Living with Cyanobacteria: Exploring Materiality in Caring for Microbes in Everyday Life

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ABSTRACT

Materiality of artefacts holds the potential to intricately and dynamically shape our daily practices. We posit this capacity can be harnessed in fostering creative unfolding of everyday care practices towards living artefacts. To explore this premise, we designed a cyanobacterial living artefact with air purifying capacity, and invited eight participants to live with and care for it for two weeks. The artefact can be situated in diverse locations within domestic spaces, wherever the participant would consider air purification necessary and certain lighting conditions beneficial for the artefact's vitality. This versatility is supported by the artefact's colour-changing, pliable, adhesive, and suspendable nature. We analysed visual documentation and semi-structured interviews of participants' experiences of the artefact. Our findings suggest distinct roles of materiality for care regarding labour, knowledge, and exploration. We further highlight the intricate design space encompassing openness, temporalities and semantic fitness towards nurturing mutualistic care in human-microbe interactions.

CCS CONCEPTS

• **Human-centered computing → Human computer interaction (HCI)**; **Interaction design**.

KEYWORDS

Biological-HCI, Human-Microbe Interactions, Care, Living Artefacts, Materiality, Cyanobacteria, More-than-Human

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1 INTRODUCTION

Care is omnipresent in everyday human life, and extends its reach to encompass more-than-human worlds [19]. As humans, we care and are cared for, within human realms [12, 37]. But also beyond it: in reciprocal and evolving relationships with other-than-human "companion species" [36], with plants [4, 15], animals [34, 38, 60, 76], microbial "workhorses" [3] and our human microbiome [9].

The concept of care for microorganisms has recently gained increasing attention across design and Human-Computer Interaction (HCI). In recognition of microbes' significance, especially of its abundance and diversity [58] and impact on the Earth's climate [14], emerging special interest groups (e.g., microbe-HCI [48]) and microbial interfaces [6, 32, 61, 63, 80] challenge existing forms of human-microbe relations. For example, scholars have generated discourse around empathy [17], more-than-human temporalities [49, 64, 80], noticing [16, 57, 80], and care [3, 16, 59], towards reciprocal and evolving relationships with microorganisms involved in living artefacts [42].

To address the challenges of temporality and scale associated with caring for microbes [49], HCI researchers have previously proposed diverse digital technological applications [3, 16]. Yet, the care actions expected from the human co-habitants of these living artefacts were predetermined by the designers. As such, it hinders the organic emergence of creative configurations for care actions in everyday life, making them difficult, if not impossible, to develop spontaneously. This could especially impede the seamless integration of these artefacts into our everyday lives, thereby affecting the sense of cohabitation and coevolution with other-than-human entities. To this end, we see great potential of materiality in facilitating the creative unfolding of care practices. Specifically, we are intrigued by the temporal and performative qualities of materials [26, 44] and the potential role of these qualities in the emergence of novel caregiving practices in the every day, while building intricate and dynamic relationships with living artefacts.

To explore this premise, we designed a living cyanobacteria artefact, giving particular emphasis to its temporal and performative material qualities. We then conducted an in-situ longitudinal study with eight participants, who cohabited with the living artefact over two weeks.

1.1 Contributions

By engaging with individuals who possess a wide spectrum of caregiving experiences towards other-than-human living beings, our study delves into the crucial role of materiality in nurturing care practices in everyday life. This exploration not only sheds light on the significance of materiality but also uncovers its potential to serve as a powerful catalyst for HCI designers aiming to cultivate creative care approaches specifically tailored to microbial living artefacts.

Given the relatively nascent nature of biological integration in design and its associated technical and practical challenges, there is a lack of longitudinal studies involving living artefacts. It requires the design of a reliable living artefact that participants can live and interact with over an extended period, this includes challenges of maintaining the organisms' vitality and ensuring adequate levels of safety for people who may interact with them. To that end, with the design of our living artefact, we strive to inspire HCI researchers, encouraging the development of innovative living artefact designs conducive to field studies. Furthermore, to our knowledge, our work represents a first longitudinal in-situ study involving cyanobacteria-based living artefacts. Our research offers insights into distinct temporal patterns and behaviours exhibited by these microbes within domestic settings, framed to offer useful guidance for HCI designers. Moreover, we showcase a potential method for designing habitats tailored to accommodate these organisms.

Additionally, no existing studies to date have specifically centred on materiality and its capacity to foster care practices for living artefacts. In this context, we offer our initial insights into how temporal and performative qualities of living artefacts could be meticulously designed and fine-tuned to elicit and shape novel care practices in everyday life.

2 RELATED WORKS

2.1 Social Dimensions of Microbial Living Artefacts

Our paper positions "care" within the context of microbial living artefacts as an initial exploration into human-microbe relationships that could potentially integrate into our daily practices. We have been actively engaging and collaborating with microbes in diverse life activities, harnessing their distinct abilities, notably in practices such as beer brewing, sourdough baking, and medicine production. In recent decades, scholars in design and HCI fields have broadened the scope of human-microbe relations to encompass more diverse organisms and contexts, such as shared environment sensing and display [6, 9, 32, 35], direct interactions [63], biotic games [51] and interactive public arts [55].

With novel functions and experiences endowed by microbes, these endeavours have sparked imaginations of alternative social interactions with non-humans, driven by an aspiration to enhance our planet's sustainability and harmonious relationships between species. More profoundly, they have triggered meaningful dialogues within design and HCI on new epistemological perspectives, associated challenges and opportunities that arise when designing and living with microbial artefacts. Besides our long-existing understanding that living media could naturally promote human empathy [17], they might also bring about an experience of shared "vitality" [61] which could lead to motivations of caring. Delving deeper into this social dimension of living artefacts, Karana et al. [42] proposed three fundamental design principles to facilitate living artefacts to be deeply embedded within everyday life: *mutualistic care, living aesthetics and habitabilities*. These design principles call upon designers to understand and embrace diverse temporalities of living beings, and to nurture reciprocal relations and sensibilities of habitat relationalities with them. Additionally, design strategies, as proposed by [49], enable the surfacing of the livingness of microbes, as a way to overcome and manage challenges in human perceptions of the distinct temporalities, scales, and semantics of the microbial world. In line with this approach, [80] proposed microbial interfaces and artefacts that align human-microbe temporal dissonance, fostering imaginaries of alternative reciprocal human-microbe relations. Our work endeavours to contribute to the ongoing discourse on the social dimensions of living artefacts by exploring how we can design for care. We collaborate with a cyanobacterium (*Synechocystis* sp. PCC6803), a microorganism that presents unique temporality that poses challenges for timely care [80].

2.1.1 Cyanobacteria Artefacts in Design and HCI. Commonly known as "blue-green algae," cyanobacteria are a type of bacteria that distinguishes itself from other bacterial species through its ability to perform photosynthesis, a biological process shared with green algae and green-leafed plants. Amongst photosynthetic species, microalgae and cyanobacteria are microbial species that have been integrated into design and HCI projects. These projects encompass a range of innovations, such as an energy-converting living light system [23], an interactive air-purifying playground [21], air-purifying garments [1], outdoor water-detoxing tiles [33], light-responsive image displays [30], electricity-producing wallpaper [68], and temporal-aligning interfaces and artefacts [80]. Leveraging their photosynthetic process, cyanobacteria can metabolise using only light, water, carbon dioxide, and various inorganic substances. To sustain themselves, they continually absorb sunlight and carbon dioxide while releasing oxygen into the atmosphere—a process known as carbon fixation, which plays a significant role in the global carbon cycle [13]. Cyanobacteria's capacity for carbon capture and oxygen generation has been demonstrated in living material designs [18, 40, 69, 73]. When exposed to light, these microorganisms accumulate green biomass over time, typically spanning days to weeks, thereby transforming the total absorbed light into green living colours [80].

Whilst most existing works have explored the functional potential of photosynthetic microbes, e.g., purifying air, [80] have called attention to their unique temporality and the challenges they pose to timely human care. They instantiated how the alignment of human-cyanobacteria temporalities could foster new reciprocal human-microbe relations, by creating a tangible interface with cyanobacteria facilitating human noticing of the microbe's wellbeing and envisioning mutualistic care enabled through the interface. Building on this work, we further explore care in situ for a potential air-purifying living artefact designed with cyanobacterium *Synechocystis* sp. PCC6803.

2.2 Care for Other-than-Humans in HCI

Care as "everything we do to maintain, continue and repair 'our world' so that we can live in it as well as possible" [54] is of vital importance in our current times of ecological crisis. Through practising care for ourselves and those around us, we aim to nurture not only our own lives but also other-than-human cohabitants that share the environment with us through intricate relations, dependencies and entanglements. Care involves not only mundane labour and affection but also higher ethical and political concerns [19]. Moreover, it is essential to also recognize that care is not always positive and fulfilling; embracing the values of discomfort that care might involve can also be unsettling [62]. Care inherently involves tensions, yet these can be desirable and generative when approached through a design perspective [37].

In the call to pursue alternatives for the long-existing destructive industrial paradigm, HCI researchers have been turning to feminist care ethics and posthumanism, and exploring care possibilities both theoretically and in practice. In HCI, caring for more-than-human and not-just-human [47] concerns moving away from anthropocentrism and functionalism [7] and convening "constituency" of humans and non-humans as matters of care before any design is committed [75]. Care for other-than-human beings is a relational, embodied, and ongoing practice that is necessarily particular [47]. Pioneering researchers committed to care-ful HCI have offered us valuable insights to design care for diverse other-than-humans. Some examples include care imaginaries towards home IoT [46], tensions in care for loved ones [37], design exploration for tactful feminist care [12], care-ful practices and artefacts initiated by local communities in farming [7], attention to animal welfare [60], and ethics of care when working with microbes [3]. In parallel, the notion of *mutualistic care* [42] has been introduced in the biodesign framework of "living artefacts", suggesting the reciprocity and evolving nature of care between humans and living organisms in the artefacts. We are eager to delve deeper into this notion of care in our research.

Care concerning specifically other-than-human living beings such as microorganisms has been a topic of interest that has gathered traction amongst artists, designers and HCI researchers (e.g., [3, 16, 20, 35, 49, 57, 59, 63, 80]). Here, we briefly discuss different ways in which care for microbes has been studied in HCI, to help us further distinguish our contribution. In Tardigotchi [20], a water bear's wellbeing is displayed as a digital avatar on a pixelated display and also made observable through a microscope on the artefact. Through digital reminders of the water bear being hungry or satisfied, people can perform feeding actions for the microbe accordingly. Similarly, Nukabot [16] is an artefact that communicates progress and the well-being of food-fermenting bacteria through digital mediation and cultural referencing that emotionally appeal to the humans who live with the artefact, to care for, and to manually stir the fermenting bran at appropriate times. Contrastingly, designers of Rafigh [35], utilise unprocessed visible aesthetics of mushroom growth, to appeal to its users to become engaged with the care practices involving speech learning and watering of the mushrooms.

Amongst these works, some have demonstrated how in-situ longitudinal studies around care for living organisms could be approached [16, 35, 59]. [16]'s artefact design revolved around familiar organisms and established care practices; [35] and [59] investigated how physical care towards a living organism influences human relationship with familiar products. However, none of the works have studied the role of materiality of living artefacts in nurturing diverse care practices over time. In these works, to elicit care actions, there is usually a set of input-output (I/O) rules in the artefact that links one specific action (e.g., stirring in Nukabot) or a targeted behaviour change (e.g., speech learning in Rafigh) to a microbial need. Yet, caregiving interactions are often prescribed by the artefacts' designers. This makes it difficult (if not impossible) for creative configurations related to care actions to emerge organically in the everyday. To delve into this particular aspect of care within the frame of designing a living artefact, we turn our attention to materiality, more specifically, the performative qualities of materials that can be harnessed in the design of the artefact.

2.3 Materiality and Performativity of Materials in HCI

Over the past decade, HCI scholars have persistently turned away from the view of the material world as passive and inert. They now share the common understanding that materiality, intended here as the material qualities of artefacts, plays an active role in the unfolding of dynamic relationships between people and interactive systems [31, 41, 67, 74, 77], offering new interaction possibilities and experiences that are intimately entangled with social practices [26].

Giaccardi and Karana [26] called for HCI designers to pay attention to the performative qualities of materials, referring to their active role in shaping our peculiar ways of doing, and ultimately, daily practices. Building on this, Karana et al. [44] presented designerly explorations of how the performative qualities of materials can invite novel ways of unfolding a social practice (in this case, the mundane activity of "tuning the radio"). To guide designers in harnessing performativity of smart materials, Barati et al. [5] offer a framework for material design process to prompt specific actions from people. In a similar vein, by examining lived experiences with a deformable lampshade, Zhong et al. [79] revealed that "deformability" of the artefact can stimulate participants' creativity in their interactions with it, such as "drawing on the artefact."

In line with these studies, we argue that materiality, especially the performative qualities of materials, holds the potential to facilitate the creative unfolding of care practices. The importance of creativity in care has been underscored in *Matters of Care* [19]. It emphasises uneventful everyday occurrences as transformative, and advocates for "improvisational haptic creativity" for humans to engage with more-than-human care, as a way to disrupt the dominant anthropocentric view of innovation ([19], p.214). In line with this call, we propose that performative qualities of materials [26] can support exploratory care practices towards living artefacts. In the experience of materials, performances are carried out and altered in the development of practice through recurring encounters with the materials [26]. In this dynamic, materials are not static;

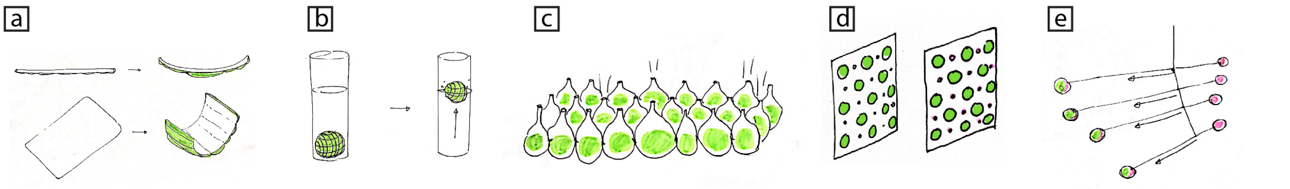

Figure 1: Initial sketches depicting possible ways to surface livingness of cyanobacteria: a) bending, caused by the gas produced by cyanobacteria during photosynthesis; b) floating, driven by the gas produced during the photosynthesis; c) making sound, through a special mechanism according to the gas produced during the photosynthesis; d) colour changing, caused by substances produced during photosynthesis; e) un-balancing, due to depletion of nutrients as the cells reproduce.

they change as a result of these performances, potentially influencing how performances further develop. Embracing the concept of materials experience in our design allows for the adaptability of living artefacts across a broader spectrum of social situations. It also opens up avenues for what could be framed as creative alternatives [10], co-performance [25] and multiplicity [75], both with and through living artefacts.

In the design of our artefact, to enhance its potential to allow for the creative unfolding of everyday care practices, we paid special attention to the artefact's temporal and performative qualities, considering both its living and nonliving components. In particular, we focused on the temporal colour changes expressed by the living cyanobacteria, along with qualities such as softness, transparency, flexibility, and stickability of the nonliving components. The form (shape and size) has also been taken into account in the final design of the artefact.

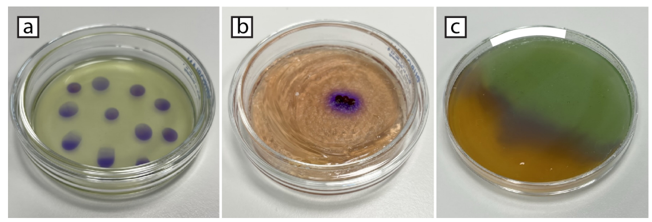

Figure 2: Explorations of different compositions of cyanobacteria culture and the pH indicator in liquid and jelly forms for colour indication: (a) both cyanobacteria culture and the indicator are liquid; (b) both substances are jellified (first, the cyanobacteria culture is jellified into beads and embedded into the indicator, then the indicator is jellified); (c) both substances are jellified at the same time.

3 METHODOLOGY

We undertook a research through design (RtD) process, through which we used the research artefact as a catalyst and carrier for discourse [72]. Accordingly, the process was structured into two key phases: the design of a living cyanobacteria artefact, and a two-week in-situ study to comprehend the real-life experiences associated with caring for this artefact. In the design of the artefact, we drew from the Material Driven Design method [43], particularly from material tinkering [65] and the making/tuning of performativity [5, 44] techniques, to explore suitable materials for the artefact, and to understand performativity of the selected material. Notably, prior to the work presented in this paper, the first author had lived and designed with cyanobacteria over the last 2 years.

3.1 Crafting Materiality of the Living Cyanobacteria Artefact

3.1.1 Viability of the Habitat. The primary objective of the artefact is to create an environment that fulfils the basic habitat requirements necessary to maintain cyanobacteria's metabolic activities and their functional potential in air purification. Cyanobacteria rely on light, water, carbon dioxide and other inorganic substances for their survival. This requires the habitat to allow for sufficient openness to facilitate permeation of light and gases (oxygen and carbon dioxide) while maintaining humidity levels. On the other hand, the habitat should also ensure safety for both humans and the cyanobacteria, by minimising risk of contamination, which could result from the growth of competing microorganisms that might threaten the viability of the cyanobacteria. Additionally, it should prevent any inadvertent leakage of cyanobacteria into the human environment. To address these contrasting requirements of openness (for light and gas exchange) and enclosure (for the safety of cyanobacteria and humans), we explored various potential materials (e.g., agar, calcium alginate hydrogel, PDMS silicone rubber and other types of silicone rubbers). After careful consideration, we selected PDMS silicone rubber - whose suitability for supporting microbial viability had been demonstrated in a previous scientific study [56]. PDMS silicone rubber is a highly robust, processable, gas-permeable, adhesive, transparent and biocompatible material. These qualities enable it to allow passage of light and gases while providing a clean and humid environment that supports the survival of cyanobacteria for over a month by maintaining its photosynthetic activity. We used PDMS rubber as a canvas material for encapsulating cyanobacteria within its cavity.

3.1.2 Surfacing Livingness and Temporality. A crucial step of caring for cyanobacteria involves understanding and tracking their living states over time. An effective indicator of their growth state is their photosynthetic activity [53]. To surface the cyanobacteria's photosynthetic activity, we explored various methods through ideation (figure 1). Ultimately, we opted for a well-established protocol using a pH-indicating solution composed of a proprietary mix of dyes

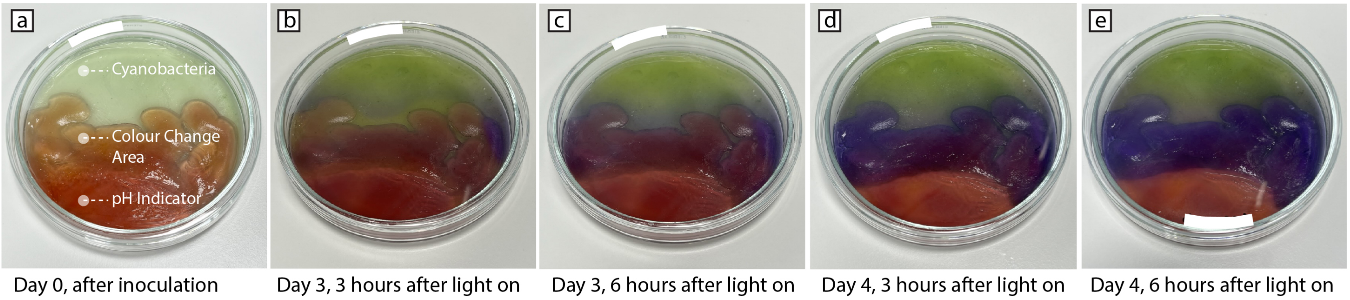

Figure 3: The intensity of Cyanobacteria's photosynthetic activity surfaced by the colour-changing jelly material, from low (a), medium (c) to high (e). The cyanobacteria appeared greener over a few days, and the pH indicator showed a purple hue over a few hours after light was turned on in the incubator.

(Bio-rad, USA). By implementing this solution, a living artefact can signal the absorption of carbon dioxide by cyanobacterial jelly beads during photosynthesis, manifesting as a colour change from yellow to purple in a matter of minutes. Building upon this technique, we further explored diverse jellification possibilities for both cyanobacteria culture and the pH indicator solution (figure 2). We focused on jellification of both substances simultaneously to form a jelly material, which could maintain its form and thus be easier to integrate into our artefact. Figure 3 shows how this jelly material surfaced photosynthetic activity of cyanobacteria through colour change. However, it is important to note that the jellification of both substances slows down the colour change. Consequently, the indication of photosynthesis takes several hours to manifest (figure 3). We think this compromise in terms of temporality is acceptable for our research. In designing the colour composition, we deliberately avoided incorporating any distinguishable patterns or shapes. This decision was made purposefully to maintain an ambiguous living aesthetic devoid of explicit connotations.

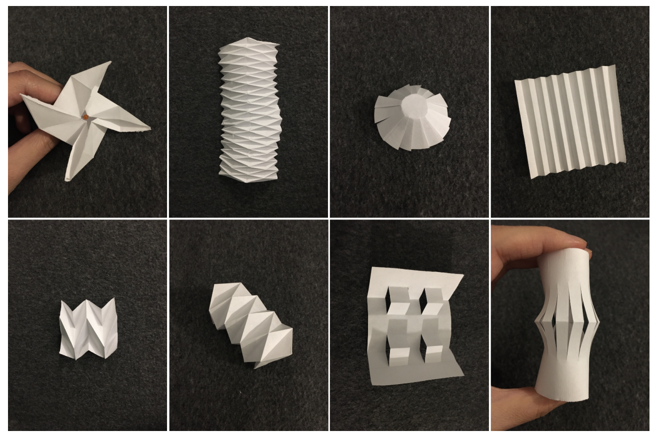

Figure 4: Initial paper mock-ups to explore diversity and degree of performativities through which light received by the material surface can be adjusted

3.1.3 Performativity and Multi-situatedness of the Artefact. It is imperative that the artefact possesses the inherent ability to prompt a wide array of performances from people. In light of this consideration, we purposefully opted for a highly elemental and ambiguous form for the artefact, consciously refraining from incorporating explicit references to any particular utilitarian object, such as a vase. This decision ensures that the artefact remains receptive to multiplicity of interpretations [70] from people. To adapt effectively to the nuanced variations in domestic lighting conditions, the artefact needs to be multi-situated. In achieving this, we drew on the tuning/making of performativity [5][44], highlighting the material's performative qualities, which could be harnessed to make the artefact versatile in terms of its placement within a domestic space.

Amongst the habitat elements crucial for cyanobacteria, we focused on light as the element that participants could modify through their interactions with the artefact. Light was chosen because it is easily perceivable and adjustable within the shared domestic environment. Within our team, we engaged in an iterative design process involving paper mock-ups (figure 4), material tinkering (figure 5), and in-situ testing of a proof-of-concept (figure 6). These phases were carried out with the primary aim of gaining insight into how different alterations of light reception by a material can be accomplished through the material's performative qualities. To delve into the diversity and degree of performativity possibilities, we departed from utilising paper mock-ups, deploying origami and kirigami techniques to create intricate light and shadow patterns. In this process, however, we opted for a seemingly simple sheet form devoid of explicit cues of specific affordances. This choice was deliberate, as this form inherently harboured the ambiguity and openness essential for enhanced performativity.

Given that the artefact essentially serves as a viable habitat for cyanobacteria, our material options were constrained to certain requirements (cf. section 3.1.1). We have considered conventional options to maintain microbes alive, such as agar plates or liquid culture in a glass flask. However, these material compositions are neither stable nor flexible enough to elicit from people the diverse creative performances we aim at (e.g., folding, sticking, and hanging of the artefact). Alternatively, we explored a method to encapsulate cyanobacteria that had been inoculated on a piece of paper, in a hydrogel (calcium alginate), as an initial way to form a simple-sheet material. Through tinkering with this technique, we discovered that thinner hydrogel yielded superior performativity, facilitating easy folding and rolling. The material's stickability enabled it to

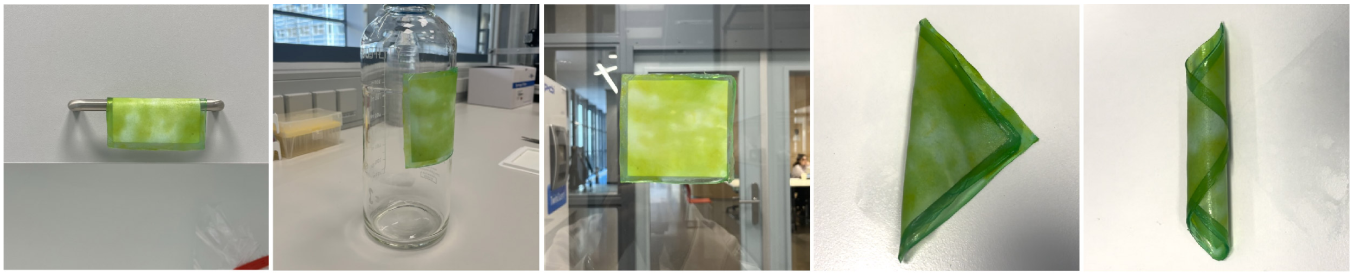

Figure 5: Tinkering with a hydrogel material to explore potential performativities

Figure 6: A proof of concept for assessing performativity and viability in domestic context

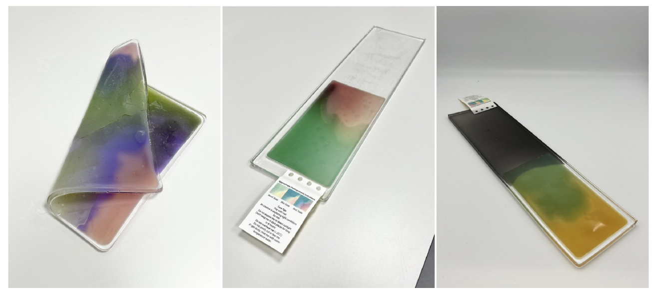

Figure 7: Final iterations on shape, size and colour of the artefact

attach to objects (figure 5), while its transparency enabled light - a crucial element for the microbes - to pass through, allowing people to place the artefact at locations of light exposure. However, the material's fragility posed a challenge to our longitudinal study involving extensive participant interaction with the artefact.

As a robust alternative, we continued to explore PDMS silicone rubber, which, simultaneously, was identified as a suitable habitat material for cyanobacteria as mentioned in the previous subsection. We first confirmed its flexibility and adhesiveness by casting thin sheets without involving the microbe. Then, by encapsulating the microbial jelly, we made an initial prototype as a proof of concept: a 120 mm by 120 mm square sheet around 10 mm thick, enclosing a round cyanobacteria-pH indicator jelly. The sheet had to be thicker than the ideal thin sheet, due to the need to encapsulate the jelly. The artefact was applied in in-situ testing by the first author, where she lived with and cared for it for a week, to assess its performativity and viability in a domestic context (figure 6). The adhesiveness and transparency worked effectively, enabling a novel interaction wherein the artefact could adhere to a window to receive more light. However, limitations arose due to its small size and thickness, hindering various light-altering forms (such as folding) and attachment methods (such as hanging), apart from propping against other objects. Additionally, the round disc shape of the cyanobacteria jelly was associated with a "finished product", limiting creative interpretations. Furthermore, we recognized the need to offer a "shade option" within the artefact itself, as excessive light could prove detrimental to the organism. Our subsequent iterations (figure 7) prioritised reshaping the artefact to offer enhanced flexibility in attachment and capacity to provide shade to the cyanobacteria through folding. Consequently, our artefact now possesses properties of flexibility, adhesiveness, and the ability to be suspended. It features a darkened half that can offer shade when folded, thus addressing the light intensity concern.

Figure 8: Care label attached to the living cyanobacteria artefact

3.1.4 Care Label. We created a care label (figure 8) attached to the artefact, providing participants with easy access to information during their interactions. The label informed participants of approximate colour indications of the artefact's well-being state, and offered suggestions that encourage participants to engage in playful and creative exploration of light conditions for the artefact, while cautioning them against potential harm. The care tips are as follows:

Play with me!
Be creative in exploring light conditions for me!
Do not expose me to direct sunlight.

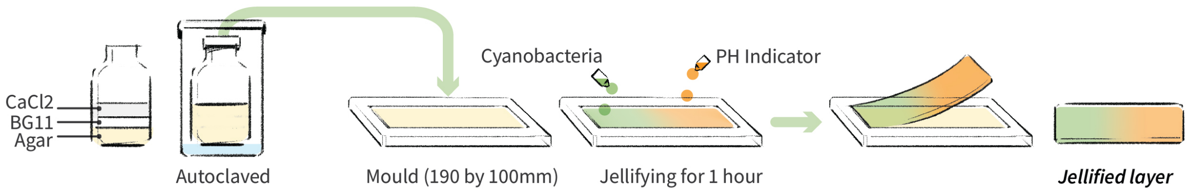

Figure 9: Step 1 of making the living cyanobacteria artefact

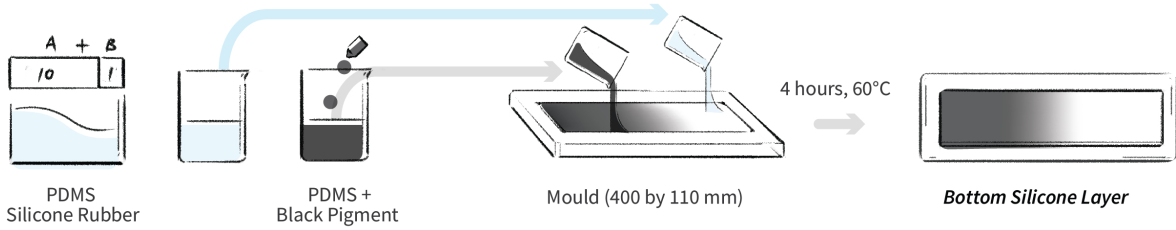

Figure 10: Step 2 of making the living cyanobacteria artefact

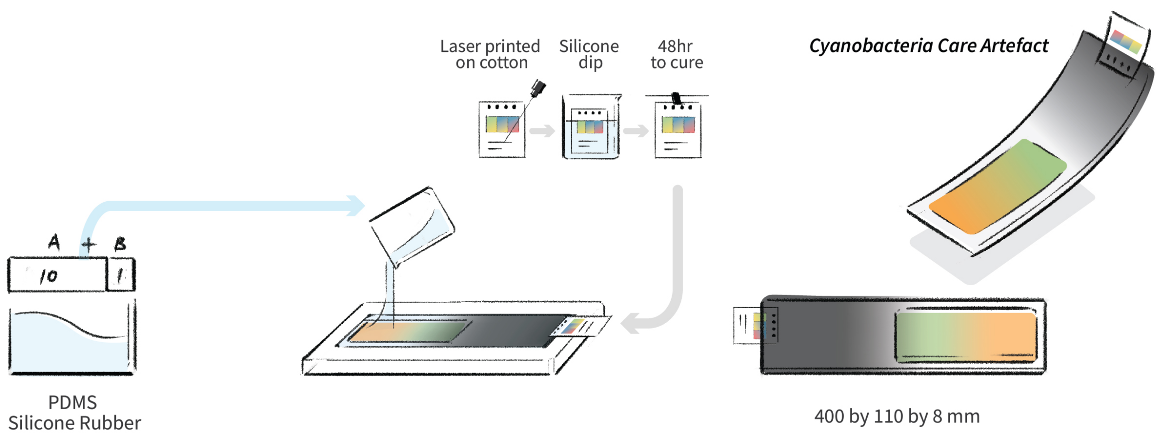

Figure 11: Step 3 and 4 of making the living cyanobacteria artefact

Don't keep me in dark places for long (< 8 hours).
Do not overheat me (< 25°C).
Do not pinch, cut or tear me.
If I get dirty, rinse me with room-temperature water.

3.1.5 Making the Living Cyanobacteria Artefact. The living cyanobacteria artefact is a soft, flat and rectangular object with a silicone outer shell. It encloses a thin layer of jelly that contains living cyanobacteria and the pH indicator, which surfaces the photosynthesis of the microbes through colour change. Below we outline the making steps of the artefact.

Step 1 Jellification of cyanobacteria liquid culture and the pH indicator solution First, agar solution infused with growing medium (BG11) and calcium chloride solution (2.5% w/v) was formulated and autoclaved for sterilisation. Within a biosafety cabinet, the heated agar solution was poured into a pre-made plastic mould (190 mm by 100 mm) and let to solidify. Second, a sodium alginate solution (5% w/v) was mixed respectively with a medium-green cyanobacteria (*synechocystis* sp. PCC6803) liquid culture and the pH indicator solution, both at 1:1 volume ratio. Third, both liquid mixtures were poured simultaneously onto the solidified agar within the mould, from opposite ends. They intermixed and diffused into each other in the middle of the mould, forming a thin layer of approximately 2 mm thick. This layer was then left to jellify for about 1 hour. Once jellified, the upper layer was carefully peeled off from the mould and placed within a sterile petri dish.

Step 2 Casting the bottom silicone rubber layer In a fume hood, two components of PDMS silicone rubber were mixed in a 10:1 ratio and evenly divided into two plastic containers. A black silicone pigment was added to one of the containers and thoroughly

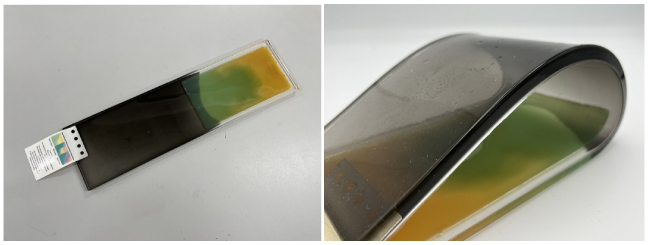

Figure 12: The final living cyanobacteria artefact

mixed. Subsequently, both silicone mixtures were poured into a pre-made mould (400 mm by 110 mm) from opposite ends, converging at the midpoint. This formed an approximately 3 mm-thick silicone layer. The silicone was then cured for 4 hours at 60 degrees Celsius in an oven.

Step 3 Preparing the care label Care instructions were printed onto a cotton canvas material using a laser printer. Following this, the label was punctured with several holes at one end, immersed in silicone rubber, and cured at room temperature for over 48 hours.

Step 4 Casting the top silicone rubber layer The previously created bottom layer of silicone rubber was kept in its plastic mould. The cyanobacteria-pH-indicator jelly was laid on top of the transparent section of this bottom layer. Simultaneously, the care label was affixed on the other end onto the silicone rubber. Same as in step 2, two components of PDMS silicone rubber were mixed in a 10:1 ratio, and poured into the mould. This process formed a top layer that covers the jelly sheet and the punctured area of the care label. The artefact was then cured at room temperature for 48 hours. The cured artefact (figure 12) measured approximately 400 x 110 x 8 mm.

Figure 13: Delivery of the living cyanobacteria artefact and its care instructions to a participant

3.2 The Study

Our study was centred around addressing several key questions. First and foremost, we sought to understand the diverse ways in which people express care for the potential air-purifying living cyanobacteria artefact, and the underlying motivations behind their chosen approaches. Furthermore, we were keen to explore the significant role that materiality plays within this context, shedding light on how it shapes caregiving practices.

3.2.1 Participants. Our study was conducted with eight participants (table 1), between the ages of 27 to 68, and from fairly distributed genders. Our selection criteria for participants included 1) that they lived within the Netherlands, and 2) that they had previous and varied experiences of caring for other-than-human living beings. Some of them did not take care of plants well (i.e. claiming themselves to be a plant “killer”), while others took care of living things as a hobby, obligation, or job. The people who took care of living things as a hobby enjoyed taking care of plants or gardening, while those who took care of them as an obligation had to do so for making beer or kombucha. Lastly, some people had jobs where they took care of living things, such as biologists who worked in laboratories. The diverse experiences in caretaking may increase risk of “care failure”, e.g., with participants who claimed to fail in plant care. However, it ensured that we could observe a wider range of motivations and creativity in caretaking for a novel living being. We did not recruit people who had children under 12 years old, to minimise any possible damage or accidental ingestion of the artefact. All participants undertook the study voluntarily.

3.2.2 Procedure. We first sent out invitation letters to potential participants, in which we explained that we were interested in what it is like for people to live with living artefacts - everyday artefacts containing living organisms for advanced functionalities (e.g., to purify air, to self-repair, etc.). We asked them to live with and care for the living cyanobacteria artefact over two weeks at their homes, and to share their daily experience and reflections with us.

The study was undertaken in three phases. First, we delivered the artefact to participants' homes, accompanied by instruction cards that introduced the artefact and the study requirements (figure 13). These cards informed participants that the artefact contained living cyanobacteria, which are capable of absorbing CO2 from their surroundings and emitting fresh oxygen, thus potentially purifying the air. Participants were directed to position the artefact in locations where air purification was considered necessary and light conditions advantageous for its well-being. Additionally, we presented the artefact's preferred light conditions, and its colour changes signalling its well-being state. They were asked to take a photo of the artefact and its surroundings whenever they observed a colour change, and in case they relocated it or altered its form. They were prompted every 2 or 3 days by the first author to share texts or photos through their preferred digital platforms (e.g., WhatsApp and email). Furthermore, they were also encouraged to assign nicknames to the artefact, as a way to familiarise with it. Complete instructions can be found in the appendix. Upon delivery of the artefact, we conducted an initial interview to gain insights into the participant's routines and took a photo of their living rooms. The second phase of the study involved semi-structured interviews, lasting 30 to 60 minutes, conducted at the one-week mark of the study. At the end of the study, we conducted a follow-up interview. Most interviews took place at participants' homes, with four of them taking place over Zoom. The questions were designed to build upon the cumulative nature of the study, with second-week interview questions shaped by the responses gathered during the one-week interviews. In total, the study generated approximately 6 hours of verbal interview data, along with 79 self-reported and 64 researcher-captured photos collected after each site visit.

Table 1: Overview of participants

Participant	Age	Gender	Roles associated with care for other-than-human living beings
P1	68	female	Plant lover / lifetime gardener
P2	51	transgender	Cyanobacteria photographer / cat keeper
P3	32	male	Self-identified plant “killer”
P4	60	male	Microbiologist
P5	34	female	Beer brewer / cat keeper
P6	27	male	Plant lover
P7	35	female	Kombucha brewer / plant lover
P8	28	female	Self-identified plant “killer”

Table 2: Interview questions of the one-week and two-week interviews

Unpacking Care	Interview Questions (after a week with the living artefact)	Interview Questions (after two weeks with the living artefact)
Opening	What is it like to live with [nickname] so far? Do you want to share anything specific you experienced last week?	How was your second week with [nickname]? Is there anything that has changed?
Performances and reciprocity	How did you take care of [nickname]? Can you show me where and how you placed [nickname] at home? And, why?	What else did you try? And, why?
Knowing and relating to the artefact	How did [nickname] respond to your actions? And, why do you think it responded in that manner?	Did you notice anything different from the previous week? Why do you think that happened? And, how did you feel about it?
Affection towards the artefact	How did you feel when you noticed changes in [nickname]? Why did you feel that way? What other feelings did you have towards [nickname]? Why?	How did your feelings change? Did you feel something else?
Making time for care	How much time did you find yourself setting aside to look after your artefact ([nickname])? Did it change your daily routine in any way? And if so, how?	Did anything change in the second week?
Motivations of care	Do you feel motivated to look after [nickname]? And why? What would motivate you even more in looking after [nickname]? Does your experience with [nickname] remind you of any other experiences you had of caring for other things, for example, a person, an animal, a plant, or other living things? And, how?	Did you feel more or less motivated this week? And why? What would motivate you even more in looking after [nickname]? How much of a good carer do you think you were over the two weeks? What do you think would help you to improve your care to [nickname]?

3.2.3 Interview Questions. Our interview inquiries focused on the evolution of care practices. It's worth mentioning that we deliberately refrained from directly probing participants about the concept of "materiality". Instead, we gleaned insights about its influence by synthesizing evidence from their comprehensive encounters with the artefact, thereby mitigating potential biases and ensuring that our questions remained accessible. In formulating our interview questions, we drew inspiration from Maria Puig de la Bellacasa's feminist care ethics framework, which has been increasingly discussed in recent HCI and design venues (see, for example, [16, 37]). De la Bellacasa emphasises the interplay between “knowing” and “caring”, and unpacks care towards the more-than-human worlds with three mutually dependent and challenging aspects: *labour/work, affect/affections, ethics/politics*. She also highlights the need to “make time” for care doings for other-than-human living beings. We also incorporated the notion of mutualistic care in biodesign [42] in the formulation of our questions. Specifically,

Figure 14: Participants placed the artefact in close proximity to their house plants that share comparable light requirements

we focused on how care relations with living artefacts can be reciprocal and evolving, and what role living aesthetics (i.e., how changes in living materials are experienced by people) plays in the establishment of mutualistic care, within this framework [42].

Accordingly, we synergized interview questions into the following five categories (table 2): 1) Knowing and relating to the organism: How are care actions facilitated through noticing the living aesthetics of the artefact? 2) Affection: How does affection evolve through care actions towards the artefact? 3) Performances and reciprocity: How do care actions evolve? How do participants navigate their performances between the function of the artefact - air-purifying - and their care for the artefact? 4) Making time for care: How does taking care of the artefact influence people's everyday routines? 5) Motivations of care: Why do people care for the living artefact?

3.2.4 Data Analysis. Following the interviews, audio recordings were transcribed. Coding and thematic analysis [11] were carried out by the first author on the photographs reported by participants, the text messages from participants during the study, and the transcribed interview data. Selective coding was used, to analyse the data under two interrelated lenses to address our research question: 1) the whys and hows of care for the artefact, and 2) how the artefact's material qualities influence care towards it. The initial coding was discussed among the first, second and last authors, which resulted in the repositioning and renaming of certain themes. Adapted themes, which will be presented below, were finalised through a discussion session by all authors.

4 RESULTS

We organise our results into two subsections: *the whys and hows of care for the artefact* and *material qualities and care practices*. Accordingly, we present a narrative that initially delves into the motivations and performances of care. Subsequently, we present observations on intricate connections between materiality and the nurturing of care practices.

4.1 The Whys and Hows of Care for the Artefact

We categorise the "why and how" into four themes, shedding light on the nuances behind participants' caretaking experiences. It's important to note that multiple motivations often coexist and can influence caregiving practices in various situations. However, for the sake of practicality and to facilitate the analysis of our extensive dataset, we initially organised these motivations into separate categories.

4.1.1 Care Practices Motivated by Livingness. A prevailing motivation observed among participants was a deep-rooted instinct to care for living entities. Many participants expressed enjoyment in living with and taking care of other-than-human life forms, such as plants, animals (e.g., young livestock), or even microorganisms (e.g., those used to cultivate kombucha). Consequently, their care

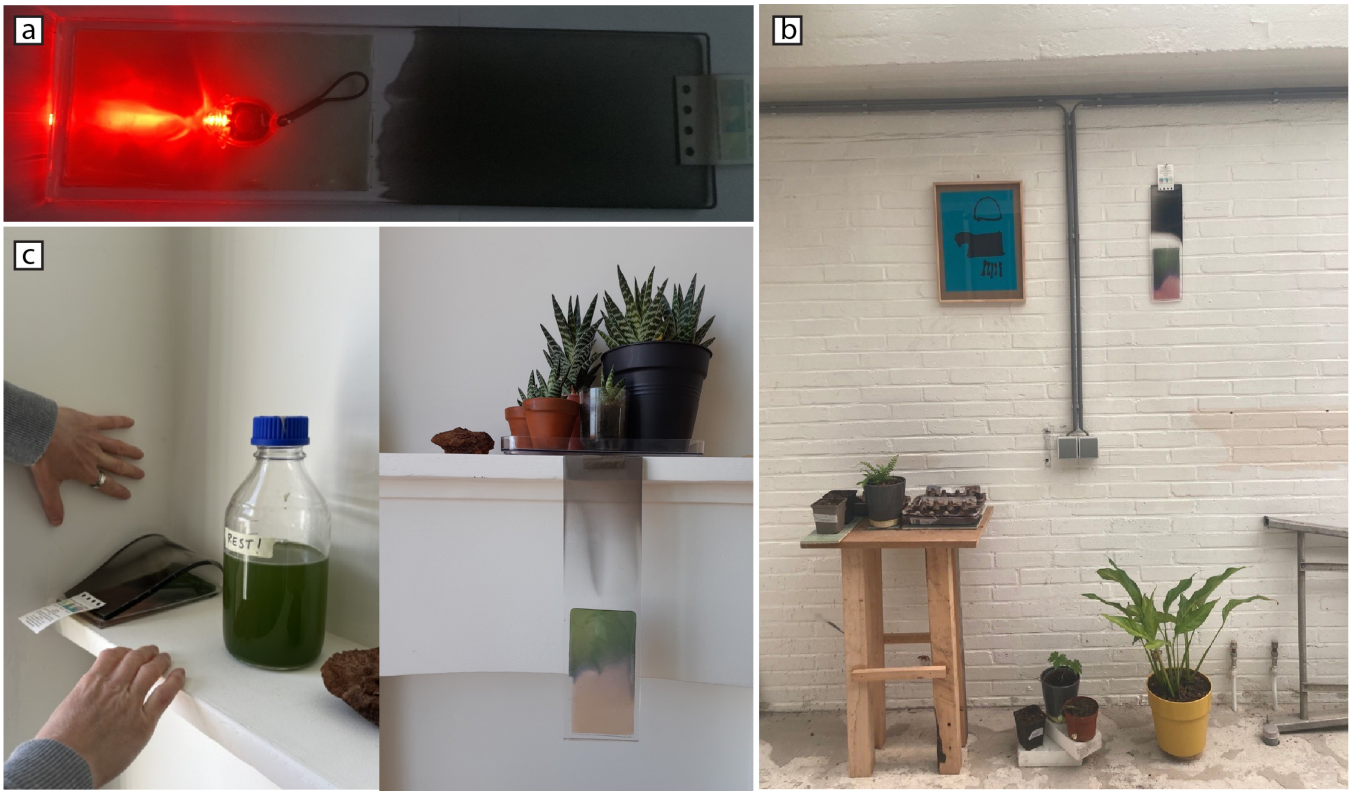

Figure 15: Various care performances elicited by the new life-form: a) conducting experiments to understand how local light conditions influenced its colour change by placing a red LED light; b) letting the artefact stay in an initially identified suitable location to "settle down" to avoid risk; c) identifying a location with better light conditions for the organism through trial and error.

practices were significantly influenced by their established ways of caring for familiar living things. For instance, some participants placed the artefact close to their house plants that share comparable light requirements (figure 14). This arrangement facilitated the incorporation of attentive interactions with the artefact into their existing routines of tending to their plants, thus serving as a gentle reminder to allocate dedicated intervals for its upkeep. Participants derived a similar sense of satisfaction from taking care of the living cyanobacteria artefact as they did for plants. For example, they expressed delight in witnessing the microbes in the artefact "growing", and seeing it "responding" to their care actions. These observable transformations in the living artefact motivated them to provide good living conditions for its well-being.

4.1.2 Care Practices Motivated by Curiosity towards New Life-form. Introducing a new life form, cyanobacteria, into everyday life made our artefact a novel experience for all participants. One participant expressed excitement over the realisation of embedded microbes, highlighting a new and futuristic "ecological connection" which presented them a unique opportunity to "communicate" with these microbes. Several participants mentioned experiencing a "new enjoyable responsibility" elicited by the artefact. One participant was particularly inquisitive about the working principle of the artefact, while another participant conducted experiments to understand how local light conditions influenced its colour change, by placing multi-coloured LEDs (figure 15, a) or a shade-introducing coin on its surface.

Participants encountered difficulty in aligning their care actions with the well-being states of the artefact in the beginning. As such, some participants retained a risk aversion attitude throughout the study, avoiding excessive experimentation. Once they found a suitable location for the artefact, they felt content with the artefact "doing ok" there (figure 15, b). Conversely, some took a more exploratory stance, adjusting their presumptions through trial and error. For instance, one participant, who had prior experience working with cyanobacteria, initially felt confident in her judgement regarding light conditions for the artefact's initial placement. However, the artefact did not exhibit an anticipated purple colour. After one week, the participant decided to expose the artefact to more light, resulting in its better state, marked by a purple hue (figure 15, c). Over time, all participants became more attentive and patient towards the artefact. As a result, they could anticipate the colour change when they repositioned the artefact.

Participants shared a common transition from excitement to relaxation while living with the artefact. It became evident that they allowed the artefact to ultimately "do its own thing". In some cases, novel care routines emerged towards the end of the second week.

Figure 16: A participant brought the artefact to a beer brewery where they worked, with the intent for the artefact to assist in absorption of carbon dioxide generated by the brewing process (benefiting humans), while receiving bright light from the brewery's interior (benefitting cyanobacteria).

For instance, one participant developed a new practice of checking the status of the artefact both in the morning and evening. Another participant regularly engaged in "documentation" to closely observe subtle colour changes, which served as a reminder of being attentive and caring.

The new life form sparked participants' imaginations, leading them to envision novel artefacts and care practices that extended beyond the current design. For instance, some suggested the idea of providing bodily warmth to the microbe through a wearable artefact. Others imagined looking for new households with more favourable light conditions for the artefact, which highlighted the possibility of nurturing care with novel social engagements.

4.1.3 Care Practices Motivated by Mutualism. Participants felt also motivated to take care of the artefact because of its potential functional benefits. For instance, some expressed an apparent disappointment of not knowing the tangible results of air purification, stating "I don't know if I will keep enjoying living with it because I don't notice so much difference in the oxygen." One of the participants named the artefact "Oxy", indicating the significance they placed on its functional value. Many participants had doubts about its functionality, with one remarking, "At this scale, I don't believe enough is happening." Several participants expressed a wish for a numerical indication of how much air the artefact had purified, which might increase their interactions with it. Furthermore, one participant took the artefact to their workplace, a beer brewery (figure 16). They intended that it could help absorb carbon dioxide generated by the brewing process (for the well-being of humans) while receiving bright light from the brewery's interior (for the microbe's well-being). This evidence emphasised mutualism as a drive for care practices.

4.1.4 Care Practices Motivated by Joyful Interactions. Joyful interactions with the artefact, also referred to as ludic and playful interactions in HCI ([2, 22, 24, 66, 71]), triggered participants to persist in their care towards the artefact. These interactions were mainly driven by a sense of accomplishment given by achieving what participants considered a "better colour". Upon achieving visually delightful appearances, some participants took a moment of pause to enjoy the artefact's beautiful hues, describing it as a "slightly meditative act". One participant expressed a particular fondness for the colour purple (figure 17, b) and was motivated to diligently care for the artefact to achieve a fully purple appearance. Two other participants mentioned that the artefact was like a splendid piece of art radiating "good energy" and "vibe", with one of them naming the artefact "Hoopla!", a joyful expression according to the participant. To enhance these joyful interactions with the artefact, participants employed various care strategies. Placing it in close proximity for constant observation was a common approach, which allowed regular admiration of the "beautiful" artefact in the

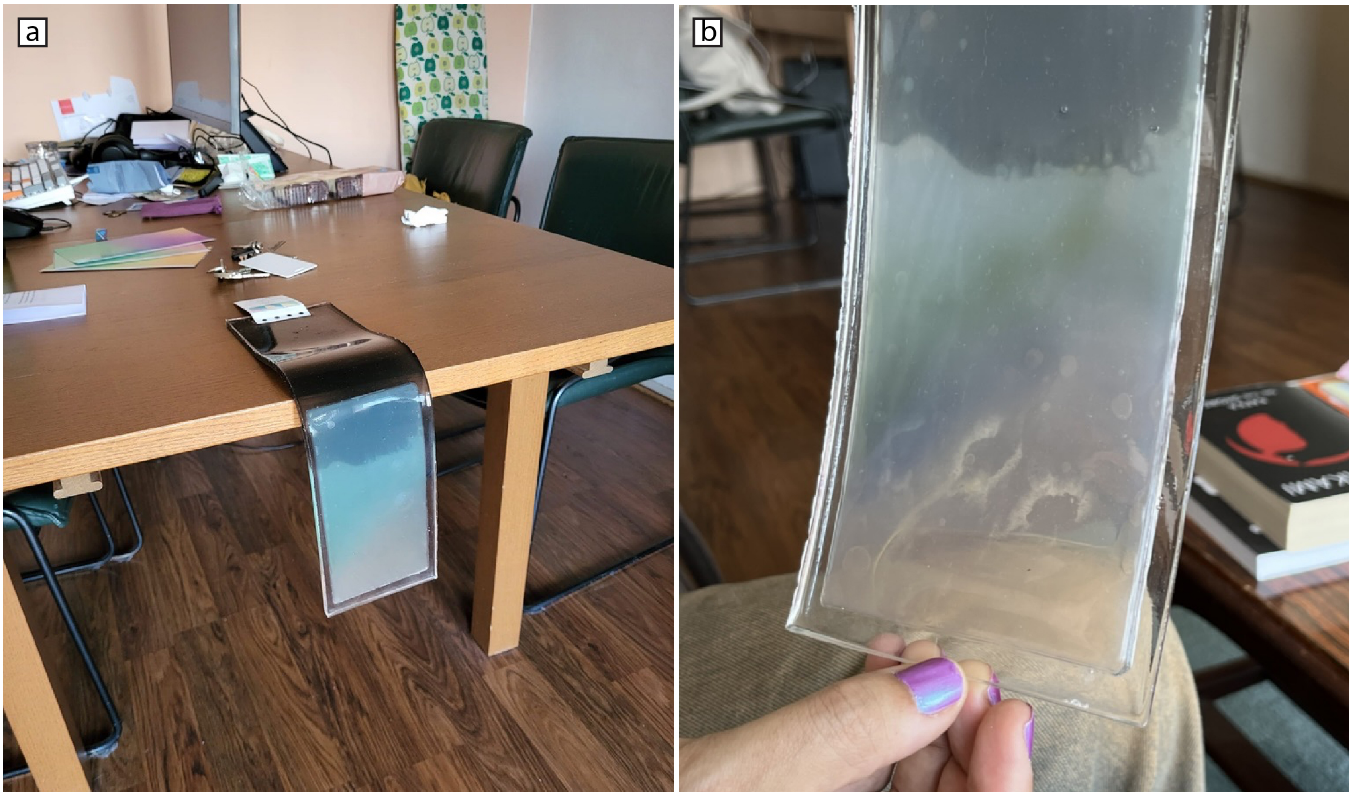

Figure 17: a) The artefact placed in close proximity for constant attention from the participant; b) A participant showing the "beautiful" purple hue in the artefact during our interview.

background of everyday tasks, such as dishwashing. One participant chose to hang it on the edge of their dining table, ensuring instant visibility from any angle upon entering the room (figure 17, a).

4.2 Material Qualities and Care Practices

The material composition supported cyanobacteria's viability effectively. In seven households with sufficient light intensity, caring for the artefact was generally perceived as "enjoyable", or even "too easy" by participants. This was because no other care actions besides finding a suitable location were needed, although participants struggled in the beginning. In one particular household with relatively limited natural light, despite the participant's efforts, such as placing the artefact in the brightest spot in the house, the artefact faded its colour after one week (figure 18, b). In their final reflections, this participant suggested passing it on to a more suitable household, as an alternative way of "care".

Several participants expressed how the beauty of the artefact made them "immediately attached" to it, taking their care responsibilities more seriously than they would with a simple bottle of culture. They appreciated the vibrant colour change resulting from the cyanobacteria's photosynthesis since it allowed them to better grasp the state of well-being of the microbe. They commented on how this is quite different from situations like "beer brewing microbes that are hidden inside wooden buckets", where their functions and well-being remain concealed. The intensifying green hue of the microbe prompted perception of "growth". However, participants expressed a dilemma; whilst valuing the ambiguous colour change as the artefact's distinctive "language", they also desired more precise colour references on the care label and detailed light intensity information. Others expressed a desire for more "immediate change" to enhance their understanding of cyanobacteria's well-being. The form and texture of the artefact also shaped the perception of livingness and thus caregiving practices. For instance, one participant compared the artefact with plants, noting that the three-dimensionality and variety of forms of plants offer great aesthetic value to the living space. This motivated them to care for plants more actively than the relatively two-dimensional artefact.

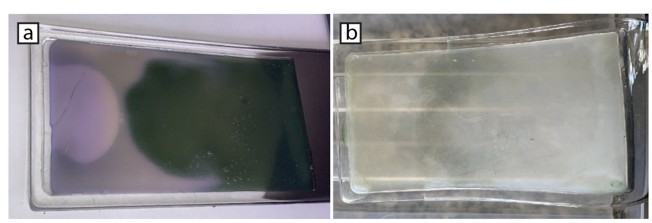

Figure 18: a) An artefact which survived two weeks b) An artefact which faded its colour after one week

Participants explored various ways to place the artefact in the home. Towards the end of the study, many participants had evolved their own unique care practices. The silicone rubber's intrinsic stickability prompted one participant to stick the artefact onto a window (figure 19, a), ensuring maximum light exposure in a north-facing living space. Another participant utilised the artefact's bendability and transparency to create a light-receiving arch on their reading desk for "catching the light" (figure 19, c). Some participants hung the artefact on a curtain rail near a window (figure 19, g), or a door frame in the garden (figure 19, e). The artefact's darkened section was folded by some participants to provide shade to the cyanobacteria when ambient light was thought to be too intense (figure 19, b). Some participants viewed the artefact more as a static art piece rather than an interactive object to carry around or engage with, compared to a cube- or ball-shaped artefact, such as a "marimo moss ball". Others refrained from "playing" with it freely, as they perceived the microbial layer as too thin and fragile. Some participants were hesitant to touch the artefact frequently because the adhesive silicone rubber easily became "dirty".

5 DISCUSSION

The deployment of the living cyanobacteria artefact in everyday life has provided insights into how its material qualities influenced participants' caregiving practices. In this section, we organise these insights into three distinctive roles that materiality can play in nurturing care practices towards living artefacts and highlight dimensions to capitalise on these roles in the design of living artefacts. We also broaden the discussion to encompass the broader opportunities and challenges associated with designing and caring for living artefacts. And to close, we acknowledge the limitations of our work and suggest avenues for future research in this area.

5.1 Role of Materiality in the Creative Unfolding of Care Practices

5.1.1 Increasing Habitat Resilience to Support Care Labour. This particular aspect focuses on the artefact's viability. This is largely influenced by the material properties resulting from the combination of the hydrogel and PDMS rubber. This composition ensured a high chance of survival amongst distributed households. Another way to increase resilience could be to design the habitat in a semi-open manner [45] in such a way that additional nutrients can be provided to the microbe or living cells can be propagated to create a new artefact. Such habitats could potentially enable richer social interactions, such as those stemming from the act of sharing "offspring" artefacts with other people. They would also allow direct engagement with cyanobacteria, hence fostering a sense of connectedness with other life forms. For further explorations in terms of openness, designers may also look into diverse material compositions, for instance, by integrating shape morphing materials in artefacts for opening and closing nutrient and organism flows, e.g., bio-based and hydrogel-based morphing textiles [39, 78].

5.1.2 Surfacing Livingness to Enhance Care Knowledge. This aspect concerns the role of materiality in surfacing livingness of microbes. This contributes to deepening a novice's knowledge of microbes' well-being and shaping affection and appreciation in caring for them. Without surfacing, the slow accumulation of cyanobacteria's green colour, spanning days and weeks, would be difficult to notice to unaided human eyes. Our use of pH-indicating material manifested cyanobacteria's photosynthesis through faster and more vibrant colour changes, effectively addressing human-microbe temporal dissonance [80](p.821). Given our artefact's predetermined temporality resulting from the pH indicator, we anticipate future designs to incorporate materials and technologies to surface microbial metabolism with divergent temporalities [8, 50, 51]. For instance, designers could consider adding a translation strategy [49](p.10) in displaying cyanobacteria's well-being with a fast-responding material [80], that could elicit urgent care responses from people whilst allowing the overall long-term accumulation of microbial livingness to be appreciated (ibid. p.824).

Another important consideration concerns managing the semantic fitness of living artefact displays [49] to effectively communicate livingness, which inherently motivates care practices. The manifestation of livingness through the artefact often requires material qualities shared with familiar living beings, such as plants. For example, the natural green hue of cyanobacteria was interpreted by the participants as "a sense of growth" or the bacteria being "happy". In contrast, the rectangular shape and two-dimensional form of the artefact diminished its perceived livingness, because people at first had the impression that the artefact was inorganic. In light of this, we encourage future research to explore three-dimensional forms and textures to embody temporal forms of familiar living things (e.g., by canvassing [49] (p.7) cyanobacteria in leaf/plant-like configurations). Investigating this approach could potentially enhance the experience of the artefact as "being alive", and thus increase motivation for caregiving.

5.1.3 Tuning Performativity to Elicit Exploratory Care. The performative qualities of the artefact (e.g., its stickability) played a crucial role in encouraging participants to actively explore various ways of placing the artefact in the home for both functionality and its well-being. This was key in leading to habitual care practices. Though our artefact's simple form facilitated creative ways of care, the results revealed an opportunity to tune the form of the artefact towards certain experiences, e.g., "intimate engagement" and "playfulness". For example, in the iteration of our artefact, we could consider designs that are "toy-like", to solicit playfulness of interaction. We call for attention to a dimension between exploratory and prescriptive approaches in crafting performativity. High ambiguity in form introduces uncertainty in how to care, risking critical functions and the well-being of vulnerable species. Striking the right balance between open-endedness and specified guidance through form could facilitate people to be creative towards microbes' care practices and to understand their diverse needs, scales, agencies, and temporalities [45], while learning about the dynamic and unpredictable nature of living systems.

5.2 On the Nature of Care: Opportunities and Challenges

In this section, we delve into the broader implications of our study for the HCI community, with the goal of illuminating new design opportunities and avenues for the creation and care of living artefacts.

Figure 19: Diverse explorations from the participants in an attempt to find the most suitable place for the living artefact. a) Sticking the artefact on a window b) Folding the dark section c) Bending the artefact and fixing it to other objects d) Folding and hiding the artefact behind another bottled cyanobacteria culture e) Suspending the artefact on a chair arm f) Suspending the artefact on the back of a sofa g) hanging the artefact on a curtain rail

5.2.1 Tuning into the Evolving Nature of Care. Our findings illuminate the dynamic nature of care practices, which undergo transitions as individuals adapt their actions for the living artefact, progressing from improvisational to more established routines. Throughout this evolution, the performative qualities of the artefact play a pivotal role in identifying an optimal range of lighting conditions. However, it is through repeated acts of care that these practices can solidify into established care relationships. These ultimate practices tend to seamlessly integrate into people's existing daily routines. For example, one participant discovered that the artefact thrived in a specific corridor of the house. This inspired them to hang the artefact on the wall of the corridor, where it served as an art piece that the participant could check upon every day while walking by. To address this evolving nature of care practices, designers may need to incorporate ways for the artefact to be responsive and for relationships to change [28], for instance, by leveraging translation techniques [49] to make living artefacts more communicative of their diverse needs (e.g., [3, 16]). They must also be sensitive to and practise the design trade-off between dimensions of openness/variety vs. familiarity, allowing the living artefact to be adaptable to rapidly changing environments during the exploratory phase, and to be integrated at a unique position within specific human practices.

5.2.2 Nurturing Mutualistic Care. In our study, participants grappled with a contradiction when determining how to interact with the artefact, balancing functional benefits (i.e., self-care) against the care of the microbe. For instance, one participant regarded the artefact as a domestic air purifier, leading to an expectation that it should remain at home, even if the home environment wasn't ideal for its well-being. In contrast, another participant, who brought the artefact to her workplace for air purification, discovered that it struggled to thrive there due to inadequate lighting conditions. Eventually, she had to bring the artefact home, even though it meant compromising her own "self-care." Overall, establishing a sense of mutualistic care [42] proved challenging in our study. This challenge could be attributed in part to our framing of the artefact as a potential air purifier, thus limiting open-ended interpretations of its functionality. Consequently, we call upon designers to be meticulous in conceptualising the function of living artefacts, allowing mutualistic care relationships to naturally evolve within everyday practices of people who live with them. Designers might consider situating the artefact's openness within dimensions of variety and enable people to customise its functions to suit familiar daily practices, similar to the approach demonstrated by [27, 52] in the everyday design of connected things as "resources". We posit that such an approach in the design of living artefacts has the potential to foster reciprocal relationships between the artefact and people who live with and care for it.

5.2.3 Designing for Multiple Dimensions of Care. Our study demonstrates that "good care" is nuanced and multifaceted, subject to a wide array of interpretations among individuals. For some, the mere acknowledgement that the microbe is alive constitutes sufficient evidence of good care. Others place greater emphasis on the effort exerted in the act of caring, prioritising the intention and diligence rather than the outcomes. Some critically evaluate their care-taking attitude, scrutinising the consistency and mindfulness with which they tend to the artefact. This rich tapestry of interpretations underscores a crucial point: there exists no universal understanding of what constitutes better care. Instead, it is a nuanced and context-dependent concept, moulded by the unique values and experiences of each individual. As we reflect on this diversity, we extend an invitation to future research in the field of HCI to embark on a journey of exploration. This exploration should involve mapping out the intricate dimensions of care [19]. By doing so, we can engage more comprehensively with the complex landscape of care, in accommodating diverse perspectives and expectations of people who may care for a living artefact. This holistic approach to design will ensure that the artefacts we create resonate with the various ways individuals conceive and practice care in their everyday lives.

5.3 Limitations and Future Work

Our decision to conduct a two-week in-situ study was influenced by several factors, primarily centred around the current limitations of our artefact's lifespan of approximately a month. These limitations stem from two key observations made during our assessment of the proof of concept. Firstly, we noted a gradual decline in the artefact's colour contrast over time. This phenomenon could be attributed to the continuous diffusion of the pH indicator into the living part of the artefact. As this diffusion occurs, the artefact becomes less sensitive in indicating the well-being states of the embedded microbes. Secondly, we observed an unexpected issue related to the artefact's humidity levels. The microbial-embedded jelly within the artefact dried out within 45 days. This unexpected outcome resulted in the jelly's volume shrinking and the formation of air bubbles within the artefact's cavity. The exact causes of these phenomena remain subjects for further investigation. In our next iteration, we aspire to address these challenges by enhancing the longevity of the artefact, which will provide an opportunity to delve deeper into the evolution of care practices over a longer period.

We intentionally selected light as the initial habitat element to explore when investigating care practices for our microbial artefact. We recognize that the well-being of a microbial artefact is influenced by a range of complex environmental factors, including but not limited to temperature, humidity, and nutrition. However, to keep our initial technical and design explorations manageable and to ensure that the study remained accessible and comprehensible to participants, we opted to focus on one specific habitat element as a starting point. As anticipated, participants found the focus on light to be relatively "easy", although they encountered challenges along the way, and expressed their interest in practice care with multiple habitat elements. Building on this, we envision expanding our exploration to encompass multiple habitat elements. This broader perspective has the potential to depict care more holistically, capturing the intricate interplay of environmental factors that influence the well-being of the microbe within the artefact. We anticipate the need for in-situ investigations to gain a deeper understanding of how these complex habitat elements can collectively impact the microbe's well-being. Furthermore, our study approached cyanobacteria well-being through photosynthesis - a metabolic process integral to their growth and reproduction. Hence, the recognition of the microbe's well-being relied on how humans experience the changes in the artefact's temporal expressions which occur due to this metabolic activity. However, we envision significant potential in future research to explore methodologies, such as thing ethnography [29] to take perspectives and agency of other-than-humans (in our case microbes) into account in exploring such everyday exchanges and relations.

Our study aimed at probing a new design space and generating novel research questions at the cross-section of materiality and care in biodesign. This led to several decisions, including describing the artefact as a potential air purifier based on cyanobacteria's reported ability to capture carbon and release oxygen (cf. section 2.1.1). However, we prioritised participants' perception of functionality over the actual benefits of air purification. Participants were informed that the artefact could potentially serve as an air purifier, allowing us to investigate how they could navigate tensions between perceived functionality and care. This decision raised new questions, such as the significance of knowing the function of living artefacts in fostering care. Further exploration is needed to compare caregiving practices in scenarios where living artefacts offer more compelling functional advantages versus situations without them. Achieving this involves further enhancing the artefact's perceived functionality, considering technical aspects of cyanobacteria as an air purifier, such as an enlarged surface area of living biomass. Likewise, contrary to investigating diverse impact factors of materiality on nurturing care practices, we focused on developing an initial viable living artefact, acknowledging the limitations of our fixed design. We anticipate that future studies will delve more deeply into nuances of how different materials and their respective qualities (e.g., texture) distinctly influence care practices.

Expanding our perspective beyond the scope of our current study, we recognize the imperative to confront the complexities inherent in caring for living artefacts within real-life contexts. Such care practices are not always characterised by positivity and fulfilment; they entail a spectrum of experiences, much like any other form of care [37][46][62]. We deeply appreciate the tensions and dilemmas that have emerged from our study and intend to delve further into these intricacies. Our aim is to explore how these multifaceted human engagements with living artefacts, driven by care, can be made more seamless, multidimensional, decentralised, and ultimately mutualistic. To achieve this vision, we believe that our understanding of care through materiality can contribute to enriching the research landscape within HCI. We encourage designers of living artefacts to harness diverse mediums and approaches to engage individuals in creative thinking and action, fostering a culture of mutualistic care that transcends rigid design prescriptions. In doing so, we envision a world where care for our other-than-human living companions is an integral part of our shared existence.

6 CONCLUSION

Our research aimed at exploring the role of materiality in the everyday care of microbial living artefacts. To this aim, we harnessed material qualities in our design of a living cyanobacteria artefact. This artefact served the dual purpose of indicating the well-being of the microbe and offering diverse performance possibilities, allowing for versatile positioning to support both its function (i.e., air purification) and well-being. Subsequently, we conducted a two-week in-situ study with eight participants with diverse caretaking experiences for other-than-human living beings. This study not only showcases a potential method for crafting habitats tailored to accommodate cyanobacteria but also demonstrates its effectiveness in supporting longitudinal in-situ investigations involving these organisms within living artefacts. Importantly, this study stands as the first known longitudinal exploration involving cyanobacteria, offering valuable insights into their unique temporal patterns and behaviours within domestic settings. Furthermore, our work illuminates the pivotal role of materiality in the care of microbial living artefacts and highlights its performative potential as an important catalyst for HCI designers seeking to develop creative care approaches specifically tailored to these living artefacts. Our findings indicate that materiality can be harnessed to: 1) increase habitat resilience for supporting care labour; 2) surface livingness for enhancing care knowledge and 3) tune performativity for eliciting exploratory care. Additionally, our research uncovers important dimensions that emerge in the design of care for living artefacts, notably between: 1) temporal dissonance and temporal alignment; 2) familiar and unfamiliar living aesthetics; and 3) exploratory and prescriptive practices of care. In conclusion, we call for HCI designers to give substantial consideration to aspects of temporality, openness, mutualism, and multidimensionality when approaching the design of care for living artefacts.

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A CARE INSTRUCTION CARDS

The artefact consists of living cyanobacteria that absorb CO2 from their surroundings and release fresh oxygen. The artefact is a small-scale prototype of a set of future artefacts, that might have different functions, such as purifying air, powering small electronic devices, sensing light and air qualities. In this study, we focus on its air-purifying ability. Thus, you are requested to carry the artefact with you to places where you need slightly more fresh oxygen. For the coming two weeks, you need to keep it alive and healthy for it to maintain its function. Below are a few tips to help in keeping it alive:

1. The artefact prefers medium to bright light, but doesn't like direct sunlight which might cause an increase in temperature and kill the living cyanobacteria.

2. During the day, when the light condition is right, you will notice a purple tint appearing gradually on the artefact, depending on how much light it receives. This indicates the cyanobacteria are doing well. If the light condition is not optimum, the purple tint would fade away gradually. Then you need to create/find the right light condition for the artefact (this doesn't need to be inside your house). Remember, The artefact is robust, you can fold, hang, stick, hide, etc.

3. During the night, the artefact naturally fades its purple tint until the next day when it receives light again. If the cyanobacteria are healthy, their colour becomes greener over 3-5 days.

4. To help you judge your artefact condition, we provide you with a set of colour cards, that shows how it would approximately look like in its best, medium or worst states. You may also use the back of the card (blank) as a background to observe colour change.

Please take a photo of the artefact and its surroundings whenever you notice a change in its colour or if you move it to a new location or change its form (e.g., by folding). I will follow your experience with the cyanobacteria care artefact every 2 or 3 days via WhatsApp/email/or other platforms you prefer. However, whenever you want to share things with us, feel free to chat or send us photos. Just a last tip, give a nickname to your artefact.