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MA thesis in Informatics, Digital Design
Autumn term 2024
Faculty of Business/Department of design

Making sense of plants

Making the invisible visible using ambient lighting to interpret the electrical signals of plants

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Författare

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Titel

Att uppfatta växter: Att göra det osynliga synligt genom att tolka växters elektriska signaler med ambien ljus

Handledare

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Sammanfattning

Den växande medvetenheten om miljömässig hållbarhet och de många praktiska sätten att använda växter som verktyg och material för att bidra till miljövård och teknologiska framsteg understryker den väsentliga roll växter spelar för att stödja människans existens. Men vid sidan av dessa användbara tillämpningar finns en ökande betoning på att fokusera på både människors och växters emotionella och sociala välbefinnande. Befintliga teknologier och studier som strävar efter att utvidga principerna för HCI (människa-dator-interaktion) till att omfatta interaktioner mellan människor och växter utvecklas kontinuerligt i takt med att nya tillämpningar och möjligheter uppstår. Genom konst, teknologi och filosofi utforskar denna avhandling mer-än-mänsklig interaktion och inkorporerar de teoretiska ramarna för somaestetik, posthumanism, lugn och långsam teknologi. Med en konceptdriven metodik för interaktionsdesign utvecklades en interaktiv installation som använder ambient ljuskommunikation för att visualisera växters elektriska signaler i realtid. Denna avhandling presenterar en hållbar strategi för befintliga lösningar inom området människa-växt-interaktion (PPI) och bidrar till interspecies empati och samarbete i ett delat ekosystem. Resultaten från kvalitativa intervjuer visar att deltagarna reagerade positivt på designartefakten och att den framgångsrikt engagerade användare i att öka medvetenheten om växters autonomi, och att växter ses som aktiva deltagare i sin miljö. Resultaten tyder på att designkonceptet kan vara värdefullt inom utbildning och i att främja miljömedvetenhet. Dessa insikter bidrar till en bredare diskurs om människors och icke-människors sammanflätning, och banar väg för ytterligare forskning om samexistens i en mer-än-mänsklig värld.

Key words

mer-än-mänsklig, människa-växt interaktion, samexistens, somaestetik, posthumanism, ambient kommunikation

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Abstract

The growing awareness of environmental sustainability and the numerous practical ways to utilize plants as tools and materials contributing to environmental stewardship and technological advancement, underscores the essential role plants play in supporting human existence. However, alongside these utilitarian applications, there is a growing emphasis to focus on human and plant emotional and social well-being. Existing technologies and studies that seek to extend the principles of HCI to encompass interactions between humans and plants continue to evolve as new applications and possibilities emerge. Through the lens of art, technology, and philosophy, this thesis is an exploration of more-than-human interaction, incorporating the theoretical frameworks of somaesthetics, posthumanism, calm and slow technology. Applying concept driven interaction design methodology, an interactive installation was developed using ambient lighting communication software to visualize real-time plant electrical signals. This thesis presents a viable approach to existing solutions in the field of people plant interaction (PPI) contributing to interspecies empathy and collaboration in a shared ecosystem. The results from qualitative interviews show participants responded positively to the design artifact and it successfully engages users in the awareness of plant autonomy, viewing plants as active participants in their environment. The findings suggest that the design concept can be valuable in education and in promoting environmental awareness. These insights contribute to the broader discourse on human-nonhuman interconnectedness paving the way for further research on cohabitation in a more-than-human world.

Key words

more-than-human, people plant interaction, cohabitation, somaesthetic, posthumanism, ambient communication

Table of contents

1 INTRODUCTION

Plants, which are omnipresent and foundational to Earth's ecosystems, have coexisted with humans since the origin of the species, playing a pivotal role in human survival. The benefits of interacting with plants and nature are well documented in research (Keniger *et al.*, 2013; Hall and Knuth, 2019a; Turnbull, 2021; Yeo, 2021; Pocock *et al.*, 2023). However, as humanity confronts the challenges that human activity has on the planet's climate and ecosystems, our relationship with nature needs to be reestablished. To reconnect and to establish a different kind of interaction with and appreciation of the natural world, possibly by addressing an important aspect of people-plant connection that has been previously overlooked or underexposed. As we delve deeper into the realm of plant intelligence, we uncover the sophisticated signaling and behaviors of plants that reveal a world rich in communication and interaction, as well as untapped design potential (Huynh and Haick, 2019; Chang *et al.*, 2022). Recognizing the significance of our relationship with nature highlights the necessity of creating methods for interpreting the subtle ways in which plants communicate.

Recent studies have revealed that the sensory systems of plants exhibit an inherent capacity to perceive and respond to their environment in complex ways that challenge the traditional notions of plant cognition and intentions (Brenner *et al.*, 2006; Gagliano *et al.*, 2017; Parise *et al.*, 2022), underlining the need for meaningful innovative interaction methodologies to enhance human understanding and appreciation of plant life on their own terms. This research employs a multidisciplinary design approach, utilizing advances in human-computer interaction (HCI), incorporating interactive ambient lighting systems that visualize plant status. By enabling humans to perceive and intuitively interpret these signals, the project anticipates encouraging people to reflect and reconnect with the botanical world, potentially transforming our environmental interactions and contributing to more sustainable coexistence.

Drawing from the practical philosophy of somaesthetics, which emphasizes the body's sensory perception (Shusterman, 2020) and by integrating posthuman philosophy, we recognize the agency of plants alongside humans in an interconnected ecosystem (Bakke, 2014). This approach stresses the need for design practices that foster a deeper, more intuitive connection with plants and explores how technology, in particular within the realm of HCI, can facilitate reflection in this engagement. As with the case of understanding, honeybees and birds can see ultraviolet (UV) light outside the range of human perception. Through the application of HCI, reconstructing the colors that animals see can help scientists better understand how they communicate and navigate the world, allowing humans to gain insight into animals' perception of the world (Vasas *et al.*, 2024). This exploration of the perceptual worlds of animals paves the way for similar innovations in the understanding of plants. Just as technology bridges the sensory gap between humans and animals, it also opens new avenues for deciphering the silent but complex signaling of plants.

As HCI evolves, we find new ways to bridge the unseen to the known, leveraging technologies to translate plant cues into forms that humans can understand and appreciate (Chang *et al.*, 2022). Human-plant interaction (HPI) delves into the relationship and communication between humans and plants. With the aid of technological tools, scientists can now detect and interpret the intricate electrical signals and biofeedback of plants, enabling them to develop a richer understanding of plant needs and experiences. For instance, with the assistance of microphones and a machine learning model, humans can hear the ultrasonic sounds of stressed tomato plants (Khait *et al.*, 2023).

Building upon somaesthesthetic appreciation of HPI, this research employs HCI techniques, such as the designs of calm technology and slow technology, by utilizing tools that make these subtle communications perceptible and interactive. Underscoring a pivotal shift towards a more inclusive understanding of intelligence, communication, and interaction beyond human-centric perspectives. This reflects a growing acknowledgment of the interconnectedness of all life forms and the potential of technology to bridge the perceptual gaps between them.

Although a body of research has explored HCI and plant interactions (Chang *et al.*, 2022), most human interactions with plants have traditionally been within the domesticative stewardship of interdependence (Rosén, Normark and Wiberg, 2022). Introducing art as a medium of interaction allows the public to engage with a nonhuman soma (body) in a tangible manner, leading to greater understanding and appreciation of the complexity and interconnectedness of all living beings (Bakke, 2014). Adding the practice of *designing-with* introduced by Wakkary (2020), in which objects and subjects are considered partners in the design process, requires rethinking the relationship with nonhuman entities and actively engaging with them as co-creators and collaborators (Wakkary, 2020). The notion that the material and environment shapes the designer as it is being shaped by the designer, emphasizes interconnectedness and is an approach that not only enriches the design process with diverse inputs and perspectives but also leads to more inclusive, empathetic, and innovative reflections that incorporate the agency of nonhuman participants (Keune, 2021; Wakkary, 2021).

However, significant challenges include communicating across species and balancing the needs of both humans and nonhumans. Incorporating the principles of Calm Technology (Weiser, 1998), where the interaction between the technology and its user is designed to occur in the user's periphery rather than constantly at the center of attention (Case, 2016), might mitigate connections to occur more fluidly. Aligning harmoniously with our innate connection to nature, ambient communication is designed to be a nonintrusive and intuitive interaction incorporating elements such as motion, sound or visual aesthetics to evoke emotions and engage users (Weiser and Brown, 1995; Vogel and Balakrishnan, 2004). Adding Tsing's (2012) conceptualization of the act of *noticing* - which is equivalent to being mindful and observant of the diversity, complexities, and interconnectedness present in the world - opens up possibilities for reimagining human-nature relationships and allows us to move away from a hierarchical and dominating approach towards more collaborative and mutually beneficial relationships with nonhuman beings.

1.1 Aim and research question

This study seeks to explore interactions across species boundaries, emphasizing mutual influence, relationality, and cohabitation in a shared ecosystem. The overarching goal of this research is to bridge the perceptible divide humans have of plants, using technology as a mediator to translate plant processes into an interpretable format, and above all, to recognize plants as sentient entities with unique modes of interaction. It aims to make the invisible - plant electrical activity - visible, through the integration of theoretical frameworks such as somaesthetic philosophy, posthumanism, and calm and slow technology. Set in the context of art, this study equally aspires to make apparent the interrelatedness found in the senses of human, plant, and technology in its situated environment. In addition, the medium of art cultivates reflection and evokes emotion and understanding.

The research question guiding this thesis is: *How can digital technology facilitate human reflection on plants' existence within a world that is more-than-human?* To address this, the study explores several key aspects, such as: how visualizing a plant's electrical signals can heighten awareness of plant senses, reveal its "situatedness" in its environment, encourage reflection on a plant's autonomy, and consider the implications of understanding a plant's place in a world that extends beyond the human. This inquiry will be pursued through concept-driven design research as outlined by Stolterman and Wiberg (2010), carefully considering ethical implications to ensure that our explorations respect the autonomy and rights of plant life.

1.2 Delimitations

This study focuses primarily on the exploration of human-plant interactions through the lens of somaesthetic appreciation and digital design, employing a more-than-human approach. The design concept utilizes ambient communication to visualize plant electrical signals through the creation and analysis of an art installation. The research interaction is confined to the translation of plant electrical signals into visual forms, omitting other forms of senses and behavior, for example sound and haptic modes. The study is experimental and concept-driven, emphasizing speculative and theoretical frameworks over empirical validation. The installation's influence on the audience is observed and analyzed, but deeper psychological or long term effects on human perception of the plant's visual interpretation are not extensively examined. The technological applications are limited to those that support the study's artistic and conceptual goals. Though possible commercial or practical plant-monitoring technologies that might for example be used in the stewardship of the environment is broached as a speculative aspect of the design.

1.3 Definitions

- **Ambient interaction:** seamless, natural interaction with digital systems integrated into the environment. This concept revolves around creating interactions that are context-aware and unobtrusive, blending into the users' surroundings and activities (Weiser, 1998) Elements such as light, sound, motion convey information subtly and non intrusively (Song and Yamada, 2019)
- **Act of noticing** coined by anthropologist Anna Tsing, it refers to the deliberate act of observing, paying attention to and becoming aware of various aspects of the environment, ecosystems, and social structures. It involves being attentive to details, patterns, relationships, and changes in the surroundings (Tsing, 2012; Verinis, 2016).
- **Calm technology** coined by Mark Weiser 1991, is a design approach that engages both the center and periphery of our attention, seamlessly moving between the two, to provide information and enhance our awareness without overwhelming us (Case, 2016).
- **Designing-with** is seeing everything as relational when designing. It involves acknowledging that both humans and nonhumans shape the world collectively and often in distributed ways (Ventin, 2023)**.**
- **Ecological self** is a concept rooted in people plant interaction that refers to a sense of self that is deeply interconnected with the natural world and its ecosystems (DelSesto, 2020)
- **Human Plant Interaction (HPI)** Interchangeable with ***people-plant interaction***, refers to the field of study and design that explores the relationship and interaction between humans and plants (Chang *et al.*, 2022).
- **Interactive art** is a form of art that involves the spectator in a way that allows the art to achieve its purpose (Priveekollektie, 2020; Tate, 2024)
- **More-than-human** refers to a perspective that goes beyond considering only human entities in a design process. It encompasses a broader view that includes nonhuman elements such as nature, animals, technologies, and other entities that interact with humans in various ways (Wakkary, 2021).
- **Nonhuman** refers to entities or beings that are not classified as humans. This includes animals, plants, and other organisms, as well as inanimate objects and natural

phenomena (Ferrando, 2014).

- **Noticing** see *Act of noticing*
- **People Plant Interaction (PPI)** see *Human plant interaction*
- **Posthumanism** is a theoretical and empirical framework that challenges the traditional notion of the human as a singular, autonomous entity and emphasizes the interconnectedness of all beings. It addresses questions about identity, agency, and the impact of human actions on the ecosystem (Ferrando, 2014).
- **Slow technology** is a design philosophy that focuses on creating technology that encourages reflection, mental rest, and a slower pace of interaction, rather than prioritizing efficiency and speed (Hallnäs and Redström, 2001a).
- **Somaesthetics** is an interdisciplinary field coined by pragmatist philosopher in 1996, Richard Shustermanthat, that explores the relationship between the body and aesthetic experiences, highlighting the role of body awareness and training in enhancing our perception and awareness of the physical world (Shusterman, 2023)
- **Somaesthetics appreciation** is a design concept, proposed by Kia Höök, that emphasizes a correspondence between the body and the interactive system, with subtle feedback and interaction that follow the rhythms of the body, guiding attention inwards and providing space for reflection (Höök *et al.*, 2016).
- **Soma design** involves training the ability to aesthetically appreciate all senses, imagine through senses, movements, and material encounters, and shape interactive artifacts that consider the end-user's somatic experiences (Höök *et al.*, 2019)
- **Volatile organic compound (VOC)** in plants are organic chemicals emitted by plants that have high vapor pressure at room temperature. VOCs are crucial chemical signals that influence plant interactions, defense mechanisms, and environmental responses (Ninkovic, Markovic and Rensing, 2021).

1.4 Thesis Structure

The following section, Background, outlines the foundational theories that will guide and inspire the research in its process. Covering the principles of somaesthetic, the philosophy of posthumanism - focusing on the more-than-human approach that encompasses the practice of designing-with. It then explores plant sensory capabilities and internal models compared to the human senses and cognition, closing with interactions and philosophies within HCI pertaining to human-plant, human-computer, computer-plant interaction in the form of art. The Methodology section focuses on the what and how of concept-driven design research interaction, which is the chosen framework of the process. The designed artifact guided by concepts in previous sections will be presented with the theoretical and practical results of the external evaluation in the coming section, Results and analysis. The Discussion section will bring up challenges and potential societal implications, as well as the acquired knowledge of the study, to finally conclude with the author's Conclusions in the last section.

2 BACKGROUND

2.1 Navigating human and nonhuman interactions

Humans navigate the world through sensations that are made aware of the physical experiences of the body. The five basic senses – touch, sight, sound, smell, and taste – as well as proprioception and other forms of interoception, such as body heat and pain, help build a perception of our world so that we can respond to any changes (Shusterman, 2020). Sensory receptors are activated by environmental stimuli, which are converted into electrical signals (Gadhvi and Waseem, 2023). In like manner, electrical signals pass through plants reacting to stimuli from their environment (Fromm and Lautner, 2007; Aditya, Udupa and Lee, 2011). Similar signaling mechanisms suggest a parallel that can be explored through somaesthetics as a framework which integrates bodily perception with aesthetic experience, and offers a unique lens for understanding and enhancing interactions with plants.

Somaesthetics, a portmanteau of the Greek words *soma*, for the body, and *aisthesis*, for sensory appreciation, seeks to integrate the mind and body, and understands that bodily perceptions are crucial in shaping aesthetic experiences and interactions (Shusterman, 2020). Thoughts and feelings are deeply rooted in bodily existence and drive actions through parts that constitute the brain and nervous system (Dolezal, 2014). Consider how certain thoughts affect the body by bringing a blush to the cheek and a change in breathing rhythms as well as heart rate. This integration of mind-body, or *soma*, perceives and acts within a world filled with other entities, serving both as an object in the world and a subject experiencing the world (Wilkoszewska, 2015). As when observing a mosquito resting on one's arm and later feeling the itch from its bite and scratching it, we are acted upon as well as acting in the world.

Imitation is a fundamental aspect of human behavior and has powerful effects on cognitive, emotional, and social development by facilitating learning, social bonding, emotional understanding, perspective-taking, and cultural transmission of appropriate social interactions (Ray and Heyes, 2011). Since infancy, humans not only imitate other humans, but also engage in mimicking nonhuman entities. The act of copying or replicating the actions, behaviors, or gestures of others involves observing the actions of another individual, entity, or object (Ray and Heyes, 2011). Doing so through the lens of creative aesthetics, this concept can be exemplified in various artistic and cultural practices, such as martial arts. Certain styles of kung fu are inspired by the movements of tigers or praying mantises, capturing the essence of these creatures' motions and dispositions (Mullis, 2013). The interpretation of the form and spirit of the tiger or mantis body movements underscores a deep form of empathy and nonverbal understanding. The recognition of visual similarity between self and others, produced by imitation, promotes mutual understanding and contributes to the development of theory of mind (Ray and Heyes, 2011). Theory of mind, much like embodied simulation (Barrett, 2017), refers to the cognitive ability to understand and attribute mental states, such as beliefs, desires, intentions, and perspectives, to oneself and others. It involves recognizing that others have different feelings and perspectives than oneself, and using this understanding to interpret and predict their behavior, engaging in complex social interactions such as empathy, deception, and cooperation (Airenti, 2010, 2018; Ray and Heyes, 2011; Barrett, 2017). Closely related to the development of theory of mind is the concept of sharedness. Sharedness is essential for successful communication as it enables individuals to convey and interpret meaning and other forms of nonverbal communication. It plays a crucial role in the formation of social bonds and acknowledges others as intentional beings willing to share experiences and favor reciprocity (Airenti, 2010).

Human beings frequently attribute human traits, emotions, or intentions to nonhuman artifacts, entities and natural phenomena (Airenti, 2018). According to Airenti (2018), people interpret the world with human-like models because human thought and action are the highest organization that they know. Plant soma is very different from a human but through the inquiry of analytic, practical, and pragmatic somaesthetic it becomes comprehensible. Airenti (2018) proposes that the attribution of human mental states and emotions to nonhuman entities are based on the same brain mechanisms that humans have developed to understand other humans. That anthropomorphism is, in fact, a particular form of interaction with nonhumans, distinct from anthropomorphic beliefs, and is grounded in relation. In the process of anthropomorphization, an imaginary dialogue is established with an entity, which implies the attribution of mental and affective states, and initiated in circumstances where an entity cooperates or hinder an activity that is perceived as in a human-like relation (Airenti, 2018). Consider, for a moment, the interactions a child might have with their pet or toy.

Additionally, using ‘anthropomorphic’ words can also be used to explain terms too complicated to understand and intentionality is the best model that humans have to describe these situations (Airenti, 2018). For example, relating the intention of a phenomenon, such as “the tornado threw the car up in the air” is simpler than explaining the physics behind a tornado where air currents rising are fast and strong, affecting a car’s gravitational pull. A study showed that coaching sprinters using external cues in favor of internal cues enhanced the performance of the sprinters by three percent over 20 meters (Moran *et al.*, 2023). Sprinting “like a jet plane taking off” seemed to create a more evocative image in their mind than having them focus on their body positions, which seemed to interfere with the fluidity of the movement. This suggests that humans use analogy and embodied imagination to enhance performance and understanding. Inner perception of feelings are reflected in our bodily stance and vice versa.

The interconnectedness of body, mind, and culture acknowledged by somaesthetics (Shusterman, 2006) also underlines the fundamental principle of posthumanism that views the relationship between nature, technology, and culture as intrinsically entangled and mutually constitutive (Ferrando, 2014). Such perspectives compel us to view human and nonhuman interactions as intertwined, with each influencing and shaping the other. The philosophy of posthumanism suggests that nonhuman entities, including plants, are not passive environmental elements but active participants. With their own forms of intention and agency, they are significant in shaping the world, thereby urging us to consider plants as integral stakeholders rather than mere backdrops (Ferrando, 2014).

Incorporating these insights, the practice of *designing-with* emerges as a transformative approach. Just like posthumanism, the principles are to move away from a human-centric perspective which privileges human needs over everything else. Stemming from the theoretical framework of nomadic practices, that views design as a dynamic multiplicity of intentionalities and situated knowing, the practice of *designing-with* emphasizes the importance of shifting attention toward the relations that form between the thing designed and more-than-human worlds (Wakkary, 2020, 2021; Ventin, 2023). It stresses the relationality and collaboration between humans and nonhumans in the design process. As you form the material, the material forms you. The material shapes the interaction in several ways from physical traits such as properties of material, texture, weight, and temperature influencing bodily experiences, to emotional, symbolic and cultural representation that communicates ideas, values, and identities (Oogjes and Wakkary, 2022). In addition it recognizes the active participation and influence of nonhuman entities, such as technologies, materials, environments, and more in the design process. Thereby, acknowledging that the design outcomes are shaped by the dynamic and complex web of relationships between various actors. The basis of designing within this multispecies world requires navigating complex situations and embracing uncertainties with humility, encompassing a variety of ways of interacting or relating with each other. By engaging in the needs and perspectives of nonhuman entities, designers can create designs that are ethical, sustainable, and inclusive (Wakkary, 2021; Ventin, 2023). Thus, *designing-with*, not only shifts the focus to relational dynamics but also allows nonhuman entities, such as plants, to actively shape the design, creating a more reciprocal and participatory interaction.

In creating an interactive installation where plant signals influence the aesthetic or functional aspects of the environment, plants are not merely subjects but co-designers. Contributing with the unseen and unknowable to be interpreted and noticed by humans in a shared experience reflecting on the embodied aspects of interaction. To succeed in this endeavor it will be necessary to explore the specific mechanisms through which plants perceive and respond to their environments.

2.2 Plant interaction and senses

Traditionally, plants' perceived immobility has often led to misconceptions that they are devoid of sensation and complex behavior (Knapp, 2019). Important for the survival of humans, as hunters as well as prey to some animals, is perceiving movement taking place within timescales from tenths of a second and blocking out the rest (Balding and Williams, 2016; Speck *et al.*, 2023). Plant motion takes place very slowly within timescales between several minutes to weeks, making visual recognition of plant movement impossible for humans and therefore making plants seem agentless and lacking in sensation (Speck *et al.*, 2023). This view, however, is increasingly challenged by scientific discoveries that illuminate the sophisticated ways in which plants perceive and interact with their surroundings (Keniger *et al.*, 2013; Fox, 2023). Already in 1880, *The Power of Movement in Plants*, published by Charles and Francis Darwin, drew attention to the similarities between animals and plants. Most prominently, likeness in sensitivity to touch, light, and gravity (Chamovitz, 2012), reasoning consequently that sensing is a form of intelligence, the result of a *nervous system* that regulate behavioral or electrophysiological states of attentiveness (Bakke, 2014; Miguel-Tomé and Llinás, 2021).

Even now a growing body of research continues to affirm the notion that plants possess sensing intelligence. They demonstrate abilities such as memory, decision-making, and complex communication, further blurring the lines between plant and animal cognition (Segundo‑Ortin and Calvo, 2022). Unlike animals, when facing peril or environmental changes, plants cannot run away. Rooted in place, it is necessary for plants to be sensitive to their surroundings, adapt to climate and changes in their environment, and be able to deploy different modes of self-protection (Chamovitz, 2012; Karban, 2021).

Communication is crucial for plant survival, facilitating everything from nutrient sharing and warning of herbivore attacks to the attraction of pollinators, as well as responding to a variety of cues such as light, touch, sound, and chemical signals (Karban, 2021). Basic plant communication refers to the ways in which plants interact and exchange information with their environment and other organisms. Communication is defined as the process by which plants emit and perceive cues that convey information to other plants or organisms, resulting in changes in behavior or physiological responses (Karban, 2021). This communication can occur through various mechanisms, including chemical signals, electrical signals, and physical responses down to a molecular level (Karban, 2021).

To interact externally with their habitat, plants release chemical compounds called volatile organic compounds (VOC) into the air, utilizing as many as 3,000 chemical signals (Nixon, 2021). Much like how the nose can detect scents in the air, which the brain reads as information about the environment, these compounds enter plants through pore-like holes called *stomata*, and travel throughout the leaf, spreading information within the structure of a plant (Aratani *et al.*, 2023). The cues emitted into the air, or through their roots, provide information about the genetic identity of the plants as well as their status, and can be detected by neighboring plants, microbes, or insects (Ninkovic, Markovic and Rensing, 2021). Take for example, dodder vines, a parasitic plant with no root and little photosynthetic ability, that must quickly locate and attach to suitable hosts to survive. Its ability to sniff out their preferred hosts, is demonstrated by choosing tomato plants and inanimate objects perfumed with tomato plants over wheatgerm (Runyon, Mescher and De Moraes, 2006; Ninkovic, Markovic and Rensing, 2021). This example highlights the crucial role of VOCs in plant interaction, where the emitted chemical signals can guide complex behaviors such as with selection, emphasizing the sophisticated and adaptive nature of these interactions. Plants are found to be more receptive to VOCs emitted by genetically similar plants. Volatile signals are often intentionally released to a kin, conveying specific information to a receiver about stress or threats triggering defensive responses in neighboring plants and organisms as well (Gagliano and Grimonprez, 2015; Ninkovic, Markovic and Rensing, 2021). For example, plants can defend themselves by using VOC that mimic the natural attractants or pheromones of enemies of herbivores to lure them to a specific location (Bouwmeester *et al.*, 2019). To repel potential threats, or attract pollinators, plants can change their color, position, and shape to advertise that they are "open for business". These visual displays, including species-specific shapes, color, and color patterns, are another prominent medium through which plants interact and communicate (Gagliano and Grimonprez, 2015).

Being sessile, plants are sensitive to changes in their environment, both above and below the ground, and react to stimuli such as light, touch, sound, taste, and air (Tao, Huang and Lioret, 2016; Parise et al., 2022). Correspondingly, the human body reacts to stimuli through the senses both within the body, and externally, converting to electrical signals traveling through neurons to the brain, resulting in action. Without a centralized brain, a plant possesses a *nervous system* that is different from that of animals; instead, information is transmitted electrically through its entire structure (Miguel-Tomé and Llinás, 2021).

Establishing evidence of a simple nervous system, Miguel-Tomé and Llinás (2021) argues in their paper, claiming support from botany research from the past 25 years, that plants also have systems that use electrical signals to transmit and process information to and from different parts of its body, allowing the organism to respond to stimuli and react to its environment. The capacity of computation differs between plant and animal nervous systems due to different evolutionary pressures and the functional requirements they face. Animals typically have a centralized nervous system, prioritizing information to the brain to coordinate different parts of the body, helping to avoid danger and perform complex behaviors. In contrast, plants have a decentralized nervous system, evolved to prefer transmitting signals, with coordination occurring within specific cells or tissues (Miguel-Tomé and Llinás, 2021). For instance, much like contracting muscles in humans and animals (Aditya, Udupa and Lee, 2011b), the plant Mimosa Pudica will exhibit movement when sensed being touched, causing electric impulses called action potentials to close its leaflets as a protection mechanism (Hagihara and Toyota, 2020).

However, some Mimosa Pudica on display at botanical gardens have stopped closing its leaflets immediately after having been desensitized from years of visitors touching them. The action of folding its leaves requires a large amount of energy from the plant. If it "understands" being touched does not implicate danger then it will forgo the action to conserve energy. This behavior is further supported by a study conducted on Mimosa Pudica plants that proved that they are capable of learning and remembering (Gagliano *et al.*, 2014). The researchers conducted experiments to test the habituation of the plant's leaf-folding reflex in response to repeated physical disturbance, by administering a standard stimulus of 15-cm fall or drop, 60 times throughout the day, marking the response time of the leaves unfolding during the course of the training until they stopped folding altogether. The habituated response of the plants remained unchanged even after being held undisturbed for 28 days, thus demonstrating that plants can acquire and express long-lasting memory for learned behavior (Gagliano *et al.*, 2014).

Habituation allows an organism to filter out irrelevant stimuli and allocate resources efficiently - even in humans. An energy efficient strategy for information processing in the brain is through its predictive coding. The brain constantly generates predictions about sensory input based on internal models and prior knowledge. It compares these predictions with actual sensory input and updates its internal models based on prediction errors, thereby minimizing unnecessary processing of familiar or predictable stimuli (Barrett, 2017). All organisms run an internal model of their world for the purpose of allostasis. Allostasis is the process by which the body and sensory systems maintain stability and adapt to changes in the internal and external environment to ensure the overall well-being and survival of an organism. So even single-celled organisms that lack a brain learn, remember, make predictions, and respond to environmental cues in service of allostasis (Barrett, 2017). The internal model serves as a bridge between perception and action by guiding both processes of making sense of sensory input and filling in missing information. It is a representation or simulation of the external world that the brain constructs based on the perspective of its body's physiological needs (Barrett, 2017). In this regard, humans have been able to expand their biological framework and advance understanding with the aid of technology. It has further allowed internal models to be refined based on new information and experiences. Technology has assisted in revealing what was once concealed, rendering the imperceptible visible.

2.3 The art of people plant interaction technology

Existing technologies and studies that seek to extend the principles of HCI to encompass interactions between humans and plants continue to evolve as new applications and possibilities emerge (Chang *et al.*, 2022). There are practical applications involving plants to improve agricultural and gardening practices and bio-integrated urban spaces using technology for smart environmental sensing (Ramoğlu, 2019; Zhang *et al.*, 2021; Chen *et al.*, 2022; Farella *et al.*, 2022). In addition, biotechnology can be implemented to harness plants to generate lighting and electricity for sustainable clean power, contributing to a circular economy (Elton, 2022). The numerous practical ways to utilize plants as tools and materials contributing to environmental stewardship and technological advancement, underscores the essential role plants play in supporting human existence.

However, alongside these utilitarian applications, there is a growing emphasis to focus on human and plant emotional and social well-being. From studies aimed at exploring ways to form emotional bonds with plants to alternative ways to “read” plants emotions (Cho *et al.*, 2015; Angelini *et al.*, 2016; Chang *et al.*, 2022). This shift reflects a broader interest in rethinking human’s relationship with nature, moving beyond exploitation toward mutual engagement, where plants are valued not only for their utility but also as sentient co-inhabitants of our ecosystems (Bakke, 2016; DelSesto, 2020; Chang *et al.*, 2022).

There are challenges in comprehending the essence or nature of nonhumans, which are largely unobservable or unknowable to humans. Today, technology can aid in catching glimpses of the imperceptible, which helps humans make inferences about what it means to be other than a human being and redefine the way we interact with the natural world (Ventin, 2023). Involving plants in HCI design research aims to create meaningful and engaging experiences for users and endeavors at people plant interactions (PPI) contributes to a deeper connection between humans and nature. Technology can translate plant experiences into human-comprehensible forms such as sound or visual displays. These interactions can help humans empathize with plants by making their responses to environmental stimuli more relatable. Simultaneously promoting environmental awareness and sustainability while exploring new forms of interaction and innovative technologies that bridge the gap between the natural and digital world (Fell *et al.*, 2022).

Despite recent advances, current understanding of plant cognition, behavior, and interaction remains in its infancy. There are significant gaps in our knowledge, particularly regarding the subjective experiences of plants if such a concept applies. Recent advancements in PPI are exploring the interpretation of plants’ internal communication via their electrical signals, which serves as a form of biofeedback enabling interspecies interaction (Chang *et al.*, 2022). The electrical signals within plants, triggered by environmental factors such as light, touch, or temperature (Fromm and Lautner, 2007) provides researchers and designers with a medium to investigate novel interaction methods. By harnessing PPI technologies, plants’ internal states can be made legible to human senses, offering a unique form of communication that emphasizes plants' active role in their environment. In the context of PPI projects that bridge this gap, sound is a popular medium for enabling interspecies empathy and creating interactive experiences with plants. For example, PlantWave is a device attached to leaves that detects slight electrical variations in a plant, which are translated into pitch messages that play predesigned musical instruments (Chang *et al.*, 2022; *The Science Behind PlantWave*, 2022). Plant Radio is another project of the same ilk that uses the EMG signals of a plant to broadcast its internal activity into sounds, making it possible to perceive a plants' internal state non-stop, emphasizing plant-centeredness (Rolighed *et al.*, 2022). Further, through technology using natural language processing, Project Florence translates human text sentiment into a light frequency that the plant can recognize and respond to (Chang *et al.*, 2022).

The aforementioned projects attempt to bridge the previously mentioned gap by encouraging interspecies interaction and creating more engaging experiences with plants. External cues are necessary considering that during nonverbal human interactions, emotions can be communicated through facial expressions and body language (Tracy, Randles & Steckler, 2015). Plants, however, are static and exist in daily life by blending in with the background. They often go unnoticed and do not receive visual attention, resulting in a concept coined "plant blindness". The term is used to describe the human tendency to overlook plant life because the brain is prone to focus on movement, colors and patterns, and potential threats (Allen, 2003; Balding & Williams, 2016).

At the same time, the human brain receives a vast amount of visual information every second, but can only fully process a small fraction of it (Allen, 2003). Nowadays screens and digital interfaces constantly demand our attention, leading to sensory overload where too much visual and auditory information reduces our ability to concentrate and relax. Therefore, applying the principles of calm technology becomes particularly relevant (Case, 2016). Calm technology, conceptualized by Weiser and Brown (1995), advocates for technology that is unobtrusive within peripheral reach, yet recedes into the background of our lives when focus is needed elsewhere. Characteristics that plants seem to embody. It then seems evident that the following principles should be integrated when designing technology for PPI (Case, 2016):

1. Technology should require the smallest possible amount of attention.
2. Technology should inform and create calm.
3. Technology should make use of the periphery.
4. Technology should amplify the best of technology and the best of humanity
5. Technology can communicate, but doesn't need to speak.
6. Technology should work even when it fails.
7. The right amount of technology is the minimum needed to solve the problem.
8. Technology should respect social norms.

Calm technology is designed to seamlessly integrate into our daily lives providing functionality without demanding constant attention. It is about making technology *less* noticeable, in contrast to slow technology, which is about making technology *more* noticeable. Notwithstanding that, the main principle of slow technology revolves around creating technology aimed at reflection and also mental rest and not as a tool to get tasks done efficiently and quickly (Hallnäs & Redström, 2001). Plants operate on natural timescales, growing and responding to environmental changes at a deliberate pace. These traits, too, align well with the design philosophy of slow technology which is characterized by deliberate slowness in various aspects of technology meant to amplify the presence of time. This slowness allows for a deeper engagement and understanding of the technology through interaction (Hallnäs & Redström, 2001).

The three design themes in the context of slow technology are: *amplified environments, time technology, and reflective technology* (Hallnäs & Redström, 2001). *Amplified environments* aim to create immersive and engaging spaces that encourage users to interact with and reflect on their surroundings. It should be aesthetically appealing, thought-provoking, and harmoniously integrated with its surroundings, as it becomes part of our activities for long periods of time (Hallnäs and Redström, 2001). Whereas *time technology* is concerned with designing technological expressions that make users aware of the presence of time (Hallnäs and Redström, 2001). As for *reflective technology*, the goal is to create technology that opens up opportunities for reflection and asks questions about its existence, inciting a need for users to engage with it consciously about its purpose and impact in their lives, as well as its broader implications (Hallnäs and Redström, 2001).

In this way, *reflective technology* is similar to certain forms of art, which expand on the presence of things, objects, or ideas. Art, too, evokes emotions and encourages viewers to reflect on their meaning and significance (Jeon *et al.*, 2019), and interactive art lies at the intersection of art and HCI as it seeks to display expressions of mood and internal states to provoke responses from an audience. Using sensor technology can implement these internal affective states and express them externally as visuals and sounds, thereby expanding an additional aesthetic layer to artworks (Jeon *et al.*, 2019).

Visualization of multidimensional information from sensors and data can be aesthetically presented using ambient light technology. Scientific evidence shows that ambient lighting can enhance well-being by creating a pleasant atmosphere, reducing cognitive load, and providing emotional support through subtle cues (Davis *et al.*, 2017). Above all, ambient light technology encompasses the intentions of calm technology, slow technology, and interactive art seamlessly. It integrates technology in our everyday environment in a way that is seamless, unobtrusive, and adapts the environment to the needs of users which is similar to the concept of calm technology (Weiser and Brown, 1995; Davis *et al.*, 2017). As in interactive art and slow technology, its aim is to create an intuitive and immersive user experience by making technology a natural and integral part of our daily lives (Beale, 2007; Davis *et al.*, 2017). Furthermore, ambient lighting can create a deeper awareness of both the technology and the surroundings, encouraging users to reflect on the interaction.

The role of technology is to enhance interaction in recognizing the importance of nonhuman participants that co-exist and participate in our ecosystem. Aiding in perceiving the imperceptible but also cultivating a deeper engagement and awareness of our environment is what anthropologist Anna Tsing calls the “art of noticing” (Verinis, 2016). It involves being curious and attentive to the world around us, and paying attention to the entanglements and connections between different species and ecosystems. The practice requires us to be observant both empirically and imaginatively, as well as open to the strange and wonderful, along with the terrible and terrifying. Understanding symbiosis is a fundamental aspect of life, such as our symbiotic relationship with intestinal bacteria in our bodies without which we cannot survive, and understates the importance of recognizing connections (Tsing, 2012; Verinis, 2016).

In line with this, the concept of the *ecological self* (DelSesto, 2020) further highlights the interconnectedness and interdependence between humans and their environments, particularly with plant ecologies. It posits that the transformation of the self occurs when attention is directed outside of the self and beyond pre-existing social formations (DelSesto, 2020). A shift in perspective where the self is seen as relational and part of a broader ecological system, leads to a more holistic and integrated understanding of one's place in the world (DelSesto, 2020). By acknowledging this, PPI technologies can promote an understanding that humans are not isolated individuals but participants within a larger ecological system. This shift in perspective is crucial for developing design approaches that are sensitive to these entanglements and respect the agency of nonhuman entities (DelSesto, 2020).

3. METHOD

3.1 Literature studies

The bibliography of this study contains peer-reviewed journal articles, conferences proceedings, news media articles, and blogs. The search for papers was primarily done using Google Scholar to extract pdf papers through the HKR Institution portal to ACM Digital Library, IEEE, and so forth, unless available as open source. Papers were filtered from 2010 to 2023. The following search terms were used at the starting point of the research: *HCI Plant, Human Plant Interaction, IoT Plant, Plant Interaction, Cyborg Plant*, *Somaesthetics, Soma Design, Posthumanism, Design-way, Calm Technology, Plant Design,* and *Computer Plant Design.* As the study and research progressed, references from each paper were searched, and as independent connections were made, they were looked up and added to the bibliography. An especially inspirational source of reference used that conducted an extensive literature review surveying existing PPI projects across HCI, art/design, architecture, and bioengineering was *Patterns and Opportunities for the Design of Human-Plant Interaction* (Chang *et al.*, 2022)

3.2 Concept-driven interaction design

The purpose of concept-driven interaction design research approach is to explore theoretical advancements in the field of human-computer interaction and to manifest the theoretical concepts in a concrete design (Stolterman and Wiberg, 2010). It complements the traditional user-centered interaction design approach in which the point of departure is the needs, goals, and preferences of users based on an existing situation (Stolterman and Wiberg, 2010). The concept-driven approach to interaction design research is rooted in imagining *futuristic scenarios*, with reasoning grounded in theory, to develop innovative concepts, contribute to the current body of knowledge, and bridge the gap between practical and theoretical approaches (Stolterman and Wiberg, 2010). By manifesting these speculations as artifacts, the act of making becomes an essential practice in the theorizing process, and in the undertaking, a concrete and creative design element unfolds. For example, Drone Chi (La Delfa *et al.*, 2020) illustrates the value of a concept-driven approach by merging drone technology with Tai Chi practices. This creates an innovative interaction scenario that blends physical movement, somaesthetic, and technological responsiveness.

This study utilizes the concept-driven design research approach to bring theoretical concepts into actual designs. The approach is both *design centered* and *theory oriented* (Stolterman and Wiberg, 2010) and fits well with the current research objective, which is interdisciplinary in its process, resulting in a final design that is optimized to a specific concept rather than a particular problem or use context, see *Figure 1*.

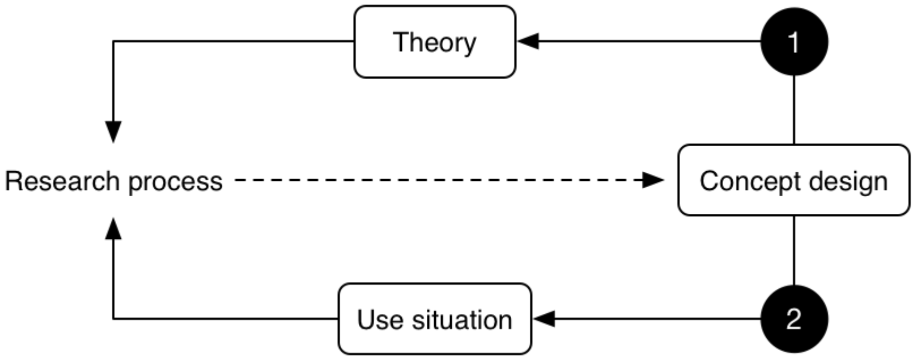

Figure 1. *Relationships between the research process, theory, and use (Stolterman & Wiberg, 2010:p 101)*

The *theorizing process* in concept-driven interaction design is a crucial component, as it plays a significant role in advancing knowledge in the field. In the study of *interaction*, which due to technological developments changes use in behavior, or cultural and social changes, theorizing becomes a matter of "sensemaking" (Stolterman and Wiberg, 2010). It involves identifying patterns, connections, and causal relationships and using this understanding to develop theoretical constructs and frameworks. Sensemaking is a continuous process that involves constant reflection and analysis, and is essential for generating new knowledge and advancing theories in various fields. In a dynamic field like HCI, theorizing is a necessary activity in the process of designing concepts and artifacts as it affects how prepared we are as we follow the observable world in its "becoming," dealing with the not-yet-existing (Nelson & Stolterman, 2012), creating a dimension that opens up a *design space* in which people gain an understanding of what is *possible* and also *desired* (Stolterman and Wiberg, 2010:p 100).

Similar to the design processes in traditional design disciplines, the seven methodological activities in concept-driven design research are as follows: *concept generation, concept exploration, internal concept critique, design of artifacts, external design critique, concept revisited,* and *concept contextualization* (Stolterman and Wiberg, 2010).

The first activity is *concept generation* and it is used to look for the unexpected to make it a new concept. Either combining earlier qualities or manifesting identified theoretical concepts as a whole (Stolterman and Wiberg, 2010). Observing and finding commonality in different life forms by way of senses enforces guidance through the principles of somaesthetics as an obvious offset in generating further similar theories. A key premise of somaesthetic philosophy is an insight that all of our experiences and interactions with the world happen through our body (Höök *et al.*, 2015). By approaching the concept of plant agency through the inquiry of somaesthetics a wide diversity of knowledge of senses might be attained, cultivating interspecies empathy as well as an understanding of a plant's sense of being.

Concept exploration strives to challenge the status quo by experimenting with material and ideas and exploring unknown spaces and understanding (Stolterman and Wiberg, 2010). Integrating natural and technological elements further explores the senses and gives rise to understanding human traits and the role of the theory of mind, while exploring the interaction entanglements of all things. Humans have long used technology as an extension of themselves to enhance their physical reach and gain perspectives (Barrett, 2017). By experimenting with technology as an extension on different life forms, i.e plants, an insight arises that there is a sense of agency involved in the process of *designing-with* (Wakkary, 2020). The concept's interaction and effect on the environment further contributes to an understanding of the development of the *ecological self* where transformation arises from engaging with and being open to the dynamic living ecology of the world (DelSesto, 2020).

Once the concepts are established, through *internal concept critique*, it is time to test the strength of the chosen concepts in relation to existing theories and how well they manifest the intended theoretical considerations to finally be crafted in the *design of artifacts*. The artifact is then exposed to the public for *external design critique*, which evaluates the assumptions embodied in manifested design. After the concept has been revisited and revised, a process done in *concept revisited*, based on the evaluation, and after a required number of iterations, a finished artifact will be evaluated against current works and concepts in the field in the final phase called *concept conceptualization.* In the concept-driven approach framework the *theoretical grounding* and *artifact crafting* are closely intertwined (Stolterman & Wiberg, 2010).

3.3 Participants

A total of 11 participants (five males and six females) completed the semi-structured interview. The participants were recruited using a convenience sample for the external design critique activity, and had an age range of 21 to 77 years old, owning as little as three house plants to as many as 59 house plants. Semi-structured interviews were conducted in groups of five or two, and two of them had one-on-one interviews. Participation was on a voluntary basis and no compensation was offered to the participants. In this study, the participants will be referred to as participants 1-11 (P1-P11) to ensure anonymity.

Table 1. Demographics of the participants.

Participant	**Interaction**	**Age**	**Gender**	**Education**	**Plants owned**
P1	group	71	Female	Upper Secondary school	20
P2	group	72	Female	Bachelor’s degree	15
P3	group	44	Female	Bachelor’s degree	20
P4	group	77	Male	Upper Secondary school	5
P5	group	74	Female	University diploma	8
P6	individual	48	Male	Master’s degrees	10
P7	dyadic	52	Female	Doctoral degree	4
P8	dyadic	21	Male	University diploma	3
P9	individual	49	Female	Master’s degree	59

P10	dyadic	44	Male	Master's degree	15
P11	dyadic	24	Male	University diploma	5

3.4 Materials

Twenty qualitative questions, divided into four categories excluding demographics, were prepared for semi-structured interviews to evaluate the initial design concept (see Appendix 1). These questions were formulated independently, based on the central theme of the design and its experiential aspects, rather than drawn from existing research. The aim was to explore participants' personal experiences and reflections, focusing on their interactions with plants, perceptions of the installation, and potential future applications of the design. Each category was designed to progressively deepen the participant's engagement with the topic.

The questions related to demographics included age, gender, education, and the number of house plants in possession. The first category touched on their initial interaction with the plants before viewing the installation (*How are you aware of plants and nature in your day to day life?*). The second category referred to their experience of the installation, and whether their initial relationships with plants were the same or different after the interaction (*What are your first impressions? Can you describe what you see and feel (in your body and mood) when interacting with the installation?*). The third category explored practical applications of the design concept pertaining to their own situation and need (*If you could monitor your favorite plants' electrical signals from a distance (such as from work), would you? And how would it make you feel?*). The last category looked toward the future of such technologies in connection to broader societal implications (*Can you imagine how this technology can be used in the future? Which scenarios come to mind?*). This structured approach was intended to move from personal experience to speculative thinking, providing a comprehensive exploration of the concept.

3.5 Procedure

The semi-structured interviews were qualitative and conducted during five different sessions. The data collection process comprised individual, dyadic, and group interviews. Specifically, two interviews were conducted with single participants, two with pairs of participants, and one session involved a focus group of five participants simultaneously. Data collection occurred through in-person interviews conducted across five different sessions. The interview settings were diverse, encompassing three distinct environments: an art gallery, a domestic setting, and an outdoor garden space. The choice of environment, though not initially planned, aligned well with the possible scenarios where the installation could be situated. These settings offered a valuable opportunity to observe how the installation might function and be perceived in different contexts, providing reflection of the diverse potential application of the design concept. The interviews were conducted primarily in English, a non-native language for all participants. Occasional code-switching to Swedish occurred, primarily for key conceptual terms. All participants agreed to be recorded and were briefed on the ethical considerations of this study, see section 3.6.

First, a brief introduction of the interviewer was provided before the first category of questions was asked. The interview progressed with a short presentation on the background of the study and the design concept before being viewed by the participants. As the participants examined and considered the design concept, the interview questions and discussions progressed to facilitate ongoing dialogue. Each interview had the same procedure apart from one, which began with a presentation followed by all the questions in the semi-structured interview. Upon completion, the qualitative data were transcribed using the online service Cockatoo (cockatoo.com) and the transcription function in Microsoft Word, for further processing and analysis.

3.6 Ethical considerations

This study adhered to good research practices involving subject interviews, as recommended by the Swedish Research Council (2017: p.40). The four important concepts are: secrecy, professional secrecy, anonymity, and confidentiality. The interviews began with an introduction and an explanation of the purpose of the interviews. Consent was obtained from all the participants. They were informed that participation in the interview was entirely voluntary and that participants held the right to withdraw at any time. The information provided during the interviews was treated with strict confidentiality and used solely for this study. To ensure the right to privacy and confidentiality of the participants, transcriptions of the recorded conversations were anonymized, and the only demographic data collected were age, gender, education, and number of plants. Participants were informed that the collected data would only be used for research purposes and would not be shared with any third party.

No plants were harmed in the process of this study, and ethical design considerations specific to HCI research involving plants were upheld. Ethical design considerations specific to HCI research involving plants, include *non-maleficence, non-interference, respect for nature, fidelity,* and *restitutive justice*. These considerations aim to ensure responsible and respectful design practices that prioritize the well-being and ethical treatment of all the stakeholders involved (Fell *et al.*, 2022).

4. RESULTS AND ANALYSIS

4.1 Concept generation, concept exploration and internal design critique

A key premise of somaesthetic philosophy is the insight that all of our experiences and interactions with the world happen through our body (Höök *et al.*, 2015) via senses. If this is true for humans then it could apply to nonhumans, such as plants. Considering a plant's body structure and nervous system being different from a human's, the assumption is their experience and sense of the world would be different too, possibly perceiving things humans are not aware of. Guided by somaesthetic comprehension and aided by technology humans can expand their view of the world by interacting and understanding plants' perception. This initial interpretation guides the stages of concept generation and exploration in this study.

According to Stolterman and Wiberg (2010), concept driven interaction design connects the research process, theory, and practical use through a structured relationship between input (the theoretical perspective and data), hardware (the technological framework and design), and output (the resulting interaction and experience) (Stolterman and Wiberg, 2010). In this case, the input is grounded in theories of somaesthetic, posthumanism, and slow technology, guiding the exploration of people plant interaction. The hardware involves embedded sensors and technologies that capture plant electrical signals. While the output is the real-time translation of these signals into ambient visual representations. This design approach ensures that the practical use of the technology aligns with the theoretical goals.

The aim of ***concept generation*** is to gain new insights from the process of discovering novel combinations of perspective. Stolterman and Nelson (2012) asserted that a designer's core judgment, shaped by creative, sublime, and life experiences, along with innate character, contributes to the creation of new meaning and value through embodied and lived experiences in the creative process. Watching the murmuration of swallows, which seem to visualize wind patterns, thereby making the invisible visible, inspired the translation of plant electrical signals into visual representations. In observing the nature of interrelatedness, in this case the individual swallow's movement in sync with one another and the force of the wind, the significance of Anna Tsing's art of noticing comes to mind (Verinis, 2016). This involves paying attention to the small details and subtle interactions that often go unnoticed. By actively noticing nonhumans, the designer can include them in the design process and consider their perspectives and contribution (Oogjes and Wakkary, 2022).

In addition to these realizations, an intriguing association emerged from how the word "ubiquitous" applies to both plants and technology. Both are omnipresent in our environment, yet often go unnoticed, which sparked ideas about leveraging the ubiquitous nature of both, and in incorporating the strengths and characteristics of each to nurture a meaningful interaction, highlighting the relationships between humans, plants, and technology.

An essential characteristic of nature is being part of the background and not adding to the mental load. This led to the conceptualization of designs that emphasize subtle, yet constant, interactions. For instance, integrating ambient lighting with plant signals can create a seamless blend of natural and technological elements, enhancing user awareness and appreciation of both (Beale, 2007). The goal is to develop an interaction that fits naturally into everyday life, aligning nature and technology by employing the principles of calm technology and slow technology, which promote unobtrusive and reflective engagement (Hallnäs and Redström, 2001a; Case, 2016). In the context of slow technology, *reflective technology* as a design theme is in focus as it has similar traits to art, in opening opportunities for reflection and questioning the validation of an artifacts' existence. Further traits applied from slow technology, but also reminiscent of Tsing's noticing were; *learning how it works, understanding why it works the way it does,* and *finding the consequences of it* (Hallnäs & Redström, 2001a). Making the visuals intentionally indefinable forces people to reflect on the meaning of the changing visuals, why and how they interpret the movements, and if plant state affects or correlates with people's own internal state.

Combining both posthuman philosophy with the practice of *designing-with* uses a more-than-human approach to creating by acknowledging the agency of nonhumans and taking a step back from human centered designing. Technology is incorporated to assist in an art scape generated and controlled by plant state. The plant's physiological signals directly influence the interactive experience. With the knowledge that plants are aware of their surroundings shifts focus to a more relational and environmental approach.

In the extensive literature study done by Chang et al.'s *Patterns and Opportunities for the Design of Human-Plant Interaction* (2022) they categorize HPI projects into four types of interaction. Informing the guidelines of interaction desired in this study is categorized as Embedded Direct Integration, see figure 2. The approach involves integrating electronic components or sensors directly into the plant's tissues or structures, allowing for real-time monitoring of the plant's physiological responses. The collected data is processed and analyzed to understand the plant's responses to different stimuli or environmental conditions.

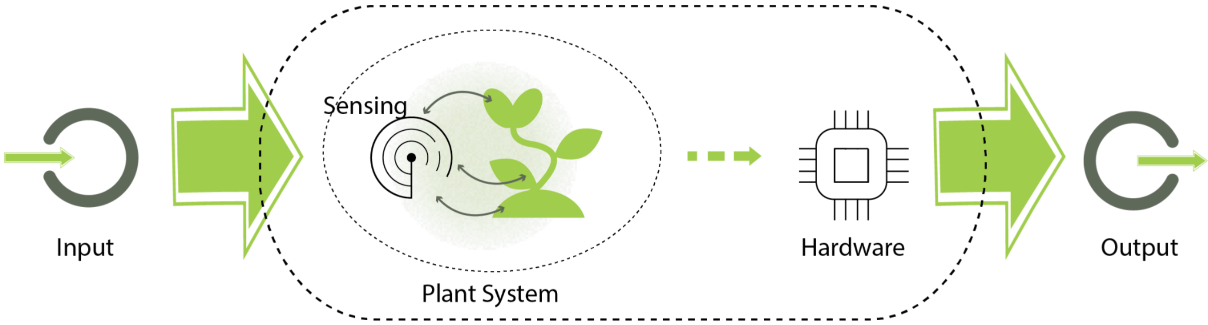

Figure 2. *Embedded Direct Integration integrating electronic components allowing for real-time monitoring of plant's physiological responses (Chang et al., 2022:p. 934).*

Concept exploration is about investigating and experimenting with different ideas, possibilities, and potential applications of a concept. The Finnish designer and entrepreneur, Tapio Rosenius, and his pioneering use of biomimetic lighting control inspired the application of ambient communication (Korkman, 2023). Generated by the software POET Creator by Skandal Technologies (https://www.poet.software/) it seemed a feasible procedure to visualize plant state in an intuitive way. The POET software platform collects data with sensors and combines it with contextual information. The implementation of physical and digital installation can consist of light, media, sound, and data, as a way to impact human behavior.

Ambient music has been used as a way of monitoring electrical signals of plants as sound. The PlantWave measures biological changes within plants, graphs them as a wave and translates the wave into pitch. Every single note you hear is a real-time expression of a shift in a plant (PlantWave, 2023). Monitoring electrical signals in real time of plants as moving visuals follows the principles of ambient interaction more accurately by being in the peripheral. Emphasizing the role of bodily perception and sensory experience in design, with visual movement, there is still a possibility to avert or close one's eyes when the need to focus arises but ignoring sound is more difficult.

Once the central concepts had been identified and explored, the internal critique sessions commenced involving presenting concepts to mentors, peers and domain experts. The ***internal design critique*** is relevant to find the uniqueness of the chosen core concepts and to see if they can be clearly expressed in the concrete design. A session with Kia Höök was initiated for insight into somaesthetic and its assimilation in the context of designing a subtle and nuanced interaction with plants that creates a space for reflection (Höök *et al.*, 2016). Reaching out to Skandal Technology whose operation is based in Madrid, Spain, contact was established with Custom Support of the software POET Creator Beta, Daniel Strazzaboschi. He confirmed the originality of the concept as they had yet to test the application on data feedback from a plant's electrical signal, but that the process ought to be feasible in practice. The interaction should engage users on a physical and emotional level, encouraging deep reflection and mindfulness through embodied experiences. It is meant to create an experience that is not just visual but also somatically engaging, helping users connect with the subtle, often overlooked, aspects of plant life.

4.2 Design of Artifact

Aimed at translating theoretical insights into a tangible, interactive installation in the context of art, the installation visualizes the subtle electrical signals of plants, a form of ambient communication embodying the principles of somaesthetic, posthumanism, and slow technology. This design artifact is deeply rooted in the principles of somaesthetic appreciation, where the interaction between the participant and the installation is designed to be an introspective, interoceptive embodied experience. The choice of visuals was informed by the need to create a sensory environment that encourages users to engage in reflective observation. The elusive, yet dynamic visual representations of plant signals aim to invoke a meditative state, aligning with somaesthetic principles that emphasize the importance of bodily perception in aesthetic experiences.

4.2.1 The visuals

The POET Creator Beta is a free software that integrates sensing and data with lighting and media controls which the user can create themselves. Experimenting with the software and the possibilities of its visual features, two different moving visuals were created and presented as representation of the electrical signals for the external design critique.

Green Cell (Figure 3) is a predominantly green image with darker boundaries reminiscent of onion skin cells under a microscope. The visual oscillates subtly in a steady manner in the valleys of the electrical waves, expanding its oscillations quickly at the peaks of these waves. *Pink Murmuration* (Figure 4) represents a likeness to the murmurations of swallows and shifts from a gradient of pink to yellow. This visual flows in a collected manner from right to left, slowly spreading to a standstill in the valleys of the electrical waves, compressing dynamically and flowing quickly towards the left at the peaks of these waves.

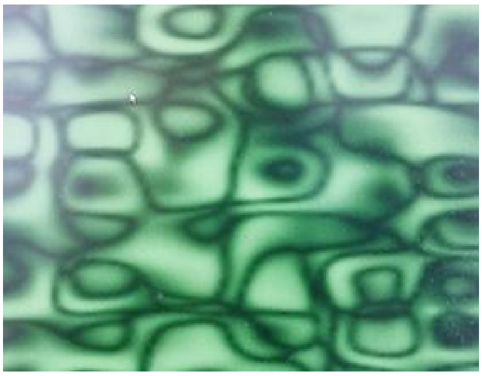

Figure 3. *Image of visuals Green Cell*

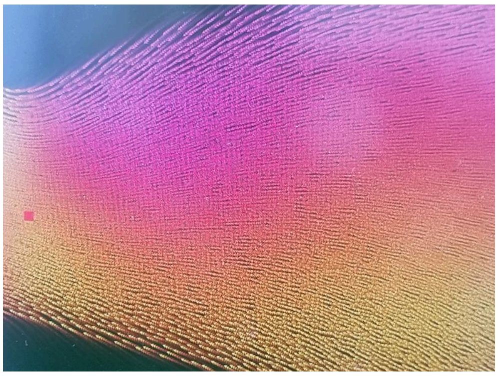

Figure 4. *Image of visuals Pink Murmuration.*

These visuals were created with intention to be contrasting in representational form, color, and variation of movement. The purpose is to evoke different feelings in the moment as they are viewed, with one perhaps resonating more with the viewer than the other. Even interpreting the movement of the visuals is meant to be a process executed in the fullness of time aligning with one's own experience and interaction with the plant. Each moving visual was programmed to display alternately every minute, with *Green Cell* (Figure 3) on even minutes and *Pink Murmurations* (Figure 4) on odd minutes during presentation.

4.2.2 Co-creation

The concept of plant agency, drawn from posthumanism, guided the decision to treat the plant not merely as a data source but as an active participant in the creation of the visual output. This acknowledges their role as co-creators, challenging the traditional notion of interaction design by placing a nonhuman entity at the center of the interactive experience, thus shifting the focus from human centric interaction to a more inclusive, ecological perspective. Utilizing the practice of *designing-with* recognizes that plants, as active participants in the design process (Wakkary, 2021), contribute their unique physiological signals to shape the interactive experience. The experience is further formed and influenced by the technologies and materials used, and the situatedness of the environment. In transforming invisible plant signals into dynamic visualization, lies an intention to motivate reflection of interconnectedness and to instill a desire to interpret the signals in the fullness of time in line with the concept of slow technology (Hallnäs and Redström, 2001). Further in line with the idea of slow technology, the use of ambient visuals make individuals aware that the use of technology is necessary for the desired outcome (Hallnäs and Redström, 2001).

4.2.3 Technical implementation and challenges

Prototyping utilized Arduino (https://www.arduino.cc/), an open-source electronics platform based on easy to use hardware and software, to capture plant electrical signals. The Arduino was chosen for its reliability and proven success in previous projects. After lengthy exploration for instructions on how to "read" plant signals with Arduino a similar project was found to use a basic lie detector code (Cho *et al.*, 2015), which resulted in searching the internet for the appropriate code. Initially, an EMG device was used to connect with the plant but after its application caused damage to the leaves (see figure 5) the basic Arduino pins attached to the stem were used instead. In the serial monitor of the Arduino interface one can see the waves of the plant's electrical signals, reminiscent of graphs from an EKG, on the screen, see figure 6 and 7.

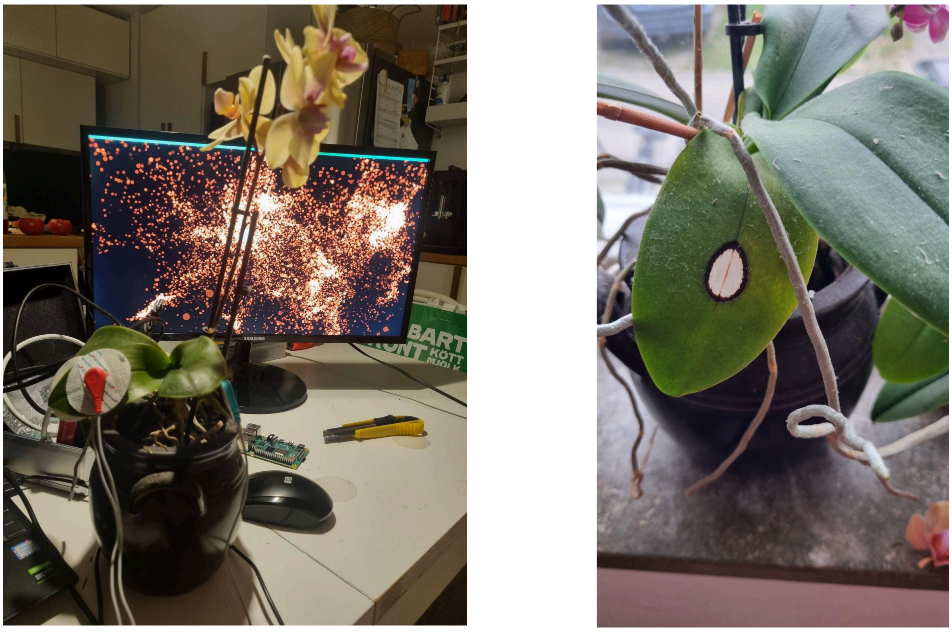

Figure 5. *Irrevocable damage done after using EMG device*

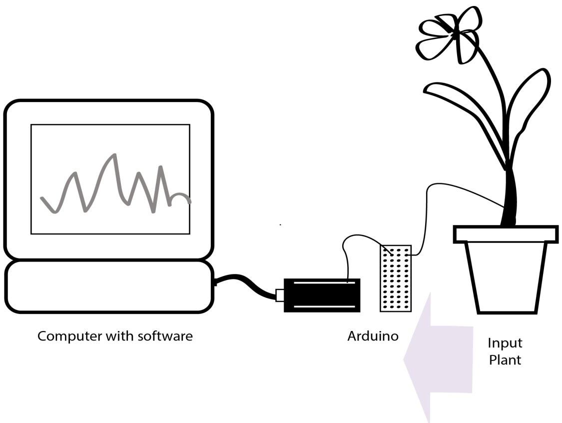

Figure 6. *Prototype setup*

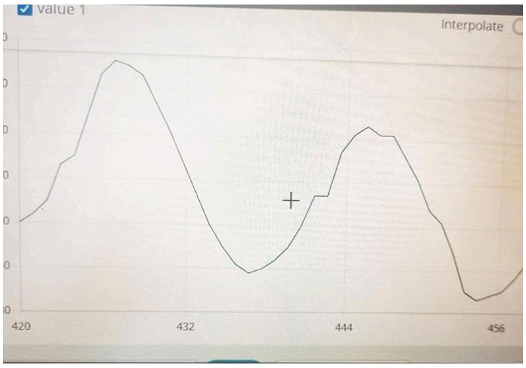

Figure 7. *Plant electrical graph shown in the Arduino serial monitor.*

To ensure that the final design not only captures the essence of the plant's responses but also provides an aesthetically engaging experience, technical challenges and refining the visual representation of plant data was addressed. After several sessions with POET Creator Custom Support and many more iterations learning to navigate the software, as well as bringing to attention a minor bug on their end, the solution to reading plant signals visualized by POET Creator arrived at its finalization. Using an Arduino ethernet shield and an ethernet switch hub, as well as adjusting the code appropriately, made it possible to finally import plant data to the downloaded software, see figure 8. The presented artifact consists of the following components:

- Digital pins to capture the plant's electrical signal.
- An Arduino board with an Ethernet shield to process and transmit the data.
- An Ethernet switch hub to facilitate the data transfer
- The POET Creator Beta software to visualize the data.
- Arduino software to code.
- Screen/ Projector to exhibit the visuals of the plant signals.

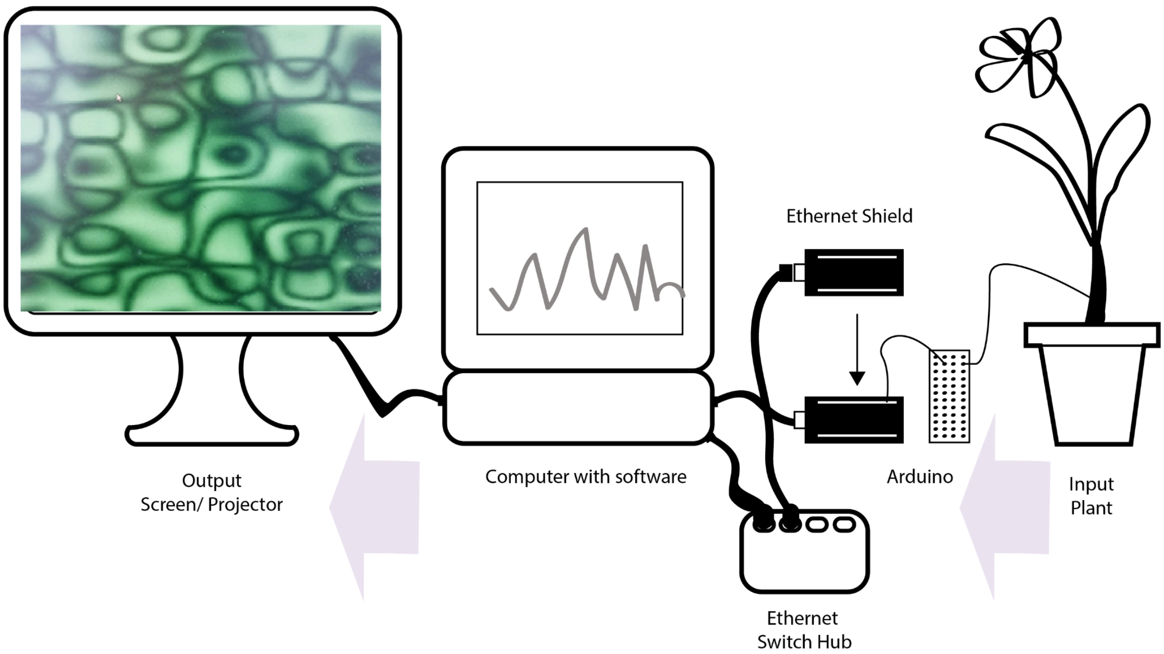

Figure 8. *Presented prototype setup*

There were significant challenges achieving the accurate representation of the plant signals to the software. Iterative testing of the code helped refine the visuals to accurately reflect the plant's electrical signals while being displayed in an aesthetically pleasing fashion. The artifact is designed to be exhibited as art with an underlying intent for passive interaction, where viewers observe the changing visuals and reflect on the plant's signals which are situated in the moment. The ambient lighting is intended to be part of the peripheral, allowing viewers to notice changes in their own time and cognitive inclination.

4.3 External design critique

A ***pilot exhibition*** took place in the Green House at the Botanical Garden in Lund using a projector showing a plant's electrical signals of one of their plants on display in the orangery, see figure 9. Figure 8 illustrates the schemata of the presented prototype installation for the pilot exhibition and the following interviews.

Figure 9. *At the Botanical Garden exhibiting a plant's electrical signal using a projector.*

After observing confusion from the audience, despite there being information available, a spontaneous presentation about the project ensued. This gathered more audience which resulted in display of interest, understanding, and appreciation for plants being expressed by the viewers. The pilot exhibition generated the first revision.

Revision 1: The audience needs initial general context. This feedback prompted forthcoming viewings to begin with a presentation before gathering qualitative data.

Before exposing the design concept to the following participants, it was essential to understand their existing relationship and awareness of plants. This initial check provides a baseline for evaluating how the installation might alter or enhance their perceptions. The interviews are conducted in the springtime when leaves and flowers are blossoming, which might have influenced participants' answers.

The participants' daily life has an effect on how much they notice plants. Some remark on their maintenance needs, such as watering, others are aware of their usefulness in supplying oxygen (P6, P10), and some make a point of talking to them just in case it matters to the plants (P5, P7, P9). Those walking or biking to school (P8, P11), or for recreational purposes find themselves outside (P4), mention noticing scents and seasonal changes. Generally, participants notice plants in terms of their color and foliage, and how it affects their mood and emotions, reporting feelings of calmness and less stress around plants. This aligns well with the result of previous research (Hall and Knuth, 2019b). Most participants state that the increasing greenery and blooms enhances their energy, as one participant expressed: *"When they're happy, I'm happy"* (P9). As to whether the participants think plants notice humans, the consensus seems to be that plants are not aware of humans as individuals, only as one of many external pressures to be noticed when it is, for example, harmed.

Participants were first introduced to the installation through a brief background presentation of the design concept, followed by a viewing. Their initial reactions provide valuable insights into the immediate impact of the artifact. Most impressions were marked by surprise and intrigue. The two moving visuals, shown alternately every minute, influenced by plant signals, were perceived positively as *"cool"* and captivating, and to some as "*messy"* and headache inducing. One participant even remarked: *"My initial thoughts were like just abstract art"* (P6). Highlighting the appeal and curiosity the installation generated, another participant expressed: *"Yeah, you know, you gave us these facts, but it is surprising that this is really the case, that it can be illustrated like this. I think it's really, really fascinating. And that surprises me. That it can be shown visually like this. I think it's really really cool."*(P7).

After letting it sink in that the visuals were illustrating plant status in real time, almost immediately, participants began to question the meaning behind the visuals, some inquiring about the possibility of clearer proof of the plant's influence over the visuals by moving the plant, harming a leaf, or screaming at it. They expressed a desire to understand the correlation between the plant's signals and the visual movements. As one participant exclaimed: *"I didn't expect to see this at all. So I had no expectations whatsoever. But this one surprises me. This one here…Because I also wondered what is actually being measured here and what's behind these different curves, and why is it going faster sometimes and slower sometimes? And what does the different colors mean? "* (P10 referring to Figure 3.). This curiosity led to frustration among some when the connection was not directly clear, with one articulating: *"I want to understand what I see. Or just accept it's beautiful and that's the purpose of it. If it says something, then I want to understand."* (P3). Suggestions offered ranged from that it would be beneficial if the visuals expressed specific plant needs, like water and sunlight, to displaying environmental information like weather and oxygen level.

Revision 2: To address these suggestions, future iterations of the artifact could include more explicit visual indicators of the plant's needs and environmental factors. Possibly in assigning certain colors to certain phenomena. Enhancing the visual feedback to make the plant's influence more apparent could improve user understanding and engagement.

One participant (P9) pointed out that we are different people and with different characteristics. Likening the interpretation of the visuals to a card trick, where one individual enjoys the show, another one dislikes being fooled, and some are curious as to how it's done. With that in mind, presenting the design concept in the context of art opens up the visuals to interpretation and individual meaning despite the fact that there is a correlation between the movement of the visuals to the plant's electrical signals. As one participant commented: *"And when you're as clueless as we are, you just enjoy it."* (P11) Noting also that: *" I guess if I would look at it for two hours I would get better at making connections, and start seeing."*

In respect to the somaesthetic responses of the participants, the moving visuals were meditative to most, instilling a sense of calmness and joy, with some participants likening the rhythms to breathing patterns (P8). The different visual patterns evoked varied emotional reactions, with most participants finding Pink Murmurations (Figure 4) to be more aesthetically pleasing to look at. Though the visual of Green Cell (Figure 3) compelled a participant to look away (P2), some preferred it, finding it soothing (P4, P7). Figure 3 was also the visual that most participants found to represent the plant more as its depiction reminded of cell structure. A couple of participants mentioned that for them adding sounds to the visual would enhance their experience of the design concept (P7, P10, P11).

Revision 3: There seems to be a need for different sensing to suit individual preferences. Adding sound or other sensory feedback could cater to varied tastes and enhance overall experience.

Since the visuals are designed to be unobtrusive it was essential to address this issue. The participants did not find the visuals distracting, but some mentioned being absorbed in a positive manner. One participant answered when asked if the visuals were distracting: *"No, no, no. I think it's very soothing." - "You know when you come home after, you know, perhaps a stressful day you can just take a break perhaps and monitor your plants and feel calmer whenever"* (P7). In reference to being part of the background, another participant suggested: *"This could be something that you put on in your TV instead of the fireplace. In the background, on the big screen, when you're having your afterwork or something… "* (P9). An aspect to consider, in regards to what aids the design concept from not being distracting or obtrusive, is illuminated by a participant's comment: *"Maybe if I, if we knew exactly what the movements meant. We would be more distracted by it because we would be like, oh, what's going on now? What's that? Ohh, I see that it."* (P11)

The influence of technology is self-evident in this study with several participants noting that without it the visualizations of plants would not be possible. Visualizing the electrical signals of plants seem to initiate a relationship with plants in an aspect that might have been missing before. One participant communicated: *"Well, without the technology, I wouldn't see and understand that I will have a visual concept of what's going on inside the plants with the pulse of the electricity and the signals inside the plant. So that's baffling to me and very exciting that I get to see that. Something that I've never known. Or never understood before, that we can see and make a visual representation of signals inside the plant."* (P6). Others phrased it similarly with another participant establishing: *"It makes it more concrete. I haven't thought of this really before. So it makes you conscious of this bond."* (P7). Whereas one participant had reservations: *"I would be stressed. It seems to be too stressful."*(P1).

The technological aspect naturally leads to contemplating other practical and futuristic applications that can be utilized. Participants suggested various possibilities, where some saw potential in using the technology for meditative purposes to reduce stress, and one participant mentioned, slightly humorously, that it might even signal when war is coming. Most of them were aware of the human-centricity in their implementation, suggesting, as mentioned earlier, visuals to communicate environmental conditions, including weather and maintenance needs in house plants, gardens, and greenhouses. Some participants, though, did propose using technology to monitor and protect nature. Suggesting that visualizing plant signals might make people hesitant to cut down trees, potentially preventing actions like those recently seen in the news in Lund where trees were cut down for amusement (*Uppemot 100 träd nersågade i Kunskapsparken i Lund*, 2023). This highlights the potential of the technology to engage in connection with nature and encourage a more responsible environmental behavior.

None of the participants had any ethical concerns in how the technology was used in this study, with a caveat in regards to understanding: *"How alive they are."* (P8), but there were concerns regarding other facets: *"I feel sorry for the vegetarians."* (P1). A concern that was quickly followed by an assurance that plants are meant to be eaten (Fox, 2023), being an understandable consternation.

When asked if the installation offered new ways of perceiving plants that had not been considered before, all eleven participants affirmed, commenting: *"I think this installation made me realize that plants have more feelings and they are more sensitive than I thought before."* (P3), *"Yes and that plants have their own life."* (P2), *"Yeah, it really adds another dimension to it that we didn't really know before."* (P11), *"I think this is mind boggling. And I'm really pleased that I've been given the chance to see it."* (P7), *"I don't think that most people realize that plants are actually alive and communicating, because it's kind of hard to imagine something that doesn't seemingly move can be alive, really. To be able to communicate as well and be able to have a tool to be able to visualize it."* (P8), *"It's a brand new way to look at plants."* (P4). Though a few were cynical about the societal impacts of the design concept, alluding to the characteristics of humans, many mentioned the heightened awareness of plant life. Participants advocated for the impact the concept would have as an educational purpose both in learning about plants and in people being aware of their influence in our environment and world.

4.4 Concept revisited and contextualization

The initial concept of this research is to create an interactive installation that visualizes the electrical signals of plants presented in the context of art. The aim is not only to captivate users with an aesthetically pleasing experience but also to provoke deeper reflections on the often overlooked sensory capabilities of plants, their autonomous roles within our ecosystem, and our relation to both plant and environment. By bridging the gap between art and science, the installation intends to contribute to a more profound understanding of plant life, challenging human centric perspectives and encouraging viewers to notice their surroundings and consider the implication of plant autonomy in our habitat.

The feedback from participants revealed that while the installation successfully captured attention and evoked curiosity, there are areas that require refinement to enhance user engagement and comprehension. Specifically, participants expressed a desire for more explicit visual indicators and additional sensory feedback, suggesting that clarity and intuitiveness of the visualization could be improved. These insights prompted a critical reassessment of the installation's design, leading to targeted revisions aimed at aligning the project's outcomes more closely with its conceptual goals, see figure 10.

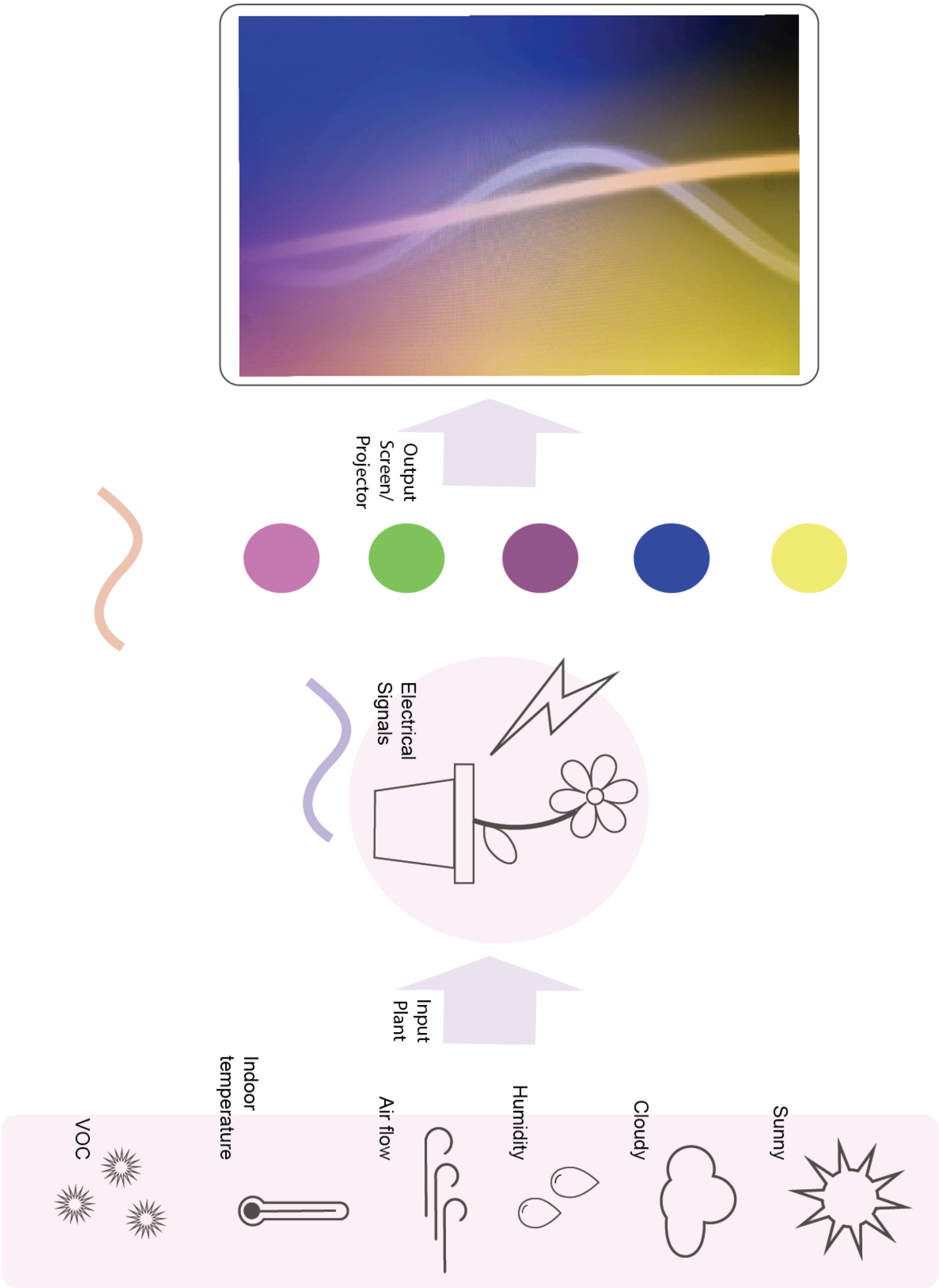

Figure 10. *Revised artifact using different color/shapes to represent different inputs*

Adding explicit visual indicators to represent specific environmental factors is beneficial. The initial intent of making the visuals indeterminate was to adhere to the principles of slow technology, allowing contemplation over time to reveal interpretive patterns in the visuals. The participants feedback to assign certain color and/or shapes to input of data from phenomena such as moisture, sunlight, and oxygen levels can make the plant's influence on the visuals more apparent. This is especially applicable within the aesthetics of ambient communication, and most of all it would not deter from the slow tech experience. Instead, it enhances it by offering different layers of perception. This revision maintains the contemplative nature of slow technology while also making the installation more accessible for educational purposes, where quicker comprehension of the visuals are favorable. Furthermore, integrating the choice of sound or other sensory feedback can cater to individual preferences and enhance their overall experience.

<u>Revisiting the theoretical frameworks</u> of somaesthetic philosophy, posthumanism, and slow technology, it is evident that the installation needs a balance between aesthetic appeal with informative value. Despite it being displayed as an art form, it is art visualizing actual data, which needs to be effectively communicated. The role of sensory perception and embodied experience in human interaction with technology aligns with somaesthetic principles. As do the installation's meditative qualities that allow users to engage with the plant signals on a deeper, more embodied level. Visualizing plant signals not only acknowledges plant agency and raises awareness of plant autonomy, but also challenges traditional human centered perspectives by placing plants as active participants in the technological interaction. It is the installation's contribution to the posthumanist discourse and therefore the plant's status and sensing abilities need to be clearer in its communication. Slow technology's emphasis on time, reflection, and long-term interaction allows for layered understanding over time. By visualizing the plant's electrical signals, making the invisible and all it entails visible, the project potentially increases engagement in environmental issues and fosters more sustainable interactions with nature. Ambient lighting communication can convey information in a way that is unobtrusive yet engaging, allowing users to sense changes in their surroundings through subtle visual cues, amplifying the environment, making it more responsive and interactive (Beale, 2007; Davis *et al.*, 2017). It can be used to make users aware of the existence of time rather than the perception of it. By slowly

changing color or intensity over extended periods it creates opportunities for reflection and contemplation within the technology itself (Davis *et al.*, 2017). Ambient lighting can create a deeper awareness of both the technology and the surroundings, encouraging viewers to reflect on the interaction.

The revisions and feedback obtained from the project contribute to new theoretical understandings in several ways. Beginning with assigning color to contribute to the integration of more explicit visual indicators and sensory feedback, enhances the interpretability and accessibility of the data, making it easier for viewers to connect with the information presented and still uphold an element of reflection (Beale, 2007). This challenges the traditional somaesthetic approach, which often emphasizes subtlety and embodied perception over clarity but aligns more with somaesthetic appreciation, where sensory feedback can enhance the experience (Höök *et al.*, 2016). In particular clearer visual indicators contribute to a more adaptable embodied application of the somaesthetic experience of plants in this research. Compatible with posthumanist theory, this application also offers a tangible example of how technology can mediate a more equitable relationship between humans and nonhumans. Having plants as co-creators in the design process (Wakkary, 2020), where their signals directly influence the visuals, introduces a new dimension of agency that extends beyond passive recognition of plant life to collaboration. This aligns with past research in posthumanism, which advocates for recognizing the significance and interrelatedness of nonhuman entities in our ecosystem (Bakke, 2014).

Designing technology that promotes reflection and observation of interrelatedness lies at the core of this research. This project reveals that the principles of slow technology, which emphasize contemplation and gradual understanding is just as relevant despite a need for immediacy. The presence of time still exists and the awareness of technology is enhanced by the lighting's influence (Hallnäs and Redström, 2001; Case, 2016).

The artifacts ability to visually represent scientific data within an artistic framework opens up new avenues for interdisciplinary research. This contributes to the body of work on the intersection of art, science, and technology. It demonstrates artistic installation can serve as a tool for scientific communication, making complex data accessible and engaging while also encouraging reflection and contemplation, and creating experiences that educate and inspire viewers to reflect on their role and relationship with the botanical world.

5. DISCUSSION

5.1 Somaesthetic signals: Exploration of plant perception through art and technology

The primary objective of this study was to explore how visualizing a plant's electrical signal could promote human awareness of plant perception, autonomy, and their interconnectedness with human beings in a shared ecosystem. Specifically, the research aimed to investigate: *How can digital technology facilitate human reflection on plants' existence within a world that is more-than-human?*

The result of this study is the creation of an interactive installation that visualizes the real-time electrical signals of plants. This research contributes to new theoretical understandings by demonstrating how ambient communication technology can be adapted for ecological data, thereby expanding the scope of digital design. Through the lens of art, science, and technology it transforms this invisible data into an artistic and reflective sensory experience that encourages emotional and intellectual connections between humans and nature.

The integration of somaesthetic philosophy, posthumanism, calm and slow technology, contribute to a cohesive, interrelated design framework. Somaesthetic principles provide a sensory-rich, embodied experience that enhances the awareness of plant life, in ways that stimulate mindfulness and reflection (Shusterman, 2023). Anthropomorphism and imitation concepts were introduced to deepen the exploration of how humans can relate to nonhuman entities (Airenti, 2018). The philosophy of posthumanism supports inclusiveness in the perspective on environmental interconnectedness, acknowledging plants as active participants significant in shaping the world (Bakke, 2014; Ferrando, 2016). In addition the practice of *designing-with* requires designers to rethink their relationships with nonhuman entities and actively engage with them as co-creators and collaborators (Wakkary, 2021).

Furthermore the influence of calm and slow technology is evident in the installation's ability to promote reflective and sustained engagement amplifying space and the presence of time (Hallnäs and Redström, 2001; Case, 2016). Observing the ambient lighting whilst applying Anna Tsing's *noticing*, can give rise to making connections with the environment and its influence on the different species' cohabiting it (Verinis, 2016). The knowledge acquired in turn affects the *ecological self* in an understanding that humans are equal participants within a larger ecological system (DelSesto, 2020).

The unique approach within this research is the integration of an ambient communication software to a plant. Applying a data generator to read and visualize plant electrical signals introduces a novel intersection between digital media and natural biological processes. This innovative use of existing technology to interpret plant data as it unfolds is distinct from static or preprogrammed installations. It differentiates this project from other research that may focus solely on traditional environment data or more simplistic visual representation of plant signals.

In summary, this study contributes to state-of-the-art approaches by leveraging digital tools, such as POET Creator and Arduino, to capture and visualize real-time plant signals, thus advancing the use of ambient technology in ecological contexts. Unlike prior application that interpret primarily environmental factors, such as weather or atmospheric conditions, this project adapts these technologies specifically to plant signal processing, extending ambient visualization into the more-than-human realm. Theoretically, the study also builds upon established concepts like the *ecological self* (DelSesto, 2020) and posthumanist perspectives (Bakke, 2014; Ferrando, 2016) which call for a rethinking of human relationships with non human entities. In this regard, the project repositions plants as active participants within HCI, where their agency contributes to a richer understanding of shared ecosystems. Combining the aforementioned theories, somaesthetics, and ambient technology aligns this study with current design practices and pushes the boundaries toward a new mode of reflective engagement with pant life and awareness of a more-than-human perspective.

5.2 Implications for practice

The design artifact has several potential implications for individuals and society. On an individual level the artifact introduces a novel interaction with plants and promotes a reflective and meditative engagement. By visualizing plant electrical signals the installation fosters mindfulness and a greater appreciation for the complexity of plant life. The portrayals, if aesthetically pleasing, can reduce stress and promote relaxation, offering mental rest and introspection. In addition, the dynamic visuals provide artistic experiences and individual interpretation about plant status and the surroundings. However, the abstract nature of the visualization, since it depicts current data outside artistic context, leads to confusion or frustration among users who struggle to understand the correlation between the plant signals and the visuals. Without clear indicators or education context, users may feel disconnected or skeptical about the installation's purpose and accuracy. This might detract from the more direct, unmediated experiences with the natural world, potentially causing technological dependence to connect with nature.

The societal implications are that the artifact supports educational initiatives by making complex plant processes visible and understandable, raising environmental awareness. It can inspire sustainable practices and a more holistic view of the relationship between humans, technology, and plants. The project interconnects technology with nature by integrating digital design with natural processes, motivating interdisciplinary collaboration that fosters scientific knowledge and innovation in interaction. It also adds to cultural experiences and shapes attitudes towards the environment given an opportunity to deepen understanding and appreciation of the natural world and humans' place within it.

The educational value of the installation can be significant, helping people understand the complexities of plant life and their responses to environmental stimuli. This is consistent with participants' suggestions for practical applications in the stewardship of nature, as well as educational uses in schools and public spaces.

5.3 Methodological considerations

A key strength of the concept driven design research method is its ability to generate novel insights through design as a form of inquiry. It is an interdisciplinary approach bringing together diverse perspectives and expertise allowing for multiple perspectives to inform both the design and its evaluation. The iterative design process, which includes participant feedback, strengthens the viewer-centered approach in the revisions, demonstrating the potential modifications in the design.

Concept driven design research also poses several challenges. One of the primary methodological concerns is the ecological validity of the research. This refers to how well the experimental conditions and findings translate to real-world settings. In this project a working prototype was presented. Still, the results may not fully represent how participants would interact with the design in diverse, everyday contexts. Additionally, the abstract and artistic nature of the visualizations can lead to varying interpretations among participants resulting in confusion, as well as introducing subjectivity in the evaluation of a design artifact and/or concept's success.

The grounds for focusing on a visual outcome, such as ambient lighting, stems from the fact that humans have evolved to rely on sight as a primary means of interpreting and interacting with the world. Given this deep-rooted reliance on visual perception, translating the invisible signals of plants into a visual form makes them more intuitively accessible, bridging the gap between plant communication and human understanding. Although the intention is for viewers to draw their own conclusions after observing patterns over time, the exclusive focus on real-time data may have limited the depth of insights into longer-term trends or delayed responses in plant behavior, which could provide a more comprehensive understanding of plant communication and adaptability.

Likewise, the process of generating and selecting concepts for further exploration can be highly subjective and potentially impacting the reliability of the research. Concept driven interaction design relies on a researcher's theoretical reasoning, meaning that researcher bias and personal interpretation can influence both the design process and the outcome. In addition, replication of the study might be difficult as another researcher may interpret and implement the same theoretical framework differently, which could potentially impact reliability.

Furthermore, the reliance on specific technological tools, such as POET Creator software and the Arduino hardware used for plant signal processing, might be limiting in terms of accessibility to the tools and replicability. The technological complexity might restrain the broader application of this method in contexts where tools are unavailable or difficult to implement. This also means that the research could become bound to specific technologies, which may result in technological determinism, where technology shapes the outcome more than the theoretical framework does. Nevertheless, the use of Arduino in this project was chosen for its simplicity and accessibility, making it a practical tool for plant signal processing. However, this choice may have also constrained the project by limiting the potential for more advanced technologies that could offer greater accuracy in interpreting electrical signals. More sophisticated technology, such as sensors capable of detecting VOCs - a primary means of plant communication and just as largely undetectable to humans - could provide a richer and more nuanced insight into plant interactions.

Other factors that might affect the results include the limited sample size of eleven participants and the lack of diversity in participant demographics as they were predominantly middle-aged and older adults with similar experience of localized plants and nature, as well as gardening habits. Perhaps broader conclusions could be drawn from a more diversified population as regards to age and knowledge of - or lack of - local vegetation.

Moreover, the practical insights that are necessary to determine this study's result require a longer period of time to make an accepted assessment of the outcome. The evaluation of the concept's effectiveness and impact on participants behavior is restricted to the duration of the semi-structured interviews. Nonetheless, the goal of this study has been to expand on the theoretical comprehension and not as much on the practical aspect, which relies more on future research to accomplish.

5.4 Future research

Future research could explore expanding the range of sensory feedback beyond visual indicators, such as integrating auditory or tactile elements to create a more multi-sensory experience. Investigating differences in plant electrical signal patterns from one another can also provide insight into the diversity of plant cognition and communication. Exploring how environmental factors, for instance light, temperature, and humidity, influence plant signals can increase the accuracy and relevance of the visualizations. Further gaining insight in plant experience and what they perceive in the world, facilitating stewardship as well as interaction. If meaning is successfully extrapolated from electrical signals then further uses might be seen to extend to other nonhumans and humans, as a method to gain understanding of feelings or intent.

Other important areas for future research is the application of this technology in various contexts, such as urban environments, educational settings, and public installations. Examining the long-term effects of such installations on people's environmental awareness and behavior can provide valuable data on the impact of interactive technologies on sustainability practices. Collaborating with experts in plant biology, environmental science, and digital design can further refine the methodology and expand the potential applications in an innovative approach to human-plant interaction.

6. CONCLUSIONS

The cumulative contribution of this thesis is the exploration of more-than-human interaction through the lens of art, technology, and philosophy, offering a design concept that visualizes plant electrical signals to invite deeper reflection on the interconnectedness between humans and nonhuman entities cohabiting a shared ecosystem. Incorporating theoretical frameworks such as somaesthetics, posthumanism, calm and slow technology, emphasizes reflection and sensory perception through ambient technology. By combining an ambient lighting software to plant data, this thesis presents a viable approach to existing solutions in the field of PPI. Participants responded positively to the design artifact, noting its ability to provoke curiosity and engagement in the awareness of plant agency and their role as collaborators. Due to the ambiguousness of the ambient communication refinements were suggested to enhance clarity and accessibility. As much as the project focuses on bringing to light the autonomy of plants, it equally calls attention to humans' role and entanglements with nonhuman entities and their shared environment.

Future refinements and application hold promise for enhancing environmental education and promoting sustainable practices, ultimately contributing to a successful cohabitation in a more-than-human world.

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APPENDIX

Welcome [participant],

This study seeks to redefine and explore interactions across species boundaries, emphasizing mutual influence, relationality, and cohabitation in a shared ecosystem. The overarching goal of this research is to bridge the perceptible divide humans have of plants, using technology as a mediator to translate plant processes into a human-readable format.

The design concept does not seek to dictate how visitors should interpret the interaction between the ambient lighting and plant signals. Instead, it aims to make the invisible—plant electrical activity—visible in a way that invites personal interpretation, aware that the plant is reacting to an environment otherwise invisible to humans. This design choice is deeply rooted in somaesthetic appreciation and posthumanist philosophies, which value the individual's embodied experience as a key to understanding plants as well as acknowledge the agency of nonhumans.

The design concept is an interactive art installation that uses ambient lighting controlled by the electrical signals of plants, encouraging viewers to engage with and reflect on the invisible interactions in the shared spaces between humans and the botanical world.

Your participation in this interview is entirely voluntary, and you reserve the right to withdraw at any time. Any information provided during the interview will be treated with strict confidentiality and will be used solely for the purpose of this research study. To ensure the protection of your privacy, all data collected will undergo a process of anonymization.

With kind regards,
Rani Samuelsson

Demographics

- Age
- Gender
    - Male
    - Female
    - Non-binary
    - Do not wish to specify
- Education
    - Elementary school
    - Upper secondary school
    - University diploma
    - Bachelor's degree
    - Master's degree
    - Doctoral degree
- Do you currently own a plant
    - Yes
        - If yes, how many?
    - No

Before the installation

1. How are you aware of plants and nature in your day-to-day life?
2. How do noticing plants make you feel (physically and mentally)?
3. What do you notice most about them?
4. How do you think plants are aware of us?

Short presentation of the installation with a powerpoint.

About the installation

1. What are your first impressions? Can you describe what you see and feel (in your body and mood) when interacting with the installation?
2. Can you see the changes in the ambient lighting?
   a. If yes, how do you intuitively interpret these changes?
3. Was there anything about the installation that surprised you?
4. How do you think the technology used in this installation contributed to your experience?
5. How did the design of the installation influence your engagement with it?
6. Do you have any ethical concerns about using technology to "read" plants?

After installation / Design concept

Overall

1. What elements of the design were most effective in engaging you with the installation? Are there some aspects that can be improved?
2. Did this installation offer a new way of "seeing" or thinking about plants that you had not considered before?
3. How do you think this installation challenges conventional views of plant communication and interaction?
4. Did the installation change your emotional relationship with the plants? How?
5. In what ways has this experience influenced your thoughts about the potential of technology to enhance our relationship with plants?

Practical application

1. If you could monitor your favorite plants' electrical signals from a distance (such as from work) would you and how would it make you feel?
2. If you could see your plants' (at home) electrical signals, do you think you would feel more connected with it?
3. If you could see electrical signals from trees or plants in parks, how would it affect your experience?

Future application

1. Can you imagine how this technology can be used in the future? Which scenarios come to mind?
2. What are the potential societal impacts of such technologies becoming commonplace in our interactions with natural environments?