Entangled Habitation: Exploring Plant-Human Interaction Through a More-Than-Human Lens

Anonymous Submission

Figure 1. A. VibrateNerve is a wearable artifact on the finger and arm that integrates multiple sensors to assess and feel the plants stress through vibration. B. BreathTogether is a wearable artifact that physicalizes plant's breath with the varying size of an airbag by interacting with the photosynthesis data of a plant. C. GrowthTouch simulate intimate touch triggered by plants' actual movement on human face.

Entangled habitation refers to a deeply intertwined and entangled living status between human and non-human beings, e.g., plants. In this paper, we explore the entangled habitation design concept to advocate a more-than-human perspective in human-nature interaction design. Following the entangled habitation design concept, we implemented three plant-based wearables to reframe human's interactions with plants. VibrateNerve translates the leaves' wellbeing information (i.e., temperature) to vibrations on a wearable ring that simulates pain. BreatheTogether transforms plants' photosynthesis effectiveness into the floating air inside a wearable lung that mimics breathing. Finally, GrowthTouch collects plants' real-time motion and maps it to intimate touch in a wearable mask. All three wearables constructed the plantness on human bodies and fundamentally questioning what plants can and might be an entangled part of human and cohabitate with human. Our design speculations also demonstrate a framework extend nonhuman sensory capabilities into human body perceptions and produce an entangled habitation.

CCS CONCEPTS • Human-centered computing • Interaction design • Interaction design theory, concepts and paradigms

Additional Keywords and Phrases: more-than-human, human-plant interaction, interaction design, wearables, plant.

1 INTRODUCTION

We are living in the Anthropocene age where humans are the leading cause of climate and geology changes [38]. The idea that "human beings is the essence of the universe and the primate of all things" [31] has increasingly shown its frangibility and limitation in the modern technological revolution. Global warming, wildfires, severe storms, droughts, and other extreme weather phenomena pose a threat to human and nonhuman lives, communities, and essential infrastructure [39] [40]. As an essential part of the ecology, plants have a very complex and diverse influence on the

climate system [41]. For example, the way plants react to carbon dioxide is critical for accurate climate forecasting [41] . This fact draws our attention to start to speculate what is an alternative and preferable relationship for human and plant.

Human-computer interaction (HCI) research historically pursue ease-of-use [42] and focused on improving user experience [23] from a human-centered perspective [36]. Recent calls for sustainable HCI [5], posthuman design [37,43–45] and more-than-human perspectives [8,13] are emerging. More-than-human perspective highlights the co-constitutive role of non-human aspects, instead of regarding human as an independent who dominates the world [13]. Such posthuman perspective presents opportunities to design plants as a medium that develops our noticing for a more-than-human world and overcome problematic narratives of human privilege and exceptionalism. In this work, we fundamentally question what plants can and might mean as a co-constitutive role of non-human aspects. To further explore the entangled habitation design concept for human-plant interaction, we make experiencing plantness possible both through wearable technologies and our senses of self and way of being. We use 'arts of noticing' as a method [21], which refers to the act of paying attention to the more-than-human world with open, attentive and responsible mindset. Our goal is to decenter the human in the design process and demonstrate how human bodies can be approached through entangled habituating with plants.

In our work, the human body is designed to be a tangible media, interfacing with a set of embodied wearable organs (i.e., body parts) that captures plants' sensorimotor consciousness. Based on plants' sensorimotor information, we proposed a series of wearable artifacts following the entangled-habitation posthumanism design concept: (1) VibrateNerve, a wearable ring that simulates haptic sensation on the human body based on plants' leaves wellbeing; (2) BreathTogether, a wearable lung on the neck that physically embodies plants breath by transforming the data of its photosynthesis effectiveness; and (3) GrowthTouch, a wearable face-wearing which simulates touch with "hands" that is triggered by plants' real-time movement. Each wearable design adopted different sensors, materials, and interactions to present plants' habitation with the human body. Through these more-than-human design provocations, we enhance human's noticing ability for nonhuman objects and speculate an alternative future for entangled habituating with plants. Based on the more-than-human theory, our innovative design speculations demonstrate how to create artefacts for entangled habitation with plants to enhance human's noticing of plants and the ecosystem, as well as the awareness of climate changes for a more-than-human future.

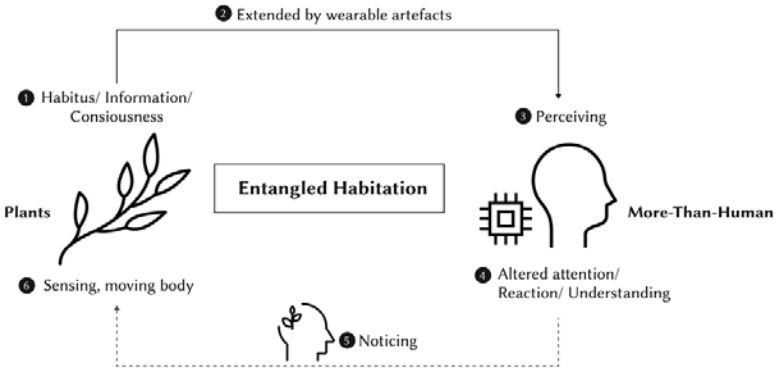

Figure 2. Entangled habitation refers to a deeply intertwined and entangled living status between human and nonhuman aspects, e.g., plants. By extending plants' living habitus to human sensation, we build more-than-human body that has enhanced attentiveness to plant as a sensing and moving body.

2 RELATED WORK

2.1 Human-species Interaction

In bio-design field, HCI researchers usually let organism participate in the interaction system through natural habitats, behaviors, and metabolisms and investigate the interactions between human and species [26]. Those studies adopt both human and nonhuman aspects to build multi-species relationships, e.g., fostering affective emotion towards microbes [7], creating physical visualization via bacteria [2], building humidity-interactive media using natto cells [34], designing kinetic interaction with algae [25], exploring cybernetic system in plants [30], or learning birds through ambient sound [29]. For instance, Pataranutaporn et al. [27]developed microbes as bio-computers to enable human-microbe interactions across different contexts and scales. In response to the calls of "think beyond the human", Fell et al. extended anthropocentric concern for vegetal life from a biocentric view on interactions between humans and nature [10].

Although digital technology dominates contemporary industrialized societies, these bio-design initiatives show that organic and biological systems may be used to rebuild our relationship with ecology. While these provocations focus on different frameworks of interaction, Similarly, we take interaction as a starting point and move forward to an entangled relationships between human and plants. In other words, our objective is to take a step further and build more-than-human symbiosis and human-plant interaction following posthumanism design theory.

2.2 Decentering the Human

In 'Staying with Trouble', feminist Donna Haraway [44]calls to make oddkin that encompasses all non-human relations. To produce an alternative future, Light et al. propose a pathway by designing "to unseat humans from the center of the universe and support a more equitable gaze" [17]. Frauenberger proposed Entanglement HCI that looks into post-humanism and relational ontologies of human and objects [11]. He stated that more-than-human theories "are not denying the social construction of our knowledge about the world but seek to emphasize that the world is no passive object in this process, but rather is intimately entangled in the knowledge production". Based on the "entanglement HCI" proposed by Frauenberger, Sarah et al. [13] made supplement by looking at conception of body from user to more-than-human. Sarah et al. advocated the more-than-human approaches to the body and highlight the co-constitutive role of non-human aspects in designing a more-than-human body. Our concept was inspired by Sarah's proposal for including a wider definition of 'user' in HCI and design the body with a more-than-human perspective.

The HCI community has responded to the call by examining the potential of posthuman design and its impact. Liu, Jen et al. [18] introduced the concept of collaborative survival and translated this theory into practice in the process of creating three provocations. Heidi et.al [29] examined how noticing affects us and our way of relating to birds through an autoethnographic bird watching practice. Smith et.al [33] unpack the entanglements of animal-human-computer interaction and promote new forms of cohabitation. Liu, Szu-Yu (Cyn) et al. [19] used photography as a method to examine nature cultures. Her team also presented an ethnographic study [20] on alternative agriculture.

HCI researchers have also proposed design practices from a more-than-human perspective to push forward cultural change. Clarke et al. [46] explored the 'more-than-human' perspective by proposing a participatory speculative urban walk. Akama et al. [1] offered novel thoughts on 'participation otherwise' , committing the concerns of climate and existential crises. Houston et al. [15] identify multispecies entanglements and becoming-world as two directions for planning theory.

From these recent more-than-human research, we can see the beginnings of an emerging ecological way of thinking in design practices. Our works aim to design for noticing and create kinship across species with a more-than-human approach to the human body. In order to do that, we attempt to extend the consciousness of nonhuman object to the human body in a way that human can perceive. Through our research process and the final artifacts, we aim to refresh humans' sense of connection with the other beings in the world to help us perceive the world with a more equal gaze.

3 METHODOLOGY

Exploring the arts of noticing as a method was a starting point for our research and was a methodology we had been examining. We also draw from theories of more-than-human approach with emphasis on decentering the human in design as part of our contribution to the project.

During the COVID-19 outbreak, the isolation time people spent at home drew our attention to the houseplants. We suddenly felt a sense of comfort when we realized that they are the living lives that were accompanying us all the time in this isolated space. We became aware that we were, at that time, noting that we had entered into a new connection with a local ecosystem, as we were still digesting the more-than-human perspective in ecological post humanist theory. There was nothing better than the plants that were around us all the time as a departure to engage with and notice the nonhuman world. These plants served as a physical visualization of our lifestyle: the plants grew fast when we remembered to take care of them; they had some of their leaves withered when we were too busy to water. This seemingly normal interaction drew us to think about how to build deeper understanding and renew the way humans and plants cohabitate in the world with the more-than-human approach.

We started with our in-depth observation of plants with multiple monitoring sensors to collect data, including humidity, temperature, heat, photosynthesis and movement. With the help of this monitoring technology, we explored and discovered the performative aspect of plants that humans could barely notice and perceive. There were many touching moments that we experienced during noticing, as we realized that plants are alive not only during the moment when we see that the leaves are healthily green, soil is moist, buds are blooming. Plants are savagely growing at every single moment: they are breathing all the time, moving all the time, and they have their own body heat that is changing all the time just like human beings. To conclude, what we began to realize about the plants was something we never noticed before -- the desire, the wanting, of a living plant. We continued to speculate that those sharing the essence of life could be the node that somatically binds humans and plants as a symbiote. There came our concept of entangled habitation -- to design for noticing by merging the physiological responses between humans and plants through the wearable artifacts on the human body. The designed plants' "organs" and human body jointly form a more-than-human body that decenters the human and speaks to a posthuman world.

The proposed artifacts start with collecting data of plants' bodies. We used digital technology to collect and convert these unique outputs and signals in a variety of ways and for a variety of purposes. Individual variations between plants' bodies provide valuable data. We then come up with ideas to transform plants' living habitus into built organs that humans can perceive and live with. Following Merleau-Ponty, embodiment is “being-in-the-world”,

and with embodiment, the distinction between subjectivity and objectivity is overcome [47]. By building an organ(body) for plants, we add another layer for nonhuman's way of being in the world. Plants' existences are extended to human bodies in a form of embodied organ, together they form the state of entangled habitation.

We created three speculative artifacts to deeply observe and engage with the plants. Firstly, they serve as tools to synthesize observations about how we and the plants' interactions and intimacies shifted over time. Those provocations were both the outcomes of the research as well as the medium for next-step digging of the more-than-human body. We can engage in performative and somatic practices by testing and wearing these artifacts, which enable us to use a full range of emotions, senses, and experiences to investigate the noticing. Therefore, this process helps us better understand or empathize with the plants for whom we design, thus coming up with in-depth subjective sensory experience for discussion.

Besides, these provocations on the human body also constructed narratives for posthuman future storytelling. The artifacts together with the human body form a product that transforms the world from its current state to a preferred state. By structuring the scenario and stories, we aim to generate insights for an alternative future for later researchers to embark on. To conclude, our research process included research through design [35], speculative design[9], design fiction[6], embodied interaction design[22] and somaesthetic interaction design[14].

4 DESIGN

4.1 VibrateNerve

Inspired by soma design's manifesto to "focus on bodies and perception", we ideated the first artifact to simulate common senses of plants on human bodies. In this way, a sense of symbiosis and empathy will be evoked in human perception, which is a potential way to practice arts of noticing. Specifically, we aim to design the noticing by bodily connecting humans and plants and building sharing sensation via the interaction. We provoked a wearable artifact on the finger and arm that integrates multiple sensors to assess and feel the plants stress through thermal imaging.

This design (see Figure 1-A) is based on the fact that temperature is one of the physiological indicators for assessing plants' wellbeing. Thermal imaging has been a feasible technology to detect the surface temperature for plants' stress detection. Thermal long-wave infrared (TIR) cameras (or simply thermal cameras) are calibrated sensors able to record emitted radiation in the thermal range (8–14 μm) and provide images representing temperature values per pixel. Different physical and chemical disturbances caused by pathogens affect the plant water status, which can be monitored by thermography [3,12,32]. While this imaging techniques has been an essential tool in agriculture[28], it offers insights for building intimacy between humans and the plants surrounding them through the process of assessing plants' wellbeing. The designed artifact integrates a thermal camera, humidity sensor, vibration motor and LCD screen on the finger and arm. To assess and care for the plants' health, a user needs to directly touch the plants' leaves with finger. If the stress is detected, the motor will vibrate and create a feel of pain/ stress on the user's arm, thus enhancing empathy between humans and plants.

Our design started with several experiments of temperature and thermal imaging data collection. We recorded the thermal imaging data and air temperature for 24 hours of three different plants: green radish, gardenia, begonia. We used Adafruit AMG8833 Grid-EYE for the following experiments. It can return an array of 64 individual infrared temperature readings over I2C [48]. For each kind of plant, we took a healthy leaf and an unhealthy leaf off. To collect the data of their thermal image, each leaf was attached to the thermal camera that was stuck to the table, which means the position and angle of the sensor remained the same. The maximum temperature (from here out:

maxTemp), minimum temperature (from here out: minTemp) and average temperature (from here out: aveTemp) was calculated and collected based on the 64 readings. A temperature sensor was also set beside the leaf to collect the environment temperature at the same time. The air conditioner was turned on in the lab so that the environment temperature would relatively be kept at 27 degrees.

The experiment result (see Figure 3) showed that green radish had an obvious temperature difference between healthy leaf and unhealthy leaf. The unhealthy leaf of green radish has a significantly higher temperature than healthy leaf (both aveTemp, maxTemp and minTemp). The healthy leaf also has a significantly lower temperature than the environment temperature. This is theoretically due to different water status monitored by thermography. This result demonstrates that it is feasible to compare the surface temperature and environment temperature to assess its stress state.

This artifact consists of several sensors and output modules. To collect the thermal imaging of a plant's leaf, a thermal camera is placed on the finger. In this way, this artifact invites users to physically touch the plants with their own hand to care for the plants intimately. Along with the thermal camera, a temperature sensor is considered on the back of arm to collect the environment temperature. This is because thermal data need some corrections related to the environmental and measurement circumstances in order to achieve a correct interpretation of the data [28]. There is an LCD on the back of the arm to visualize the detected thermal imaging of the plant's leaf. A vibration motor was designed inside the band on the arm to create stress on the human's arm according to the stress state of the plant that is being touched. In this way, plants' stress state is transformed to a similar experience that humans can perceive.

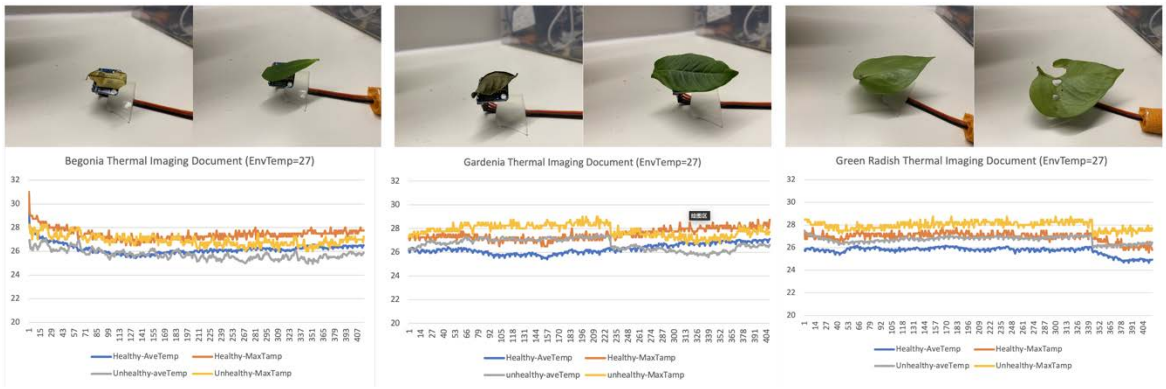

Figure 3: Thermal imaging experiment process. A) The thermal imaging data of different state of begonia leaf do not show a significant difference (left). B) The unhealthy leaf of gardenia has a higher temperature than healthy leaf (middle). C) The unhealthy leaf of green radish has a significantly higher temperature than healthy leaf (right).

The interaction process starts with the intimate touch between a human's finger and a plant's leaf. The user can have a real time thermal imaging to gain knowledge of the plant's wellbeing. If the plant is detected to have abnormal thermal imaging (in the case of our experiment result, the leaf's temperature is approaching the environment temperature), the vibration motor will vibrate to create stress on the user's arm. During the whole process, there are two levels of 'arts of noticing' to build the ultimate more-than-human symbiote: the noticing starts with the intention to care for the plants and proactive touch of the plants. Then the noticing moves to the next level: the sharing sensation between humans and plants. This series of human behaviors and senses facilitated by the wearable artifact constitute the symbiote: the sensor on human's fingertip serves as the receptor of the plants, the artifacts on human's

arm embodied the effector of the plants. Together they form a more-than-human sensory system that human's physical stress feeling, plants' wellbeing state, and the intimate touch between the two are entangled.

We tested the design by wearing it on the finger and arm and carefully touching each leaf of the green radish. This is the experience we never had with the plant -- that we put all our time and attention to the plant in front of us, and that we were concentratedly touching every leaf of the plant. In each moment of touch, we were able to see the surface temperature of the leaf to better understand the leaf's wellbeing state. Occasionally, we feel the harsh vibration on our arms that causes a certain uncomfortable feeling when we touch some leaves that are assessed to be unhealthy. There was a contradictory feeling of tension (because the vibration is sudden and strong) and a feeling of intimacy (because we related to the plants through the tension) at the same time. These are outward-looking and community-creating experiences for us brought by the digital sensing process.

4.1.1 Intersectionality

VibrateNerve stimulates plant's skin (receptor) and pain nerve (effector) on human body, thus creating the intimate connection and misplaced senses between human and plants. Human body, plants' body, plants' stress state, human's feeling jointly merges a sensory system, an entangled more-than-human body. Through the encouraged intention to touch the plants, the uncomfortable feeling shared by the plants, we decenter ourselves and look outward to the other beings in the world. We touch the others with our own body, and we feel the pain of the others. As Kimmerer stated "*Paying attention to the more-than-human world doesn't lead only to amazement; it leads also to acknowledgment of pain. Open and attentive, we see and feel equally the beauty and the wounds, the old growth and the clear- cut, the mountain and the mine. Paying attention to suffering sharpens our ability to respond. To be responsible.*" Through this artifact, we intend to show an approach that we can explore the 'arts of noticing' by encouraging physical engagement and creating sharing sensory experience. In this lens, the intertwined behaviors and senses bind the human body and nonhuman, which picture a scenario of entangled habitation.

4.2 BreathTogether

Carbon dioxide's warming effects as a greenhouse gas have been recognized for a long time. However, insights into the conditions of the carbon dioxide level in the air around a plant, in which a plant conduct photosynthesis and grow, can also provide valuable information for human about how plants are responding to the environmental conditions. "Plants have a very complex and diverse influence on the climate system" [41]. Caldeira et al. found that the way plants react to carbon dioxide is critical for accurate climate forecasting. This offered many insights for us to explore a more-than-human body in a broader sense -- to improve the representation of land plants and build more-than-human body in an effort to care for ecological crisis.

This design is based on the concept of breathing together with plants. In Figure 1-B, we build a breathing plant organ on human body that represents plants' photosynthesis effectiveness, which also reveals its wellbeing and provides insights for climate system. Photosynthesis is the process through which plants take carbon dioxide from the air, mix it with water and light, and produce carbohydrates. MH-Z19B NDIR infrared gas module is a common type, small size sensor, using non-dispersive infrared (NDIR) principle to detect the existence of carbon dioxide in the air. BreathTogether is a wearable artifact that physicalizes plant's breath with the varying size of an airbag by reading the carbon dioxide data from a plant.

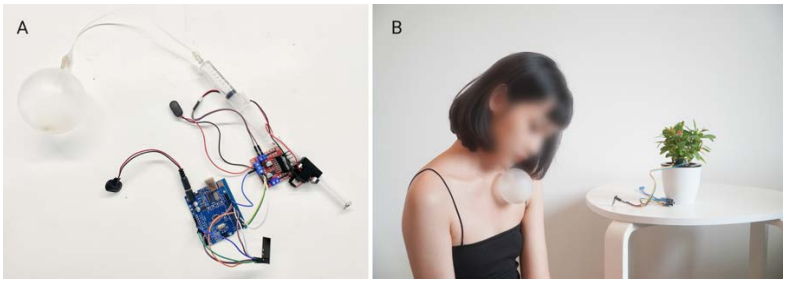

Figure 4: Design process of BreathTogether. A) BreathTogether includes two parts: carbon dioxide reading module and wearable breath simulation. B) The air bag is designed to be placed on the chest of the wearer, which is the same position of human's lung.

4.2.1 Design Process

This design system (see Figure 4-A) includes two parts: carbon dioxide reading module (from here out: CDR) and wearable breath simulation (from here out: WBS). A MH-Z19B NDIR infrared gas module was adopted in the CDR part that reads the carbo dioxide level (ppm). This sensor is placed in the flowerpot surrounded by the green radish's leaves. Similar to GrowthTouch, nRF24 was also considered this system to send carbo dioxide reading from CDR to WBS. In the WBS part, we used an air bag to represent the 'lung' of plant. The air bag's size is changing according to the photosynthesis effectiveness. To control the size of the air bag, a mechanical structure was designed to push and pull the plunger, which pump and deflate the balloon. The mechanical structure includes a N20 motor and a rack putter that can drive the plunger to move vertically. The system was programed to push and pull the plunger all the time, while the distance (that determines the size of the air bag) and the velocity (that determine the air bag's rate of the change) of the plunger that moves are influenced by the photosynthesis effectiveness. The lower the carbo dioxide level is, the higher the photosynthesis effectiveness is, which leads to bigger and faster change of the air bag, and vice versa.

BreathTogether's interaction process started with the reading of the carbon dioxide level from plant's side. The nRF24 module will send the real time data to the WBS part on the wearer. The air bag is designed to be placed on the chest of the wearer, which is the same position of human's lung. This is aimed to provide an intimate connection from 'inside': the wearer is breathing with his/her own lung and feeling the other lung's breathing powered by the plants at the same time.

We test the design by wearing the artifact on chest for 2 hours. (see Figure 4-B) The balloon is changing between big and small size repeatedly, with different size and velocity every time. It was such a lively scene for us -- that wearing the artifact and watching the movement of balloon brought us the same experience as meditation. In the process of meditation, people should focus entirely on their breath and their own body. What is more during this process is that we are not only feeling our own breath and body, but we are also observing the plants breath and picturing plant's body. There was nearly twenty minutes when we were addicted to watching the variation of the air bag: watching it varying from big to tiny, fast to slow. When it becomes big, the balloon is squeezing and rubbing our skin. When the movement is subtle, we have to carefully look at the balloon in order to observe the breath. We were even influenced by the plant -- at some time we would adjust the frequency of breath to follow plants breath. It was such a unique experience that we can perceive how the plant is being in the world, with our own body. At some moments we feel that our body is not only ourselves, but a symbiote with the plant that is living and being in the world together.

4.2.2 Entanglement

Through this lens, we draw human's attention to nonhuman (in our paper, plants) by building a more-than-human body that create tactile impulses and shared sensation. In a broader sense, we aim to design for noticing that the kind of plant on the surface of our planet and what that plant is doing is very essential in determining our climate. In an effort to do that, we build an entangled breathing system that human is breathing and actually perceiving the real-time breathing of the plants at the same time. While we are breathing in the O2 and breathing out the CO2, contradict things are happening on plants. That is, when we breath out, the air bag becomes bigger, and vice versa. The entanglement stem from the realization that we are exchanging the subjects and co-habituating since the beginning.

4.3 GrowthTouch

GrowthTouch (see Figure 1-C) was ideated based on the fact that a plant can perform tropisms, which means it responds to environmental changes by altering the texture of stem and leaf parts and growing leaves in specific directions. One of the most common tropisms is phototropism, and it happens when plants move towards sunlight [49]. It is such a performative, dynamic and aesthetic evidence for plants' being in the world, yet it is also a view that humans can hardly perceive. It inspired us to "*integrate a wider definition of the user in HCI as a sensing, moving, and performative body*"[13] by enabling humans to perceive the performative aspect of plants. With GrowthTouch, design for entangled habitation and the arts of noticing led to a design to simulate plants' touch triggered by its actual movement. Through this process, humans 'notice' and engage with the existence of plants through the intimate touch of plants.

4.3.1 Design Process

This artifact design started from several observations of plants movement by recording time-lapse. The aim of the observation is to examine how the plant would move in 24 hours and how fast it would move. Raspberry pi along with its camera module were adopted to take the time-lapse. We set up the program to take photos every 10 minutes within a duration of 24 hours. The plants were placed in both indoor and outdoor for different time lapse shooting. Three kinds of plant (Green Radish, Gardenia, Begonia) were observed in the experiment.

The time-lapse turned out that green radish and begonia had obvious movement within a day (see Figure 5). The outdoor green radish has the most obvious motion change compared to other kinds of plants and compared to the indoor environment. From 6 AM to 4 Pm, the leaves would slowly move downward due to the sunshine. From 4 PM to 7 PM, the leaves would slowly move upward back. The frame taken in the time-lapse turned out to be different from the previous frame. This result showed that plants were active and performative in every moment and it was feasible to detect the motion of the plants even within a short period.

Figure 5: Time-lapse experiment. A) From 2021/07/17/22:00 to 2021/07/18/22:00, capture one image of gardenia (left) and green radish (right) every 10 minutes in an outdoor environment. B) From 2021/07/18/23:00 to 2021/07/19/23:00, capture one image of begonia every 10 minutes in an outdoor environment. C) From 2021/07/20/9:00 to 2021/07/21/9:00, capture one image of green radish every 10 minutes in an indoor environment.

This artifact includes two separate parts (see Figure 6-A): motion detection module (from here out: MDM) and wearable touch simulation (from here out: WTS). We achieved the motion detection on Raspberry pi with a python program revised from an open-source script written by brainflakes[1]. An nRF24 module was connected to the Raspberry pi so that it can send the motion detection signal to the simulation part wirelessly. In the touch simulation part, three servo motors along with an PCA9685 16-Channel Servo Driver were installed on the wearable facial mask to simulate the touch. Ultralight clay was adopted as the material to build the touching surface, which is light and soft for skin contact. The other nRF24 module was connected to the Arduino to receive the motion detection signal, so that the movement of the plants can remotely trigger the wearable touch simulation on the human body.

The final design came out after several tests and iteration on the human body. In the first version of this artifact, we designed the touch simulator to be attached on the upper part of the back. The artifact was fixed on the body with the aluminum wire intertwined around the shoulder. Although feasible as a proof of concept, after testing the experience by wearing it, it turned out that the feeling of being touched was somehow weakened if the moving part was out of vision. During the time we were wearing it, the main feeling we had was something moving on the back. However, the subtle touch scene was lacking in the process, which was an important part that constitutes the experience of being touched. Therefore, as shown in Figure 6 - C, we built another version of this design to be worn on the face, which is one of the most sensitive and personal parts of our body. This version turned out to provide stronger connection with the plants both mentally and physically, by having the simulated plants' "hands" slowly sliding on the face.

The interaction started with the motion detection of the plants. We set up the MDM (a camera module connected to the Raspberry pi) in front of the green radish that is placed on the balcony (see Figure 6 - B). The MDM will send a motion detection signal to WTS via the nRF24 module built in both parts. If a motion is detected, the MDM will return a 'true' and send the signal to the WTS, which will trigger the motors to spin from 0 to 180 degrees. The motors drive the plants 'hands made by ultralight clay to slide across a wearer's face. This system creates a 'remote touch' from the plant for the wearer to constantly feel the existence and intimate attempt of a plant.

In Figure 4-C, we tested the design by wearing the artifact on our face for half a day. Nearly every one to two minutes, the motion detection will trigger the motor to spin and slide the clay across our face. This was a strangely intimate experience for us once we know that this touch was powered by the plants. It was a unique and rare experience for us to be passively touched by a seemingly still plant with its actual real-time moving. The texture of the ultralight clay simulates the human skin well, the intimacy of the skin and the slight itchy feeling made us felt that plants' subjective consciousness was endowed. Through the haptic sensation, we had a stronger entanglement with the plants through the touch that translates the idea of plants growth. By feeling the growth, instead of perceiving the plants as a still object, we as a species start to notice the dynamic and performative aspect of plants as other beings in the world.

[1] https://pastebin.com/raw.php?i=yH7JHz9w

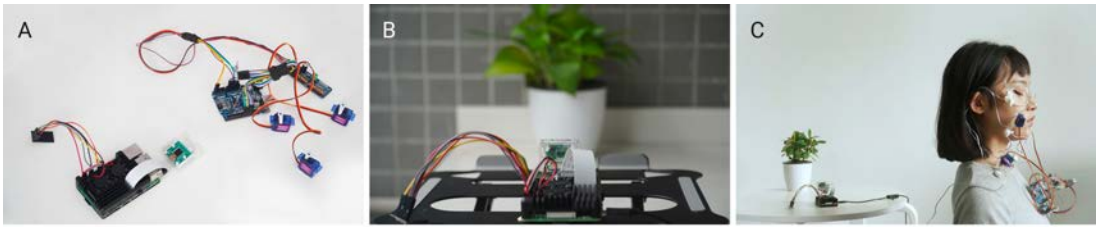

Figure 6: Design process of GrowthTouch. A) Motion detection module (from here out: MDM) and Wearable touch simulation module. B) Motion detection module setup. C) Testing the artefact by wearing it on the face for half day.

4.3.2 Attentiveness

This artifact explored the arts of noticing by exploring the performative aspect of a plant -- that how bodies may act and perform in the world [13]. Though humans are able to notice the growth of a plant by observing the change of the leaf and the blooming of a flower, it is almost impossible for humans to perceive the constant movement of a plant body due to its tiny motion. However, we argue that the constant moving of a body is a powerful and aesthetic aspect of a living life. Within this lens, we intend to explore the more-than-human symbiote by constructing plants' performative bodies on the human body, thus enabling humans to perceive the constant movement of a plant and gain attentiveness to the nonhuman beings. The movement of a plant, the simulated touch, the embodied performative plant body, the human body, altogether form an entangled system that transform, represent, and create multiple senses. GrowthTouch provides an approach that wearers can use their intuitive, haptic, and emotional capabilities and come to an intensive understanding of how plants are being and living in the world and decenter themselves by having more attentiveness to the nonhuman beings.

5 DISCUSSION

Based on Light et al. [17] and Liu et al. [20]'s idea of utilize noticing as an approach to decenter the role of human in design, our research set out to design from a more-than-human perspective and investigate noticing as a strategy and as an approach in entanglement HCI. Through our design research of noticing and decentering, we elaborate the wearable artefacts as a method to build entangled habitation with plants. Eventually, we aim to provide inspirations for innovative technological approach that shifts human's perception positively towards non-human beings and allows human to live entangled with the ecosystem.

5.1 Being As an Entangled Way of Noticing

We create entangled habitation as a posthuman way of living in a potential future. We build plant-empowered organs on the human body to help us perceive the world in a collaborative way. Through this lens, we experience the world not with our own body, but plant-enacted hybrid senses. In our attempt to build a more-than-human relationship with plants, we realize a need to communicate beyond vision and sound, to explore methods of forming meaning that don't simply rely on looking at the plants and sensors' data, but feeling how the plants sense, move and perform in an entangled way. In this case, we create new forms of wearable being to notice plants' sensorial, embodied behaviors, thus enhancing our performative interactions with the plants. It was the act of touching the plants, feeling the plant's movement, breath and sensation that enabled us to further understand our embodied and emotional experience of cohabiting with plants. Through this iterative process of making, wearing and feeling, we attempt to build a

symbiotic, intertwined, entangled relationship with plants. We see how creating an alternative way of being can be an approach to divert our attention from human to the nonhuman world.

Through designing an entangled habitation in design, we explore multi-sensorial, multi-model interaction experience through a series of provocations. While much design research has been done on sensory wearable projects, some of them focus on designing tools for more-than-human engagement based on human behaviors [30] or translating environmental data into wearable artefacts [4]. Many researchers have also looked into interaction design systems based on creatures, they often focus on the display function of plants [30] and microbes [2,16,25]. Our provocations focus on exploring plants-enacted embodied experiences that include sensing (VibrateNerve), moving (GrowthTouch) and breathing (BreathTogerther) in terms of sensory dimension. We also investigate different models of interaction between human and plants that includes both passive (BreathTogether, GrowthTouch) and proactive (VibrateNerve). Ultimately, we invite plants to play a key role and decenter the human through our multi-sensorial, multi-model provocations.

5.2 Wearable Technology As An Approach Of Decentering The Human

In our attempt to build a more-than-human body with plants, we see how sensory artifacts mediate our behaviors and mindset towards nonhuman objects. VibrateNerve requires users to touch the plant's leaves with their fingers and feel the plants' wellbeing state through vibration. During the process, we proactively, repeatedly touch every single leaf, with our mindset concentrating on the leaf and our nerve feeling the vibration. Before every touch, we were experiencing a short period of tension, worrying a harsh vibration would happen along with the touch. Both the proactive touch, the moment of tension and the feeling of stress were ultimately part of our attentiveness to the plants and ecologies in different ways. GrowthTouch creates embodied subjectivity for plants and builds a strange intimacy between humans and the plants. During the time we were physically, distantly touched by the plants' actual movement, more cultural and emotional aspects of interaction dominate our experiences with plants. Ultimately, the created intimacy and the emotion constitute an enhanced attention for the nonhuman world. We build our entangled habitation with plants by letting humans constantly feel the plant’s being in the world in plants’ photosynthesis process. The symbiosis in turn improves the representation of plants and refresh the plant-human relationship to care for ecological crises in a broader sense. Through these cases, we see wearable technological artefacts as powerful tools enabling us to perceive and widening our sensory outward towards the nonhuman world.

5.3 Entangled Habitation for the Future

We attempt to respond to the call of ‘including a wider definition of user in HCI’[13] by perceiving plants as stakeholder in the design interaction system. We see plants as equally sensing, performing, living objects as humans in the world and we build our design based on this argument. Motivated by what Introna stated ‘Humans and things are ‘ontologically inseparable from the start’[11], we see our built more-than-human body as a productive way for HCI to evolve in this constantly changing world. ‘Arts of noticing’ as a method and more-than-human perspective as an approach inspired us to explore the plant-human habitation, and our design research stands as an example for interpreting the theoretical literature into practices. Specifically, we introduce the design system that invites nonhuman objects as users and constructs dynamic symbiote based on humans and plants. While this paper offers one specific way of building a more-than-human body, we would welcome others to draw their own.

5.4 Next Step

While our provocations construct more-than-human body based on human senses and plants' living behavior, we see main future work based on our research regarding (1) wearable as an approach for building entangled habitation between human and nonhuman (e.g., plants); (2) wider range of evaluation of our provocations beyond personal experience, addressing people's subjective experience and cognitive change after wearing the artefacts.
By designing and prototyping the wearable artefacts on the human body, we see potential in how interactive technology mediates and reforms our relationship with plants. As we have mentioned earlier, more-than-human scholars state that humans become more entangled with nonhuman objects such as things, spaces, and materials [11,13]. The key benefit of a more-than-human approach is that it combines the politics and ethics with the bodies [13]. Our project focuses on a specific part of the more-than-human body construction, which is human and plants. We see great potential in how design research helps form the framework of a more-than-human body and serve as both product and evaluation tool for human behavior change.

We used a first-person research methodology in order to capture somatic, embodied, nuanced reflection on plant-humans interaction. It was advocated as a powerful method for developing embodied design [22] as well as a starting point for critical discussion on the design process[24]. During the testing process, we gain vital results of the user's behavior and cognition change towards a posthuman lifestyle. We see valuable future work in social computing by conducting a wider range of user study. We see our wearable artefacts as a tool to study the potential and opportunity in creating an alternative future. We attempt to gather more data of the influence that these artefacts have on humans' perceptions.

6 CONCLUSION

This paper responds to the call of design for existential crisis and more-than-human shift in HCI, where HCI researchers advocate to decenter the human and raise attentiveness to nonhuman aspects in design. Through a series of design provocations constructing a more-than-human body, we began to see the potentials in reframing an entangled-cohabitating plant-human relationship mediated by wearable technologies. We describe the design concept and prototyping process of three provocations (VibrateNerve, GrowthTouch, BreathTogether) that build plants' organs on the human body. These wearable artefacts extend plants' sensory and living ability to the human body and renew human's perceptions outward towards a nonhuman world. Intersectionality, attentiveness and entanglement respectively emerged from the three artefacts, ultimately enhancing the 'noticing' ability of humans and building more-than-human entangled habitation. The process of our design research shows the potential of constructing 'being' as an approach for raising 'noticing'. We also demonstrate the liability of wearable technologies as a media for reframing human bodies and constructing plant-humans symbiosis. By designing the multi-sensorial, multi-model interaction experience between humans and plants, our provocations explore multiple possibilities of how human habitat with other beings in the world. Our novel perceptions and cognition of connection with other non-humans in the world via the design research process and create artefacts in order to help us view the world with a more decentered and equitable gaze.

REFERENCES

[1] Yoko Akama, Ann Light, and Takahito Kamihira. 2020. Expanding Participation to Design with More-Than-Human Concerns. In *Proceedings of the 16th Participatory Design Conference 2020 - Participation(s) Otherwise - Volume 1* (PDC '20), 1–11. https://doi.org/10.1145/3385010.3385016

[2] Mirela Alistar and Margherita Pevere. 2020. Semina Aeternitatis: Using Bacteria for Tangible Interaction with Data. In *Extended Abstracts of the 2020 CHI Conference on Human Factors in Computing Systems* (CHI EA '20), 1–13. https://doi.org/10.1145/3334480.3381817

[3] Matilde Barón, Mónica Pineda, and María Luisa Pérez-Bueno. 2016. Picturing pathogen infection in plants. *Zeitschrift Fur Naturforschung. C, Journal of Biosciences* 71, 9–10: 355–368. https://doi.org/10.1515/znc-2016-0134

[4] Heidi R. Biggs and Audrey Desjardins. 2020. High Water Pants: Designing Embodied Environmental Speculation. In *Proceedings of the 2020 CHI Conference on Human Factors in Computing Systems* (CHI '20), 1–13. https://doi.org/10.1145/3313831.3376429

[5] Eli Blevis. 2007. Sustainable interaction design: invention & disposal, renewal & reuse. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 503–512. Retrieved August 25, 2021 from https://doi.org/10.1145/1240624.1240705

[6] Mark Blythe. 2014. Research through design fiction: narrative in real and imaginary abstracts. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems* (CHI '14), 703–712. https://doi.org/10.1145/2556288.2557098

[7] Dominique Chen, Young ah Seong, Hiraku Ogura, Yuto Mitani, Naoto Sekiya, and Kiichi Moriya. 2021. Nukabot: Design of Care for Human-Microbe Relationships. In *Extended Abstracts of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–7. Retrieved July 6, 2021 from https://doi.org/10.1145/3411763.3451605

[8] Markéta Dolejšová, Sjef van Gaalen, Danielle Wilde, Paul Graham Raven, Sara Heitlinger, and Ann Light. 2020. Designing with More-than-Human Food Practices for Climate-Resilience. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (DIS' 20 Companion), 381–384. https://doi.org/10.1145/3393914.3395909

[9] Anthony Dunne and Fiona Raby. 2013. *Speculative Everything: Design, Fiction, and Social Dreaming*. MIT Press.

[10] Jan Fell, Travis Greene, Jyun-Cheng Wang, and Pei-Yi Kuo. 2020. Beyond Human-Centered Design: Proposing a Biocentric View on Design Research Involving Vegetal Subjects. In *Companion Publication of the 2020 ACM Designing Interactive Systems Conference* (DIS' 20 Companion), 209–214. https://doi.org/10.1145/3393914.3395883

[11] Christopher Frauenberger. 2019. Entanglement HCI The Next Wave? *ACM Transactions on Computer-Human Interaction* 27, 1: 2:1-2:27. https://doi.org/10.1145/3364998

[12] Michael K. Grimmer, M. John Foulkes, and Neil D. Paveley. 2012. Foliar pathogenesis and plant water relations: a review. *Journal of Experimental Botany* 63, 12: 4321–4331. https://doi.org/10.1093/jxb/ers143

[13] Sarah Homewood, Marika Hedemyr, Maja Fagerberg Ranten, and Susan Kozel. 2021. Tracing Conceptions of the Body in HCI: From User to More-Than-Human. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–12. Retrieved July 6, 2021 from https://doi.org/10.1145/3411764.3445656

[14] Kristina Höök. 2018. *Designing with the Body: Somaesthetic Interaction Design*. MIT Press.

[15] Donna Houston, Jean Hillier, Diana MacCallum, Wendy Steele, and Jason Byrne. 2018. Make kin, not cities! Multispecies entanglements and 'becoming-world' in planning theory. *Planning Theory* 17, 2: 190–212. https://doi.org/10.1177/1473095216688042

[16] Seung Ah Lee, Engin Bumbacher, Alice M. Chung, Nate Cira, Byron Walker, Ji Young Park, Barry Starr, Paulo Blikstein, and Ingmar H. Riedel-Kruse. 2015. Trap it! A Playful Human-Biology Interaction for a Museum Installation. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems* (CHI '15), 2593–2602. https://doi.org/10.1145/2702123.2702220

[17] Ann Light, Irina Shklovski, and Alison Powell. 2017. Design for Existential Crisis. In *Proceedings of the 2017 CHI Conference Extended Abstracts on Human Factors in Computing Systems* (CHI EA '17), 722–734. https://doi.org/10.1145/3027063.3052760

[18] Jen Liu, Daragh Byrne, and Laura Devendorf. 2018. Design for Collaborative Survival: An Inquiry into Human-Fungi Relationships. In *Proceedings of the 2018 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–13. Retrieved July 5, 2021 from https://doi.org/10.1145/3173574.3173614

[19] Szu-Yu (Cyn) Liu, Jeffrey Bardzell, and Shaowen Bardzell. 2018. Photography as a Design Research Tool into Natureculture. In *Proceedings of the 2018 Designing Interactive Systems Conference* (DIS '18), 777–789. https://doi.org/10.1145/3196709.3196819

[20] Szu-Yu (Cyn) Liu, Shaowen Bardzell, and Jeffrey Bardzell. 2019. Symbiotic Encounters: HCI and Sustainable Agriculture. In *Proceedings of the 2019 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–13. Retrieved August 4, 2021 from https://doi.org/10.1145/3290605.3300547

[21] Szu-Yu Liu, Jen Liu, Kristin Dew, Patrycja Zdziarska, Maya Livio, and Shaowen Bardzell. 2019. *Exploring Noticing as Method in Design Research*. https://doi.org/10.1145/3301019.3319995

[22] Paul Marshall, Alissa Antle, Elise Van Den Hoven, and Yvonne Rogers. 2013. Introduction to the special issue on the theory and practice of embodied interaction in HCI and interaction design. *ACM Transactions on Computer-Human Interaction* 20, 1: 1:1-1:3. https://doi.org/10.1145/2442106.2442107

[23] John McCarthy and Peter Wright. 2004. *Technology as Experience*. MIT Press, Cambridge, MA, USA.

[24] Carman Neustaedter and Phoebe Sengers. 2012. Autobiographical design in HCI research: designing and learning through use-it-yourself. In *Proceedings of the Designing Interactive Systems Conference* (DIS '12), 514–523. https://doi.org/10.1145/2317956.2318034

[25] Netta Ofer, Fiona Bell, and Mirela Alistar. 2021. Designing Direct Interactions with Bioluminescent Algae. In *Designing Interactive Systems Conference 2021*, 1230–1241. https://doi.org/10.1145/3461778.3462090

[26] Amanda Parkes and Connor Dickie. 2013. A biological imperative for interaction design. In *CHI '13 Extended Abstracts on Human Factors in Computing Systems* (CHI EA '13), 2209–2218. https://doi.org/10.1145/2468356.2468742

[27] Pat Pataranutaporn, Jaime Sanchez De La Vega, Abhik Chowdhury, Audrey Ng, and Galina Mihaleva. 2018. Toward Growable Robot : Exploring and Integrating Flexible – Biological Matter with Electronics. In *2018 International Flexible Electronics Technology Conference (IFETC)*, 1–4. https://doi.org/10.1109/IFETC.2018.8584034

[28] Mónica Pineda, Matilde Barón, and María-Luisa Pérez-Bueno. 2021. Thermal Imaging for Plant Stress Detection and Phenotyping. *Remote Sensing* 13, 1: 68. https://doi.org/10.3390/rs13010068

[29] Heidi R. Biggs, Jeffrey Bardzell, and Shaowen Bardzell. 2021. Watching Myself Watching Birds: Abjection, Ecological Thinking, and Posthuman Design. In *Proceedings of the 2021 CHI Conference on Human Factors in Computing Systems* (CHI '21), 1–16. https://doi.org/10.1145/3411764.3445329

[30] Harpreet Sareen and Pattie Maes. 2019. Cyborg Botany: Exploring In-Planta Cybernetic Systems for Interaction. In *Extended Abstracts of the 2019 CHI Conference on Human Factors in Computing Systems* (CHI EA '19), 1–6. https://doi.org/10.1145/3290607.3313091

[31] William Shakespeare. 1991. Hamlet : [1604] / William Shakespeare. Retrieved August 19, 2021 from https://ota.bodleian.ox.ac.uk/repository/xmlui/handle/20.500.12024/1446

[32] M. Smigaj, R. Gaulton, J. C. Suarez, and S. L. Barr. 2019. Canopy temperature from an Unmanned Aerial Vehicle as an indicator of tree stress associated with red band needle blight severity. *Forest Ecology and Management*. https://doi.org/10.1016/j.foreco.2018.11.032

[33] Nancy Smith, Shaowen Bardzell, and Jeffrey Bardzell. 2017. Designing for Cohabitation: Naturecultures, Hybrids, and Decentering the Human in Design. In *Proceedings of the 2017 CHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1714–1725. Retrieved August 4, 2021 from https://doi.org/10.1145/3025453.3025948

[34] Lining Yao, Jifei Ou, Chin-Yi Cheng, Helene Steiner, Wen Wang, Guanyun Wang, and Hiroshi Ishii. 2015. bioLogic: Natto Cells as Nanoactuators for Shape Changing Interfaces. In *Proceedings of the 33rd Annual ACM Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 1–10. Retrieved July 11, 2021 from https://doi.org/10.1145/2702123.2702611

[35] John Zimmerman, Jodi Forlizzi, and Shelley Evenson. 2007. Research through design as a method for interaction design research in HCI. In *Proceedings of the SIGCHI Conference on Human Factors in Computing Systems*. Association for Computing Machinery, New York, NY, USA, 493–502. Retrieved August 6, 2021 from https://doi.org/10.1145/1240624.1240704

[36] 2017. *The Design of Everyday Things*. Retrieved August 25, 2021 from https://www.basicbooks.com/titles/don-norman/the-design-of-everyday-things/9780465050659/

[37] 2021. *The Mushroom at the End of the World*. Retrieved August 25, 2021 from https://press.princeton.edu/books/paperback/9780691220550/the-mushroom-at-the-end-of-the-world

[38] The "Anthropocene" | SpringerLink. Retrieved August 19, 2021 from https://link.springer.com/chapter/10.1007/3-540-26590-2_3

[39] Global Warming of 1.5 ºC —. Retrieved August 25, 2021 from https://www.ipcc.ch/sr15/

[40] Communication on The European Green Deal. *European Commission - European Commission*. Retrieved August 25, 2021 from https://ec.europa.eu/info/publications/communication-european-green-deal_en

[41] Carbon dioxide's effects on plants increase global warming, study finds. *ScienceDaily*. Retrieved August 25, 2021 from https://www.sciencedaily.com/releases/2010/05/100503161435.htm

[42] Funology - From Usability to Enjoyment | M.A. Blythe | Springer. Retrieved August 25, 2021 from https://www.springer.com/gp/book/9781402012525

[43] *The Companion Species Manifesto*. Retrieved August 25, 2021 from https://press.uchicago.edu/ucp/books/book/distributed/C/bo3645022.html

[44] Duke University Press - Staying with the Trouble. Retrieved August 25, 2021 from https://www.dukeupress.edu/staying-with-the-trouble

[45] Posthumanism and Design - ScienceDirect. Retrieved August 5, 2021 from https://www.sciencedirect.com/science/article/pii/S2405872616300971?via%3Dihub

[46] More-than-human urban futures | Proceedings of the 15th Participatory Design Conference: Short Papers, Situated Actions, Workshops and Tutorial - Volume 2. Retrieved August 4, 2021 from https://dl.acm.org/doi/10.1145/3210604.3210641

[47] Phenomenology of Perception. *Routledge & CRC Press*. Retrieved August 25, 2021 from https://www.routledge.com/Phenomenology-of-Perception/Merleau-Ponty/p/book/9780415834339

[48] Adafruit AMG8833 8x8 Thermal Camera Sensor. *Adafruit Learning System*. Retrieved August 25, 2021 from https://learn.adafruit.com/adafruit-amg8833-8x8-thermal-camera-sensor/overview

[49] Track the Slow-Motion Movement of Plants. *Science Friday*. Retrieved August 25, 2021 from https://www.sciencefriday.com/educational-resources/track-a-plants-movement/