protect it. So I think the relationship with would be not so different from the relationship with the hard drive.
Another participant remarked that Algae Cloud would work best for archival purposes and not data one would need to interact with daily. *"I think this really only works as a repository. Like, I don't think you would use this for the files you use regularly or updating. " - P1*

3 OTHER OPPORTUNITIES

3.1 Sharing

Participants discussed how a big aspect of the current cloud is being able to share and create data together. With Algae Cloud, sharing would mean bringing a physical sample of algae to someone else. “Exchanging files could be very interesting.. maybe I take care of a file and exchange my paper with you, you could go back and.. it would die eventually.”- P6.

3.2 Propagating

This relates to what might happen if different algae data mixes with other algae or other ecosystems. P6 discussed opportunities with this and what could happen if it could grow freely. *“algae doesn’t only die, it also propagates. It makes more of themselves; that's what life does. So what if you could just pour it into the ocean and then let them swim free without taking care of it, and then whenever you need to access it, you go to the sea again.”* Participants also discussed what happens when algae grows, and how data sets might mix and compete, and how it might create a mix of different data. P1 made a joke about this *“How does the way the organism reproduces impact your data? [..] maybe you can put two files together, like your literature and your observational data, and then the organisms procreate and synthesise your result, and then you don’t have to do that analysis.”* In other words, what happens when an algae data propagates and creates more of itself can be interesting.

3.3 Data influencing algae properties

Participants imagined how the physical algae might be able to change state depending on the data. P9 said “I imagine now that when you reach like 99% capacity of the algae, then you should like affects the algae colour or something. If it’s red, it’s full.” There was also some confusion about how the data affects the organism, this is addressed in section 5.1.

3.4 Tangible crimes

This theme relates to what hacking and crimes might look like when data is stored in physical algae. *“I imagine this mission Impossible scenario where people try to break into this laser guided room with this one important algae in there. It's more tangible and easy to understand than thinking of encryption in the cloud. I don't know how it works, but it's massive.”-P2*

3.5 Different care and meaning to different species

Participants discussed how storing data in different types of organisms can impact care qualities and relations to it. P7 discussed how the tools themselves impact the perception of care; “if it is something more emotional or ornamental... you know, using tools that are associated with plants or gardening.. it would be an even stronger motivation for me to take care of a file or a cloud.” P6 also discussed that he would like to keep his precious data in a tree;

P6: “When we’re thinking in analogies, I would like my important data to be in oak. I would plant it somewhere, and then when it gets big enough, I will have new seeds which I can plant something else. So a little bit more robust organism than the algae”

P5: “I like that analogy because it lives for some time. Longer than humans, but not forever.”

4 CRITICAL REFLECTIONS ON CURRENT PRACTICES

This section presents reflections on current practices related to data storage and mutualistic care for living organisms, addressing RQs 2b and 3b. It should be noted that many of the qualities and ideas indirectly address these reflections by imagining new opportunities different from what people are currently used to now.

4.1 Hidden non-human entanglements

This theme refers to discussions participants had about how humans are already dependent and entangled with non-humans like algae and data storage. P8 reflected on how there is already a lot of care happening to maintain the current data storage infrastructure. *"There are some similarities in the sense that "the cloud" also grows and also has people taking care of it. Just in a different magnitude."* There was also a discussion around data storage already being entangled with humans and non-humans, and how the prototype could highlight that. *"what this could do is to bring more visibility to these things that maybe in a data center context are a bit obscure, like the human and non-human bodies that are part of us storing our data in a cloud versus here at least we are a bit more aware of these things, at least we see it." -P8.* P2 also discussed this and the perceived distance between ecological impact and current data interactions *"in the current way where there are so many layers in between the interaction and the ecological impact of storing your data."* P1 also discussed how she was currently entangled with her houseplants *"I suppose it makes it kind of makes explicit the interdependence that we have with living organisms like plants. You know, I keep it in my home because it looks nice. It supports putting oxygen into my house. But the plant also benefits from being in my house because it gets to exist."*

4.2 Data Ownership, immortality, clutter, and neglect

This category is not discussed in detail here, since the themes were identified in the previous focus group discussed on pg. 55. The themes were also present in this study. Data ownership refers to data storage not feeling like it belongs to people using it, which is addressed in 2.1. Data immortality refers to data feeling like it will never die but can still suddenly disappear, which addresses 2.3. Data clutter and neglect refer to data storage feeling like a cluttered and careless practice, which relates to 1.1.1 and 1.1.2. These themes were also apparent in these focus groups, for example, expressed by P5 *"My attitude towards the cloud, actually, is that I think it's quite careless. [..] I'm thinking with this kind of replica of files in a physical way, it makes me think that I could take care of the cloud in a different way."*

5 IMPLICATIONS

5.1 Black box

P1 discussed how Algae Cloud is still a black box in the sense that even though it is living and physical, it's not straightforward how the data is stored and how it works. *"I felt like there's quite a lot of black boxing. [..] And I think most things, even if you really try and break them down, there's something invisible happening."* There were also some questions from participants on details of how the data storage would actually work. For example, if it would impact the growth of the organism, how much memory storage space there was, and if the files would actually change or not.

5.2 Not inherently good or bad

This theme refers to how having data storage that needs care and generates oxygen wasn't seen as inherently good or bad by participants, but it matters how the technology is developed, and who cares (addressed in section 1.3.2). Participants discussed this and how the technology could still be commercialised, and care would be outsourced. P4 mentioned, *"If this will continue, it will be optimised the highest amount of data storage with the least amount of care."*

5.3 Who has power in a relationship with Algae Cloud?

Power or the ability to direct or influence the behaviour of others or the course of events, is a bit more ambiguous with Algae Cloud. It is interesting in the sense that there are two living organisms (human and algae) who have agency in deciding how the data storage will go, which could impact the power balance. Still, humans have a long history of domesticating plants and living organisms for resource purposes, so this didn't seem like a huge issue. P1 reflected on how this power balance would play out if, for example, she stored her data in her cat.

"I would feel more weird about storing my data in my cat. That would take a power balance somehow, in some way. I guess she almost has more power over me. If she gets sick.. but then I'm kind of like exploiting my relationship with her.. I don't know." - P1

5.4 Is it right to mess with DNA?

This theme relates to the ethical implications of messing with the DNA of living organisms and possible dangerous scenarios. P1 discussed what rights the living organisms have; *"I just immediately thought like that slippery slope.. where the boundaries? what are the rights of these living entities?"* The participants also discussed possible harmful side effects of giving everyone the opportunity to alter DNA of living organisms. P4 discussed this *"Not everyone is as experienced.. Maybe you accidentally create something that will be damaging."*

In summary

SUMMARY OF RESULTS:

1. Mutualistic care (RQ1)
Mutualistic care with Algae Cloud on a practical level (1.1) suggests blending practices related to data and algae care. For example, labelling and sorting physical algae cultures (1.1.1), and deciding what to keep and what to let die (1.1.2). Concerning affect (1.2), the ambiguity of Algae Cloud being between algae and data brings questions about why people care and what they are caring for (1.2.1). People might be caring out of fear that their data files will disappear (1.2.3). This ambiguity can also create opportunities for emotionally impactful experiences (1.2.2). In relation to obligation, larger questions can be asked on who should feel the obligation to care for Algae Cloud and if people feel a moral responsibility to take care of life or data (3.1, 3.2). All in all, the discussions brought opportunities for different aspects that influence and implicate mutualistic care.

This is discussed more in detail in the next chapter.

2. Other perceived qualities
Caring for Algae Cloud could bring opportunities for feeling ownership and responsibility over data files (2.1). Algae Cloud might grow and evolve, making it an interesting artefact over time (2.2). It affords data to die, so data doesn't linger around (3.2). Participants also reflected that Algae Cloud would be best for archival storage, and the overall relationship resembles caring for a hard drive (3.3).

3. Other opportunities
Living with Algae Cloud could entail new ways of sharing data (3.4). Data stored in algae also brings opportunities for algae data propagating and growing in the wild (3.5), and for new types of tangible data crimes (3.4). Different species of living organisms and the type of care tools that are used could impact the interaction around care and data storage (3.5).

4. Critical reflections on current practices (RQs 2b and 3b)
Participants reflected on current notions of data storage as careless (4.2), and discussions were related to previously identified themes about data ownership, immortality and clutter and neglect. Participants also discussed how humans are already entangled with and dependent on living organisms and data storage in different ways (4.1).

6. Implications
Algae Cloud as a concept also comes with implications. Participants said it is still a black box (5.1) and not inherently good or bad (5.2). Participants also discussed broader implications like "messing with" DNA (5.3). In a mutually caring relationship with Algae Cloud one can also raise questions about who has power; the algae, the human or both.

6 OPPORTUNITIES FOR IMPROVEMENT

6.1 Balancing Isolated interactions and algae livingness

As discussed in pg. 91, Algae Cloud was meant to be experienced as isolated from current notions of data storage, for example, USB sticks and memory cards, to avoid confusion. The prototypes were also made sterile to prevent fears of what could happen if organisms mix in the natural world and to visually resemble current gene-editing and algae care practices. Although there was significantly less worry about this than in the first focus group (pg. 52), it also partly contributed to a sterile, disconnected feeling of Algae Cloud as something scientific and controllable rather than organic and situated. P9 discussed this: *"The algae seems like you can take care of it in a very scientific way.. there's a formula, basically, like maybe a computer... If you do this and this, your algae slash your server will stay alive."* Although participants, through discussion, reflected on the implications of Algae Clouds' livingness, it could have been more apparent in the video sketch. For example, by adding clips of microalgae under a microscope or altering the "feel" of the prototype. As discussed by Auger (2013), careful crafting of the speculation can impact how people relate to and think about it, which was also the case here.

6.2 Further crafting the care tools

Another reflection is that the "care tools" could be further iterated and tested in a way that brings people closer to microalgae. Perhaps also using more "natural sensors" and intuition like checking the colour. This wasn't a priority because the tools were made for a video format and not hands-on interactions. Still, it could have also contributed to a stronger "feel for" the algae in the video.

LIMITATIONS OF STUDY AND THINGS TO THINK ABOUT

Focus group format and analysis limitations

Results from focus groups depend highly on how the focus group is facilitated, the participants, the atmosphere (Freeman, 2006), and a certain inevitable degree of subjectivity in analysing the data, which is likely also the case here. In other words, the results may vary if there were other participants, someone else leading and analysing the discussions, or the questions and format were different.

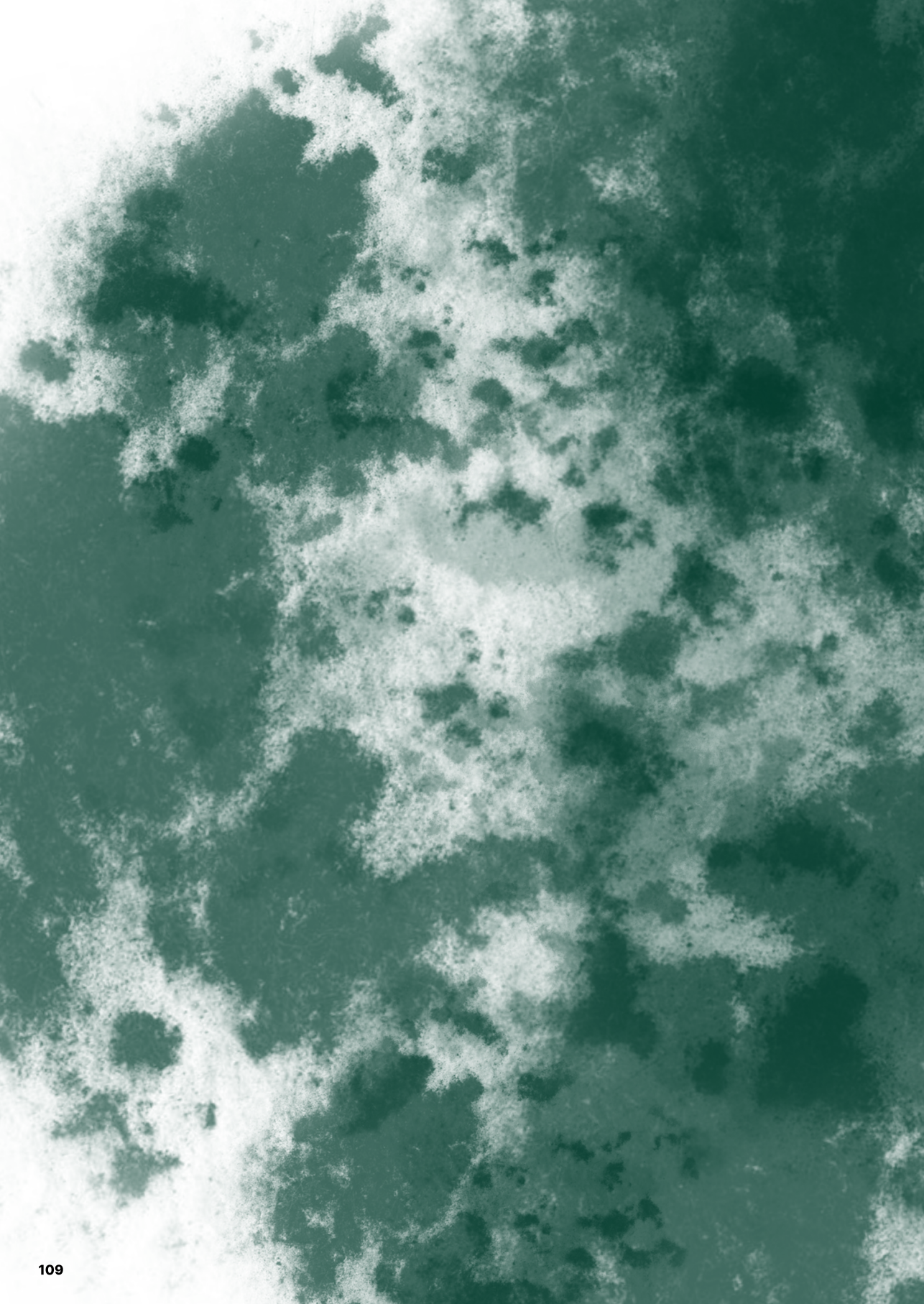
Exaggeration of technology abilities

As mentioned by Gough (2021), pairing speculative design with bio-design could bring opportunities for imagining opportunities and implications and generating discussion. On the other hand, it might bring unrealistic expectations for what the technology can actually do, which is also a limitation here. Storing (especially synthesising DNA and genetically engineering it into an organism) and retrieving data from living organisms is currently a very complicated, time-consuming process that is highly simplified in Algae Cloud.

CHAPTER SUMMARY

This chapter presented how the final focus groups discussing Algae Cloud were conducted, along with results and a summary of results.

The results suggest how mutualistic care between people and Algae Cloud might look like and how different factors can influence care. Other findings suggest new opportunities for blending virtual and organic worlds with DNA data storage. Algae Cloud might also make people reflect on careless notions of data storage and care towards living organisms. The next chapter discusses these results presents further opportunities.



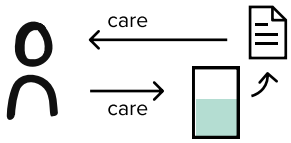
ch. 8

DISCUSSION AND LOOKING FORWARD

Discussion

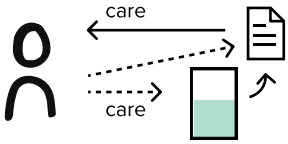
WHAT IS MUTUALISTIC CARE WITH ALGAE CLOUD?

Mutualistic care in Algae Cloud is complicated. Karana et al (2020) discuss how mutualistic care includes caring for a living organism and receiving a practical benefit in return. This is also the case in Algae Cloud, where algae care is exchanged for data storage.



A big difference from other examples of living artefacts is that the data storage property isn't directly linked to nor taking advantage of natural processes happening in the algae, other than the algae having living cells that carry the data.

Mutualistic care is also complicated when adding the dimension of care towards data. Algae Cloud suggests that perceiving data storage as living might make people more mindful of what data to store, and cherish their data more, adding a dimension of care towards data. Caring for data might involve practices that conflict with algae care, for instance throwing unimportant algae data away. Simultaneously, algae care might cause conflicts with data care, like entailing that all data needs care all the time. For instance, as discussed in the focus groups, should workers feel the obligation to care for their work-data also in their free-time? De la Bellacasa stresses how care isn't always linked to love and affection; it can also feel depleting, overwhelming, or wrong.



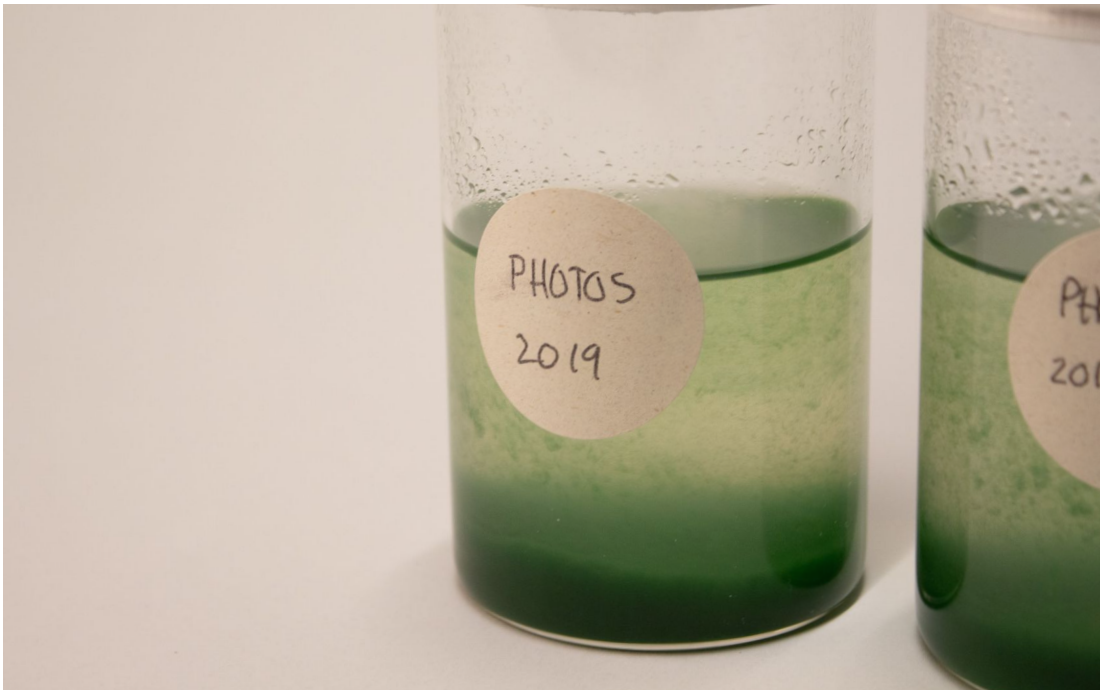
To sum up, the results suggest that mutualistic care might be complicated when data is stored in algae.

WHAT CAN WE LEARN FROM STORING DATA IN ALGAE?

Algae Cloud is a main contribution of this project as a speculative design provocation that intends to inspire designers to think of new ways of designing for mutualistic care between humans and living organisms and between people and the things they use. It intends to address a feeling of disconnection in today's world, not only from our intimate bonds with other living organisms but also from data storage as a weightless and intangible entity in the air. Algae cloud highlights this by depicting the elusive cloud as a living, breathing culture that requires and provides care.

The project does not suggest that all data should be stored in algae, nor is it implying that having a relationship with living organisms through a human-centric motive like data storage is inherently good or bad. It is trying to raise questions on if we could relate to things, alive or digital, in new, co-dependent ways in a disconnected world.

Moving beyond algae and data, this project suggests that relating to things like data storage as alive and exchanging care with something living and breathing might inspire new relationships to things we otherwise just use. The results suggest that having to care and attend to the resources we use can make people mindful of what to keep and what to discard or not use in the first place. Livingness might inspire meaningful connections with things, and having to care might encourage a sense of ownership. At the same time, mutualistic care is not inherently good. The focus groups highlighted implications of care, for instance, who should care, and caring because of fear. When mixing organic and digital worlds, one can also start to ask; what are we caring for? The practical benefit, the living thing, or something in-between?


PHOTOS
2019

Design recommendations

Here are some recommendations for how this work might be valuable for other areas within HCI and design practice.

RELATED TO PREVIOUS WORK WITH DNA DATA STORAGE IN LIVING ORGANISMS.

This work could complement previous work within HCI that explores design opportunities and implications for DNA data storage in living organisms.

More-than-human relationships

Previous work by Kim et al. suggests that the technology could be used to foster better human relationships with more-than-human entities (2022), which is also suggested in other projects like Grow Your Own Cloud (G.Y.O.K., nd) and Symbiosis (Jang, X). This project might complement this work. Algae Cloud highlighted mutualistic care in one hypothetical relationship and, by unpacking it in a focus group, found some implications and opportunities that might be interesting to think about.

- How tools and species influence the human relationship with more-than-human entities
- What type of data being stored implicates care
- Do people care for the data, the living organism, or both?

New interaction quality opportunities

The first analysis (in Appendix H) highlighted Algae Cloud Ambiguity, livingness and tangibility as perceived qualities. these might be of inspiration for future designers wanting to explore DNA data storage in living organisms.

Relatability in tangible interfaces

Semina Aeternitatis (Alistar & Pevere, 2020) highlight how DNA data storage in living organisms brings opportunities for using living matter as a tangible interface to data that is relatable because life is a shared experience. This work adds to this by saying that the relatedness will also be implicated by how people relate to and experience the species the data is stored inside.

Data mortality

One of the key affordances of DNA data storage, is that it can make data practically immortal, which is also highlighted by Alistar & Pevere (2020) and Kim (2020) as an opportunity. This project suggests that also playing with the notion of data as living´, dying, and needing care, which DNA data storage also affords, might open new opportunities for relating to data while challenging current notions and feelings of data storage as immortal.

RELATED TO LIVING ARTEFACTS AND MUTUALISTIC CARE

By looking at mutualistic care through a speculative design lens, this project suggests how living with and caring for living artefacts, which are *"ecologically and socially embedded in everyday life."* (Karana et al., 2020) might unpack opportunities and implications for how the mutualistic care happens.

One result was that people who live with living artefacts might, for instance, ***delegate care***. Similar to how people water each other's plants while on vacation. The results also raised questions about ***who should care***, highlighting that caring can also be a burden. Furthermore, the results suggest that speculative design can be used to look into broader social aspects of living with living artefacts, which could again inspire biodesigners to think of broader implications and interaction opportunities of living artefacts.

The project also introduces data storage as a relation of mutualistic care. As discussed on the previous page, this brings implications for what the care is for. This might not be an exclusive question only for data storage. For instance, would people care for “living light” because they need the light, because they care for the organism, or are they caring for something in-between?

CHALLENGE "DATA CARELESSNESS" AND "DATA IMMORTALITY" THROUGH DESIGN

Additionally, results from this project suggests that virtual spaces like where we store data can feel weightless, limitless and immortal. This is problematic because the virtual world is entangled with ecosystems, human and non-human bodies and the planet in very heavy and ecologically circumscribed ways in a web of devices, optical fiber network cables, and data storage centres. Of course, most of this data is not profound information like cherished photos or important documents like in Algae Cloud, but mainly "big data" sets.

In relation to sustainability and CO2 emissions, virtual spaces offer great opportunities like not having to fly somewhere to have meetings or not having to print information on physical papers. Still, the way we are using and relate to virtual resources like data storage is problematic, with data storage currently requiring more resources than the aviation industry while storage space demand is growing exponentially.

The results from this project suggest that approaching data storage with more care and challenging data immortality might provide opportunities for shaping how people treat and relate to data storage. By incorporating these principles into design, interaction designers who shape people's perception of virtual spaces can challenge careless data practices.

Mindful storage
Insights from this project suggests that people can feel quite overwhelmed thinking of how much data they have (pg. 52) and the virtual mess it creates. Interaction designers could help shape systems that encourage mindfully deciding what data is worth storing and what people can let go of.

Data mortality
This principle means giving users a feeling of data having a lifetime. This could involve deleting data after a certain period of time, but designers could also experiment with what data would feel like if it were perhaps evolving or gradually decaying.

EXPERIMENT WITH DESIGNING FOR MUTUALISTIC CARE AND CO-DEPENDENCY IN NEW TERRAINS

A goal of the Algae Cloud prototype is to inspire designers to look into new arenas of exploring mutualistic care, suggesting that maybe embedding living organisms into practical things we are very dependent on might create new incentives to care in a world where the care going on between humans and non-humans can feel distant.

A few reflections

OVERALL PROJECT LIMITATIONS

This project has a lot of limitations. First of all, the very nature of Algae Cloud being a speculative research project means that I don't know if this can lead to actual, change ever. I hope that it can inspire designers, but it's hard to know how this would be discussed outside of a fixed, planned focus group scenario like the one I conducted.

Also, the project process included a lot of qualitative analysis with a selection of people who are mostly designers at TU Delft. In other words, it is made with a limited audience and there was also probably, inevitable, some subjective interpretations here and there.

THE PROMISE AND PROBLEM WITH DNA DATA STORAGE IN RELATION TO THIS PROJECT

In this project, DNA data storage is partly used to imagine new relationships with living organisms, and partly as a tool to reflect on current anthropocentric relationships with data storage. The very development and promise of DNA data storage as a commercial technology supports this anthropocentric relationship with data storage in the sense that it might provide incentives to treating data storage in the same way as we do now until it (maybe) arrives, instead of starting to rethink relationships with data storage (which would be more in line with more-than-human design philosophies).

EXAGGERATING TECHNOLOGY

As mentioned on pg. 108, "uploading" data to an organism is a very complex and time-consuming process, and the way it's presented in algae cloud is highly simplified, which might in turn contribute to exaggerated hopes about the technology. In hindsight this could maybe have been avoided by not including the "uploading" part as a part of the speculation, or "outsourcing" it to another service. This part is very very complicated with current technologies, and I think the "uploading" might also be what people associate with fears of unintended biological consequences and letting everybody edit genes freely. Which are valid concerns.

USING ALGAE FOR DATA STORAGE

I am also not sure what I feel about "using" algae for data storage. In Algae Cloud, some algae with less important data is also thrown in the trash. On one side, you could say that including living organisms into everyday practices is a way to connect with them, but you could also say that it is exploiting them just in a different way. I have also unfortunately killed a lot of algae while working on this project. I hoped that including it in the video might complicate care and highlight that caring for data and caring for algae sometimes is in conflict, and maybe it would make people reflect over that as well, but I'm not sure wether doing that in the video was good or bad. You could probably argue for both.

WHAT RELATIONSHIP WITH LIVING THINGS TO WE WANT WITH BIODESIGN?

As discussed by scholars in biodesign before me, it's not inherently good or bad. And there are also wider, ethical implications related to synthetic biology that aren't addressed thoroughly here. Also, even if storing data in algae was something everyone could do very easily, the wider implications of it could turn out to be less good for the planet overall. Connecting with algae through data storage is also a very different way of relating to algae. Overall: I want to summarise these questions and wider implications with this quote:

How do we imagine other biological futures? [..] Since we are part of nature, and can't live without it, what relationship with nature do we want, and what will we get? What relationship with other humans would those futures enable? Who should we ask? Who gets to ask? Can biology show us other ways to imagine?

Ginsberg, A. D., & Chieza (2018)

To sum up

This project started with the intention of making something that combined digital technologies and living organisms to make people feel a sense of interspecies empathy.

While navigating interspecies empathy, it became apparent that people's relations to living organisms and ecosystems around them is deeply connected to everyday practices. The project steered towards looking at practices that could instil a sense of dependency between people and living organisms through emerging biotechnologies, and DNA data storage in living organisms was further investigated.

A new concern arose by making speculations meant to help people imagine opportunities for care with DNA data storage in trees. Instead of talking about how people would care for trees, people also started talking about how they relate to data storage. Here, the project shifted to address current anthropocentric relationships with data storage as a careless practice. After choosing spirulina to work further with, and iterating on a speculative scenario, Algae Cloud was developed as a speculative research artefact to inspire new opportunities around mutualistic care between people, algae and data.

Algae Cloud was presented in a focus group for people with expertise in bio-design, more-thanhuman design and data-centric design with the intention of unpacking opportunities and implications of caring for Algae Cloud.

The results suggest that blending virtual and organic terrains might bring new opportunities and implications for what care could mean and what it looks like on a practical level. The project comes with a lot of limitations, but it the results can maybe also inspire other areas in design and HCI.

All in all, although the prototype, results and design process comes with limitations, the aim is to inspire people to imagine new opportunities for mutualistic care with non-humans; both alive beings like algae, and digital things like data storage.

PERSONAL REFLECTION

If I had a time machine, went back to myself two years ago, and tried to explain that I would be writing my thesis about storing data in algae, but not actually storing it in algae, just pretending to, so that people discuss and think about it, I think I (two years ago) would be a bit confused, mainly from the time machine with me being there but also from the project description.

While navigating this project, I have felt a mix between very fascinated and very confused. The speculative design mechanism behind opening questions and imagining futures makes room for rethinking and challenging current notions of how we relate to the world, which might feel fixed. But the practically oriented designer in me also thinks: Well, that's great, but do these thoughts and ideas lead to something?

It's hard for me to say if the ideas Algae Cloud might trigger will lead to tangible, measurable system changes that influence how we relate to the world and other species. Still, like different speculative designs, I hope it can be a tool for inspiring others to start thinking in new directions.

One thing I know for sure is that this project has inspired at least one person to design a bit differently: my self! I am glad to be leaving TU Delft and entering professional design practice with a shift in perspective on how we design technologies shape how we perceive the world and all the beings in it.

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