Enhancing Awareness of Urban Greenbelts through the Integration of Soft Robots and Cultural Storytelling:

A More-Than-Human Design Approach

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Table of Contents

Abstract

Despite constituting more than eighty percent of Earth's biomass, plants typically escape our attention. With recent development of post-humanism and environmentalism, more actions are taken to promote the importance of nature, calling for public awareness. Simultaneously, the field of soft robotics, rapidly progressing and drawing inspiration from nature, especially plants, demonstrates considerable potential as an intermediary for human-plant communication. To enhance public understanding of plant-related information, this study employs a dual approach, combining Research for Design (RfD) and Research through Design (RtD). The research initially explores More-Than-Human design strategies, investigating how plant information is disseminated by scientists, botanists, and researchers through interaction design. Through expert interviews, field observations, and case analyses, ethnographic codes are identified, revealing diverse communication methods for plant information and underscoring a lack of attention to the cultural aspect of plants. Consequently, this thesis introduces an interactive prototype integrating soft robots and audio cultural narratives to communicate information about Elm trees. To test the prototype, fifteen semi-structured user interviews across three distinct groups were conducted, with one group listening to the cultural narratives, one interacting with soft robots and an Elm tree, and one experiencing both. Results reveal heightened awareness of urban green belt trees in most cases. In a short incomplete conclusion, the result shows that the integration of soft robots and cultural storytelling resulted in an increased awareness for most participants. More detailed results are explained in the user evaluation section.

1. Overview

1.1. Introduction

1.2. Research Methods

1.1. Introduction

With the progressive integration of digital technologies into our everyday lives and the enduring emphasis on human-centric societal advancement, two phenomena become apparent upon observation. Firstly, there is a disconnect between our daily professional endeavors and the natural surroundings. Secondly, there is a deceptive perception of complete mastery of digital tools facilitated by technological advancements. Alongside these two distinct aspects, there is a growing need to envision alternative relationships between humans, technology, and nature.

In recent years, the integration of microorganisms or plants within the framework of human-computer interaction has been the subject of many research studies. These studies highlight the potential for fostering a more sustainable coexistence between humans and non-human entities in the future (Kim et al., 2023; Pataranutaporn et al., 2020; Chang et al., 2022). While many examples explore the integration of living organisms and technological applications, little attention has been paid to communicating the deeper biological and social connections between humans and other organisms. Considering that humans and plants are two different species with an evolutionary connection dating back to the distant past, it would be both interesting and meaningful to explore such connections.

In this thesis, I propose to draw inspiration from relevant technologies to facilitate human-plant interaction that enhances human awareness of plants. In this case, the concept of 'More-Than-Human,' with its core in challenging human exceptionalism and promoting a holistic view of the interconnectedness of all elements, is particularly valuable (Abram, 2017; Giaccardi & Redström, 2020). As a fundamental philosophy that promotes a balanced human-plant interaction, it emphasizes the importance of considering the wider ecological context and recognizing the agency of non-human beings.

Because the broadness of the More-Than-Human philosophy and the human plant interaction field, the research question came only at the end of the research process. First, this thesis used the methodology of research for design (RfD) to define an appropriate research question. This consists of the theoretical analysis of More-Than-Human (MTH) philosophy and relevant design strategies (chapter 2), literature review of human plant interaction (HPI) and interactive soft robot cases (chapter 3), and the practice of the art of noticing (chapter 4). Thereafter, the methodology of research through design (RtD) is taken to answer the research question, which consists of prototype building and user tests (chapter 6 and 7). For readers who are not interested in the process through which I define the research question, please feel free to skip the first four chapters.

Overall, this thesis seeks to address the disconnection between humans and nature, challenge human exceptionalism, and foster a balanced and meaningful human-plant relationship. Building upon previous examples of human-plant interaction and drawing inspiration from the philosophical concept of the MTH, this thesis aims to develop an interactive installation that serves as a conduit for communication between humans and plants. This will be achieved by the pneumatic technology that utilizes the transformative potential of soft materials. The final prototype endeavors to showcase the profound interconnection between humans and plants while elucidating the inherent agencies intertwined among humans, technology, and plants.

1.2. Research Methods

Literature review

A literature review typically takes on one of two forms. Either as a background section that lays the foundation for and supports the proposed study, justifying its value and identifying information gaps that are addressed, or as a component of the study itself, presenting research findings without collecting or analyzing primary data (Francis et al., 2019). In this thesis, the literature review fulfills the first role by establishing a good understanding of More-Than-Human philosophy, Umwelt, and experience design, while also showcasing the current research trends in integrating bio-organisms in HCI.

The art of noticing: expert interviews and field observation

To understand how people interact with plants in their daily lives and the ways plant knowledge is communicated to the public, expert interviews and field observations in Hortus Botanicus Amsterdam and Leiden are conducted to gather primary information. These activities are conducted following the practice of the art of noticing in more than human design methods. The collected data will later used for inductive thematic analysis to search for behavioral patterns and design opportunities.

Thematic analysis

To identify patterns and themes, I will apply thematic analysis following Braun and Clarke's (2006) framework. By familiarizing myself with the collected data and generating codes and themes, I will develop a thematic map to aid in constructing an interactive experience concept.

Thing ethnography

Thing ethnography is a More-Than-Human design technique that comes from the viewpoint of a physical object. This approach aids in challenging anthropocentric presumptions and brings to light new relationships that exist between people and non-human objects (Giaccardi et al., 2016). An essential technique employed in thing ethnography involves the utilization of sensors or cameras to gather inconspicuous primary data during individuals' everyday activities. However, limited by the necessary timeframe for conducting thorough firsthand thing ethnography, this thesis will mostly utilize secondary data acquired through desk research. Thing ethnography will be integrated into the research process as a reflective guide and conceptual inspiration.

Material Driven Design: material tinkering and experience characterization map

In this study, the texture and shape of the soft material play a significant role in the interaction process. To achieve a better interactive experience with the final prototype, this thesis will adopt the material tinkering process and experience characterization map in the Material Driven Design method proposed by Elvin et al. (2015) to find out how to properly integrate the chosen material into the final prototype.

2. Theoretical Background

2.1. More-Than-Human Concept: Philosophical Grounding and Design Strategies

2.2. Understand Experience: Human and Plant Umwelt

2.1. More-Than-Human Concept: Philosophical Grounding and Design Strategies

As the grounding concept for this thesis, the More-Than-Human concept provides both philosophical grounding and the values to pursue this research. To facilitate a better grasp of the main content, this section offers a brief introduction to the More-Than-Human concept and outlines the relevant design strategies that will be applied later in the study.

2.1.1 Philosophical grounding: brief history and standpoint

From Medieval times to the Renaissance era, western philosophy shifted its emphasis away from theological and deductive reasoning and moved towards a human-centric view that focuses on the value and agency of individuals and empirical observation while rejecting dogmatic learning. This shift has resulted in progress toward individual freedom and dignity, as well as cultural and scientific advancements. The human-centric movement, which advocates for diversity and the enhancement of human well-being, has undeniably brought about significant merits. Yet, along with them, also nonnegligible problems. Many scholars pointed out that this emphasis on human individuals can lead to an unduly anthropocentric worldview that fails to recognise the importance and agency of collective responsibility (Heidegger et al., 2019; Latour, 2018; OCLC, 2017). This can be seen in two main areas. One concern is climate change brought about by a large number of human activities and its relevant consequences, such as the loss of biodiversity and natural resources. The other concern is the lagging adaptation of society to increasingly connected IoT (Internet of Things) and AI technologies (Whiting, 2022; Giaccardi & Redström, 2020). These developments emphasizes the need for collective responsibility for the world and its people.

Consequently, two comparable viewpoints have gained popularity since the mid-20th century. Both posthumanism and the More-Than-Human concept place an emphasis on the interconnectivity of all entities, including humans and non-human beings, as well as the necessity of ethical thought and care for the natural environment. With many overlapping concepts, they provide great insights into decentralising the anthropocentric belief, and are often used interchangeably among scholars. Between the two, posthumanism was fundamentally built on humanism with mostly critical theories and has an alternative meaning closely related to cyberpunk and sci-fi fiction. The More-Than-Human concept thrives recent years as a post-posthumanistic ideology and focuses on the entanglement of universal elements, with available practices. Here, in this article I will only apply the More-Than-Human (MTH) concept as the theoretical foundation to maintain practicality and clarity (Forlano, 2017).

Before the MTH perspective is widely used as a term in academia, various indigenous and non-Western cultures have long acknowledged the interconnectedness of all entities, including both human and non-human beings (Abram, 2017). On a material level, Barad (2012) explains the sensation of intra-active self-touching (cellular-interaction within us) through a simplified interpretation of the relationship between electrons and virtual photons. Such a theory supports the idea that humans themselves are not separate entities but are constantly under the influence of other living and non-living beings that exist alongside and within us.

Overall, the discussions and practices surrounding the MTH philosophy can be found in four main sections. Research in fundamental sciences reveals the invisible parts of the world that deviate from the unique identification of humans as active world constructors (Barad, 2012). Such changes continuously influence societal understanding of human and physical ecology, culture and history, as well as design and technology. These four sections interact with each other, constantly reformulating our mental understanding of the world, the corresponding technological developments and behaviours. With my limited understanding, I hereby identify the five aspects acknowledged by the MTH perspective: 1) the entangled connectedness of human and non-human (both living and non-living) entities; 2) different agencies derive from the interaction of these entities; 3) the diverse and different knowledge and experience form of different humans and non-humans; 4) Sustainable and ethical value that goes beyond temporary fixated needs and linear progress; 5) The limitation and incompleteness of western-centered storytelling and geographical division (Barad, 2003, 2007; OCLC, 2017; Latour, 2018).

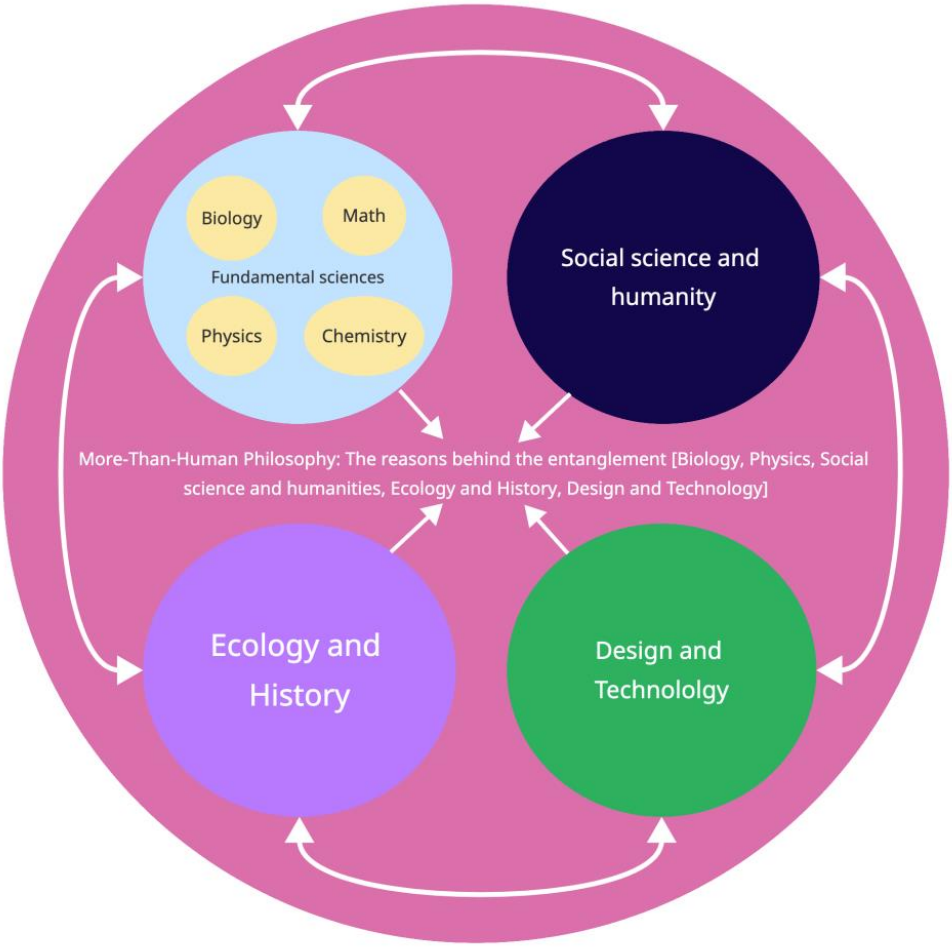

Figure 1. More-Than-Human way of thinking

Here, it is worth noting that the MTH perspective is not a rigid theory, but rather a framework for distinguishing between explorative, inclusive research and traditional methods that tend to be fixated on linear improvement (Wright, 2014). It is a malleable concept that pushes the boundaries of traditional anthropocentric humanism, with the goal of continuously shaping the notion of humans along with active curiosity driven exploration in a world full of entangled fields. Due to its broad coverage in various fields, I hereby provide an incomplete taxonomy regarding MTH practices that I have encountered in different fields. With the inclusion of figure 1, I hope to help future researchers who are interested in but overwhelmed by the broadness of the MTH concept to navigate towards their area of interest in an easier manner. Considering the scope and time limitations of the thesis, the subsequent content will only address the first three perspectives that I mentioned on the previous page.

2.1.2 More-Than-Human design strategy

Design, as a practice closely connected to human activity and the ever-changing environment, occupies an indispensable position in creating relationships through various perspectives and structures. With the examples shown by Laura Forlano (2017), whether it is the reformation of chicken farms to provide a better life experience for farmed chickens or the controversy surrounding CRISPR/Cas9 gene editing technology, we have entered an era where humans need to confront the consequences of past human-centered design and become more aware of the potential risks that may accompany such designs. Although many social theories have been trying to decenter the human by pointing out the butterfly-effect-like relation between iterative changes in material and behavioural changes and the larger scale of cultural change, design is still largely framed within the scope of designing for human needs (Forlano, 2017).

This long human-centered development of design heritage and the gap in the design space for all the rest of the non-human stakeholders suggest the need for everyday designers and professional designers to think beyond the capitalist economic model, which perceives consumers as the sole stakeholders. As the entanglement between non-humans and humans has already been extensively explained in the previous section, to maintain clarity, I will refrain from introducing further social theories. For readers who are interested in actor-network theory, object-oriented ontology, non-representational theory, and transhumanism, I recommend referring to 'Posthumanism and Design' by Laura Forlano (2017). Instead, I would like to provide some examples of MTH designs with valuable strategies from which this thesis can draw references.

2.1.2.1 Noticing as a complementary technique of design efforts

The 'art of noticing' is a method proposed by Anna Tsing to call for attention to details beyond the scope of progressive development. It aims to cultivate an alternative understanding of the problem space by making connections with diverse actors, and is often suggested as a strategy for broadening perspectives in technological intervention (Liu et al., 2019). Previous techniques used by design researchers include close reading, developing embodied knowledge through walking, ethnographic participation, etc. (Ibid.). To bring more organised methodological principles and apply noticing as a strategy for getting closer to the design focus, Liu et al. implemented a series of activities in a one-day workshop to help researchers develop their own unique way of noticing. These activities are summarised as follows: developing a mental map through reading, presenting, discussing, and building mind maps; going on a walking probe that focuses on the research topic; documenting with audio recordings, photos, feelings, and bodily reactions, etc.

2.1.2.2 Taking a thing's perspective: Thing ethnography

Taking the perspective of a material object is a way to help look beyond human needs. Although not specified in thing ethnography design studies, I found the reflective questions proposed by Forlano (2017) inspiring during the conceptualizing stage. To bring traditional human-centered thoughts out of the routine thinking frame, she suggests asking the following questions:

"*1) Who or what— human/nonhuman, human/animal, individual/organizational/network — are the user(s), and for whom or what should the design be desirable? 2) How, and in what ways—competitively/collaboratively, hierarchically/horizontally — are capabilities, agency, and power distributed across human, machines, and natural systems? 3) What new knowledge(s), questions, stakeholders, and partnerships are needed in order to adequately design for this problem? 4) How are ethics, values, and responsibilities reflected and embedded throughout the design process?"*

For practical techniques in executing thing ethnography, Elisa (2020) suggests the strategy of MTH design partnership to cooperate with things in our life to form a better understanding of our day to day behaviors. This proposal is accompanied by three MTH case analysis, with each applying a different kind of MTH design partnership. One of the examples is the case of designing Taiwanese Smart Mobility.

In this instance, thing ethnography is utilized to comprehend the often-overlooked relationship between scooters and their human owners. To capture daily activities from the scooter's perspective, the research group employs a camera attached to the scooter, capturing time-lapse photos. Trained actors then review this recorded data, performing it for designers to illuminate the daily experiences witnessed by the scooter. This method enables designers to identify subtle behaviors among scooter riders that might escape conventional observation, thus facilitating the development of innovative functionalities beyond the traditional transportation paradigm.

Thing ethnography, in the design context, leverages technology to unveil moments typically imperceptible or disregarded by designers. Which empowers designers to perceive phenomena from a unique vantage point, fostering a nuanced understanding of user behavior and enabling the creation of novel design features.

2.1.2.3 Material tinkering as an inspirational approach in design

Over time, materials have evolved from being merely passive elements that designers use to fulfil functional needs. They have transitioned into active components within the design process, playing a pivotal role in shaping new ideas and ultimately influencing the final product (Zhou et al., 2022). Materials, as tangible media, have the remarkable ability to serve as carriers of information. Each material possesses the potential to convey distinct emotional meanings and behavioural cues when they interact with the environment and other entities. Understanding the material and allowing it to yield unexpected results could be particularly beneficial in the design process.

Material Driven Design (MDD) is a methodology proposed by Karana et al. to explore material possibilities beyond the scope of their technical characteristics (2015). The method start with understanding the material itself before coming into a vision for possible design. In general, the method is broken into four steps: "(1) Understanding The Material: Technical and Experiential Characterization, (2) Creating Materials Experience Vision, (3) Manifesting Materials Experience Patterns, (4) Designing Material/Product Concepts." (Ibid.).

Among them, the first two, also known as the material tinkering process, plays a major role both in understanding the capability of the material and in guiding the possible designs. Material tinkering is a design practice that "helps to gain knowledge about materials and to develop procedural knowledge through experiential learning. Tinkering fosters sensorial awareness of material qualities” (Parisi et al., 2017).

Due to the large online resources of DIY (Do It Yourself) material instructions, creative experiments and engagement with materials through active experimenting can be easily achieved. The presented case study by Parisi et al. (2017) demonstrates the effectiveness of active experimentation and experience interviews in enhancing students' ability to design more comprehensive and compelling projects. Not only did the students engage in self-experimentation, but the valuable insights derived from material interview data greatly contributed to their overall success.

For the scope of this thesis, which does not encompass material-specific research, the application of MDD primarily lies on the first two steps. This focus helps to gain a comprehensive understanding of how individuals interact with the selected material, which will be used in constructing the prototype.

2.2. Understand Experience: Human and Plant Umwelt

According to Jakob von Uexküll, experience in its essence is the product of any living organism's autonomous interaction with its perceivable environment (Feiten, 2020). It encompasses how an organism senses environmental objects, makes sense of the perceived information, and acts upon its own needs. To the subject itself, the meaning derives from the perceived information, its own actions, and the changes imposed on the perceivable information by the actions. To the observer, the subject's need or intention can be interpreted or speculated through its action or behaviour. This means, an experience, be it from our own or from another subject, contains meaning to both the observers and the subject itself. It is also this meaningful subjective experience that constitute our understanding of the liveness of an object (Cummins, 2021).

Therefore, for humans to perceive the liveness of a thing, it requires its capability to experience, to be able to perceive and react to its environment. Since plants behave on a different time scale that is not perceivable to humans, it is therefore difficult for humans to be aware of their liveness. Thus to design a proper human plant interaction, I will first discuss the necessary understanding of Umwelt in both human and plants. Then I will briefly introduce the concept of agency to underscore the autonomy in different entities. For readers who are already familiar with the concept of agency, please feel free to skip that section.

2.2.1 Umwelt

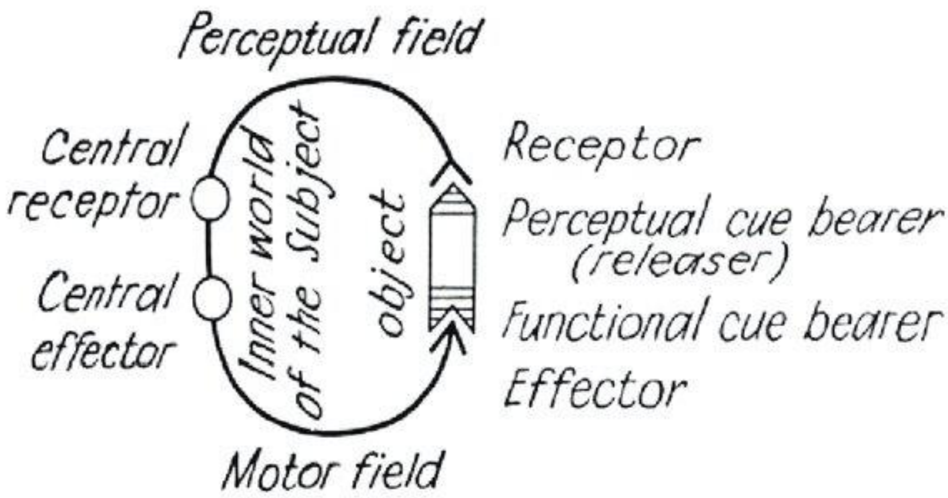

Figure 2. Umwelt model (functional cycle) according to Jakob von Uexküll (Rafieian, 2010)

Primarily inspired by the notion of synthetic aprioris by Kant, Jakob von Uexküll continued his research in exploring the unique perceptual and experiential world that an organism inhibits, which he later calls Umwelt (Cummins, 2021). Uexküll's Umwelt, in short, explains how an active experience within a particular environment is shaped by the physiology of the organism's sensory apparatus (Feiten, 2020). To provide a more detailed illustration, he constructed a perception and action model referred to as the early scheme for a circular feedback loop. Figure 2 shows the translated model of Umwelt (functional cycle) according to Jakob von Uexküll (Rafieian, 2010). According to Uexküll: ”*everything a subject perceives belongs to its perception world [Merkwelt], and everything it produces, to its effect (motor) world [Wirkwelt]. These two worlds, of perception and production of effects, form one closed unit, the environment [Umwelt]”* (Uexküll et al., 2010, p. 42). This model is widely applied in areas of study such as ecological psychology, system modelling, and anthropology (Ibid.).

For Uexküll, it is fundamental that only living beings can have Umwelt, that is the ability to experience and act (Ibid.; Cobley & Kull, 2010). Although not mentioned by Uexküll, it has been pointed out that like animals, plants also have intricate ways of perceiving and interacting with the world around them (Chamovitz, 2013). This means, plants, as different as they are to mammals in appearance and behavior, also have their own Umwelt. Feiten (2020) highlights two pivotal themes that characterized Uexküll’s research endeavors. The first centers around the the relation between affordable environmental objects and the subjects’ mechanical reaction (behaviour), while the second delves into the profound realm of natural philosophy concerning the meaning of a subject's behavior (Ibid.). Here in this thesis, the focus lies mostly on the first theme, to understand how humans interpret specific mechanical reactions of plants manifested through soft materials, and what interaction it can bring. To pave the way for the conceptual design of this interaction, it is crucial to comprehend the disparities between the human and plant Umwelt as described in the first theme.

2.2.2. Umwelt in human and plants

When discussing the first theme of Umwelt as categorized by Feiten in humans and plants, the primary elements involved include the differing sensory abilities that humans and plants possess, as well as the perceivable sensory stimuli and the relationships between receptors and their corresponding stimuli. It is important to note that each individual's Umwelt differs based on the specific environmental conditions it is exposed to and its unique bodily structure. Despite these variations, there are certain general elements of Umwelt that are commonly shared by most individuals within their respective categories of humans or plants. However, due to the constraints of time and knowledge, this thesis only scratches the surface of sensory abilities involved of the first type of Umwelt in humans and plants, and does not delve deeply into the intricate mechanical and chemical principles associated with these sensory abilities.

The human Umwelt presents a complex and subjective experience that involves our senses of touch, sight, hearing, smell, taste, and the perception of space and gravity. In comparison, a plant's Umwelt, given our current understanding, appears to be more rudimentary. However, plants exhibit remarkable sensory capabilities in their own right. Through various receptors, plants also encompass six sensibilities: touch, sight, hearing, smell, taste, and gravity.

Described in Appendix A, these sensory abilities in both humans and plants illuminates a fascinating interplay of sensory perceptions, stimuli responses, and the intricate relationships between organisms and their environments. Such combined sensory experiences, along with memory (which is not covered in this thesis), form an individual's Umwelt, whether it is a human or a plant, and they work together to shape their subjective understanding of the world. The remarkable diversity of sensitivities that govern the experiences of both humans and plants highlights the nuanced ways in which plants also interact with their surroundings as lively as humans do.

Despite knowing the captivating information concerning the sensory realm of plants, apprehending their vitality remains challenging without deliberate attentiveness to the assimilated knowledge. Naturally, akin to other creatures, human beings also struggle with various constraints in comprehending and perceiving the surrounding world. Yet humans' ability to utilize tools can mitigate these limitations to a certain extent. This is where the realm of artificially constructed interactions assumes significance.

2.2.3. Agency as performance of practices

As defined in the Cambridge Dictionary, “agency” pertains to "the ability to take action or choose what action to take" (Cambridge Dictionary, 2023). Keeping this concise definition in mind, the philosophy of agency encompasses a wide array of subjects, including diverse types of agencies, the metaphysics of agency, and its intricate relationship with consciousness (Schlosser, 2019). Due to the exceedingly intricate and obscure notion of agency, this article will narrow down the discussion exclusively to agency relevant to human-computer interaction.

The term "agency" encompasses a broad range of implications in the design of human-computer interaction. So far, users have attributed agency either to the perceived agency of the system or to specific functionalities of the system, such as decision-making processes and intentionality (Koch et al., 2021). The perceived agency of the system could refer to intentional movement or the ability to generate and present alternatives for the user's assessment on the system’s ability to act, i.e. the capability of the system (Ibid.).

Identified as a sense of control, agency can influence the interaction process and its subsequent effects in various ways. In his research on creative agency, Bown (2015) emphasized the importance of studying the activities and dynamics of interaction when empowering different participants with their inherent or post-composed agency. In simpler terms, actions can be guided by the intentional design of agency.

Different forms of agency manifest when relevant affordances are recognized by an agent. These affordances attract the agent's attention through environmental cues, specifically semantic signals that trigger particular actions. Subsequently, the agent assesses these cues in alignment with its objectives for action.

For instance, consider the perceivable agency of a Venus flytrap, which involves the response of closing its leaves when its sensitive spikes in the middle are touched. In the case of a human without prior knowledge of this plant, this perceivable effect of agency remains invisible until they discern how to interact with it. Therefore, providing an explanatory sign encourages humans to initiate a tactile action.

3. Case Analysis

3.1. More-Than-Human human plant interaction with technological mediation

3.2. Soft Robot Applications on Alternative Experiences and Its Potential in Human Plant Interaction

3.1. More-Than-Human Human Plant Interaction with Technological Mediation

This section showcases noteworthy instances of technologically facilitated human-plant interactions (HPI). The selected cases of MTH human plant interaction are Homo Viridis (Christiansen et al., 2020), Entangled habitation: breath together (Xiying, 2023), Symbiome (Spačal, 2016), and Flora Luma - an Agential Provotype (Frankjaer, 2017). They delve into the sphere of computer mediated HPI, transcending conventional boundaries and adopting a perspective that acknowledges the intricate interplay between humans, technology, and botanical life. Therefore, providing an up-to-date overview of HPI examples through the lens of the MTH perspective. These cases emphasize transforming plant Umwelts through various sensory abilities perceivable to humans. This section hence aim to explain how researchers effectively communicate their intended messages in their final projects and provide insights into the unique role of technology within each undertaking.

The first two employ plant bio signals to trigger soft robot movements, facilitating a novel form of embodiment. Symbiome communicates the outcome of a biological process through sound, while Flora Luma achieves this through tactile and visual effects. Although all chosen cases communicate plant Umwelt (mechanical/ biological behavior) through interactions, the information they deliver to the public differs due to their specific designs. This section only provides an overall analysis, for more details of these cases, please see Appendix B. Of the selected cases, only Homo Viridis and Flora Luma address participants' feedback. Although these works offer different sensory experiences—one through embodiment and the other through visual change—they both evoke increased empathy towards the plant among participants. This phenomenon may be attributed to participants' active engagement with the installation and the plant, fostering an awareness of the correlation between perceptible changes and the plant's response to their actions. Therefore, making them aware the liveness of the plant through perceiving its Umwelt.

On the other hand, although both Homo Viridis and Entangled habitation use soft robots as a mediation between human and plants, they differ in how they actuate their soft robots. Homo Viridis utilizes the capacitance value collected from the plant, while Entangled Habitation measures the exchange rate of O_2 and CO_2 in the air. The use of distinct data reveals different information that researchers aim to convey. Homo Viridis aims to transcend the plant Umwelt artificially, aspiring to establish a posthuman entity that combines both human and plant elements. Therefore, actual bio data from the plant becomes essential. Entangled habitation: breath together, however, attempted to communicate the concept of a co-living situation between human and a plant. Thus, the researcher anthropomorphizes the photosynthesis process of the plant, manipulating the soft robot's breathing movement figuratively through the measurement of O_2 and CO_2 levels.

Likewise, Symbiome also delves into the idea of a symbiotic relationship. In contrast to the human-plant dynamic in Entangled Habitation, Symbiome focuses on the intricate microeconomic negotiations between a red clover and Rhizobium bacteria. The constructed system manifests this negotiation through the frequency of water ripples within the greenhouse and accompanying soundscapes presented to the audience. Notably, the mere presence of a human audience holds significance, as the bio negotiation process, crucially dependent on CO_2, may be influenced by their presence, impacting the overall presentation.

3.2. Soft Robot Applications on Alternative Experiences and Its Potential in Human Plant Interaction

As early as 1960, scholars have directed their inquisitive gaze toward the utilisation of pneumatic structures within architectural design, product development, and artistic installations. Depending on the composition of materials involved, researchers have been able to freely embark on uninhibited experimentation with various shapes and structural elements, all the while realising their objectives at a reduced cost. While the passion for pneumatic structures in architecture waned towards the end of the 20th century, their exploration continued to thrive in the fields of robotics and human-computer interaction.

Instead of fading away, this exploration of pneumatic technology has rather undergone a shift, with researchers redirecting their efforts towards harnessing the possibilities offered by computational technology for the manipulation of diverse pneumatic structural configurations. This transformative endeavour, now recognised as the domain of "soft robotics," has witnessed a surge in prominence during recent years, captivating robotic scientists, engineers, designers, and artists alike. This field encompasses a wide spectrum of aspects, spanning from the investigation of actuators, materials, and fabrication techniques to matters of control, and extending to the diverse applications of soft robots for the purpose of artistic expression, or the facilitation of enhanced social interactions.

For the purpose of this thesis, I will not delve into the technical control aspect of soft robotics. Instead, I would like to provide illustrative examples of soft robot applications within the realm of MTH research, focusing on alternative experiences in the context of human computer interaction. These examples will serve as comparative cases to the human-plant interaction cases previously presented. I will first begin by exploring functional aspects of soft robots in human computer interaction. Thereafter, combining example cases discussed in the MTH human plant interaction section, I will provide insights into the potential opportunities that soft robots introduce to this field. This section only provides an overall analysis, for more details of these cases, please see Appendix B.

The examples chosen here are Furl (Chung, 2014), and Sarotis (Aghakouchak, 2016). In these two projects, soft robots serve unique functional purpose. Furl explores the incorporation of soft robotics within rigid architectural frameworks. Through the utilization of EEG signals derived from participants' brain activities to control the modular soft robots, this integration transforms conventional static architectural forms into dynamic structures that people can interact with. Sarotis explores the connection between people's spatial awareness and the tactile sensations, in this case the soft robots are designed to exert rhythmic force to create recognizable patterns. The flexibility of the soft material therefore allows researchers to design and test the viability of tactile guidance for people with visual impairment.

Examining the three examples provided as well as the two applications of soft robots in HPI mentioned previously, soft robots serve as a valuable means to represent and explore alternative experiences in three key aspects. Firstly, they leverage their organic texture to infuse artificial vitality into the design of interactions between humans and cold architectures, as demonstrated in Furl and Homo Viridis. Secondly, the capacity of soft robots to exert force, thereby influencing the embodied experience of the agent, is elaborated in Sarotis. Lastly, the manipulation of air flow in these robots introduces a rhythmic element that can be perceived both visually and tactilely by humans, offering a new perception to familiar concepts, as exemplified in Sarotis and Entangled Habitation.

The distinct interactive features of pneumatic robots, particularly visual organicity and pronounced tactile sensations, set them apart. These characteristics are exclusive to pneumatic robots and cannot be replicated by auditory or visual effects found in other technology-mediated HPI projects such as Symbiome and Flora Luma. However, it is essential to clarify that this distinction does not imply that these qualities of pneumatic robots are superior to others. Instead, it highlights their uniqueness as elements that can be applied in various contexts. Considering the crucial role touch sensation plays in decision-making and the feelings of compassion, soft robot could be a useful tool to apply in an interaction design that aims at bringing out awareness and empathy (Keltner, 2010; Hsu, 2010).

4. Communicating Plant Information and Concept Model

4.1. The Art of Noticing: Expert Interviews and Field Observation

4.2. Conceptual Framework for HPI Experience

4.1. The Art of Noticing: Expert Interviews and Field Observation

In the last section, I investigated the application of computer mediation in HPI and discussed the opportunities brought by soft robots. In this section I adopted the method the art of noticing to understand the reality of HPI, by interviewing plant specialists and conducting field observations. The interviewed group encompassed botanists and interaction designers with substantial experience in projects related to plants. Simultaneously, I conducted firsthand observations at Hortus Botanicus Amsterdam and Leiden to glean insights into both visitor-plant interactions and techniques employed in plant exhibitions.

In this subsection, I present a thematic analysis resulting from a hybrid coding approach applied to the primary data collected from both interviews and observations. This hybrid coding approach incorporates three distinct methods: deductive coding, predetermined by the interview questions; inductive descriptive coding, utilized to categorize responses from the interviewees. Latter two coding methods assist in formulating a more defined direction for the prototyping concept, based on the initial predefined codes; and process coding is employed to categorize data observed within the botanical garden.

4.1.1. Deductive coding

Based on prior literature analysis regarding Umwelt (various beings' ability to experience), HPI and interactive soft robots cases, I established four pre-defined codes as relevant factors for finding inductive codes in the expert interviews and field observation: 1. valuable aspects of plants, 2. techniques for conveying information, 3. challenges associated with human-plant interaction, 4. human plant interaction envisions. Although questions have been adjusted to align with the different conversations during the interviews, there remains four primary questions guiding the discussion in this thesis which align with the four deducted codes. Be aware that the order of the codes and questions are rearranged in writing to deliver a more logical understanding. In the following context, I will use "dc" to refer to the corresponding deducted codes:

1. What insights do you wish to convey to the general public about plants, and what drives your desire for disseminating this knowledge? [dc1: valuable aspects of plants]
2. How do you present information to the public to foster a greater appreciation or understanding for plants overall? Describe your methods of distributing and engaging the public with this information. [dc2: techniques for conveying information]
3. The realm of designing with plants has seen numerous endeavours, ranging from plant-centric approaches focused on plant welfare, to human-centric methods employing plants as tools for human well-being. Are there any challenges or dilemmas you perceive within this practice? [dc3: Challenges associated with human-plant interaction]
4. If human-plant interaction had no limitations, what would be your vision for the manner in which humans and plants interact? [dc4: human plant interaction envisions]

4.1.2. Inductive descriptive coding analysis of six interviews

This section introduces inductive codes I have collected through expert interviews based on four questions correspond to the four dc codes mentioned above. The interviewees involved in the expert interviews are six individuals possessing specialized knowledge either in the field of botany or in the design of interactions related to human-plant dynamics. The interviewees consisted of two botanists, one specializing in plant sensors, and three design experts with prior experience in human-plant interaction projects. To keep the flow of the reading experience, I will only mention the name of these inductive codes to maintain clarity, the detailed explanation of inductive codes under the first three dc category will be explained in Appendix C.

dc1: valuable aspects of plants

Based on responses from various experts to all the question, three categorizations emerge for effectively communicating valuable aspects of plants (dc1) to the public: the remarkable biological processing abilities of plants, the intricate cultural interplay between plants and humans, and the adoption of a plant-centered perspective for reflective purposes. The biological processing abilities here refers to plants' real-time reaction to its surroundings like electrophysiological change or actions captured by time-lapse recordings. The cultural interplay refers to activities involving both humans and plants, from plant colonization in history, to the plant origin of highly processed food in supermarkets, etc. The adoption of a plant-centered perspective refers to workshops organized by designers for designers or the public to learn to think in a plant-centered view. Because the final aspect does not align with the aim of this thesis, it will hence not be considered in the later content.

dc2: techniques for conveying information

All interviewees are researchers in either the field of design or botanical science, and they disseminate information primarily for educational purposes. Among these interviewees, consisting of both botanical experts and designers engaged with plants, distinct approaches in disseminating knowledge emerge. Here these different approaches are coded into traditional approaches and reflective approaches. Traditional approaches refer to unidirectional communications, with visitors positioned as passive recipients of information. Reflective approaches aim to convey abstract concepts that encourage extended exploration, this is achieved through avenues such as small group workshops or the creation of wearables that facilitate novel forms of physical perception and nurturing interactions.

dc3: Challenges associated with human-plant interaction

Three main challenges around HPI are concluded from the expert interviews. They are ethical debate, limitation of human, and inadequate interactive representation of plant-centered narratives. The ethical debate mainly orients around the wellbeing and relatively passive position of the plants, however, this discourse appears to vary depending on individual's background. Due to its controversy, this will also not be taken into account when designing the later prototype concept. The limitats of humans brings forward the lack of human ability in fully understanding and controlling plants. Inadequate interactive representation of plant-centered narratives quite obviously criticizes the excessive focus on technological mediation of HPI and calls for more attention to the plants themselves.

dc4: human plant interaction envisions

Analyzing the responses to the third question, it becomes evident that an emotional connection to plants, fueled by curiosity surrounding their vast amount of unknowns, constitutes a shared aspiration. This sentiment is particularly pronounced among individuals who have had direct interactions with plants. Several similar responses merit attention. Noteworthy among them are the desires: to comprehend plants' sensations, needs, and perceptions; to engage in dialogue with plants; and to attentively listen to plants' communication among themselves. These desires collectively underscore the aspects of human emotionality and care.

Moreover, an interesting aspect highlighted by two interviewees is the plants' unique perception of time, which differs from that of humans. Additionally, three other interviewees mentioned particular scenarios. For instance, one proposed the creation of an interactive 3D environment for visitors to explore while listening to plant communication. Another suggested translating the bio-electrical signals of plants into audible pitches discernible to humans. A third interviewee proposed the concept of either accelerating plant processes or decelerating human perception to facilitate a more profound and meaningful interactive experience.

4.1.3. Process coding analysis of field observations

For field observations I visited Hortus Botanicus Amsterdam twice and Hortus Botanicus Leiden once, each time I observed how visitors react to the surrounding plants for about two hours and have taken pictures of representative moments to aid my analysis. Since the observations lacked verbal communication, I employed process coding as a method, given its emphasis on movements and occurring events. Based on my observations, I have identified five distinct procedural codes: Reading; Seeing and listening; Following tours; Acting according to guiding signs; and Relating. For detailed elaboration of each processing code please see Appendix C.

4.2. Conceptual Framework for HPI Experience

Starting with the overarching MTH concept and its design, extending to Umwelt in humans and plants, diverse examples of MTH experiences and the extensive development of background narratives has facilitated a comprehensive understanding of the subject. Consequently, this lays the foundation for me to finally formulate a conceptual model for the HPI experience in this thesis. In this section, I will show a general analysis of the codes collected from the last section, and explain how I apply this framework to come up with the final concept and research question.

Figure 3 below illustrates the methodological model I employ to develop the final concept of the prototype. This model consists of three main stages: the preconceptual stage, the concept exploration stage, and the final conceptualization. The first three purple deductive codes (dc) collectively establish the foundational framework for subsequent, more detailed coding. The secondary codes attached to each corresponding deductive code derived from prior research, including literature reviews, interviews, and field observations. After defining all essential codes, I move on to constructing possible concepts by answering Forlano's four question. This will then eventually assist me making my decision as to the final prototype concept.

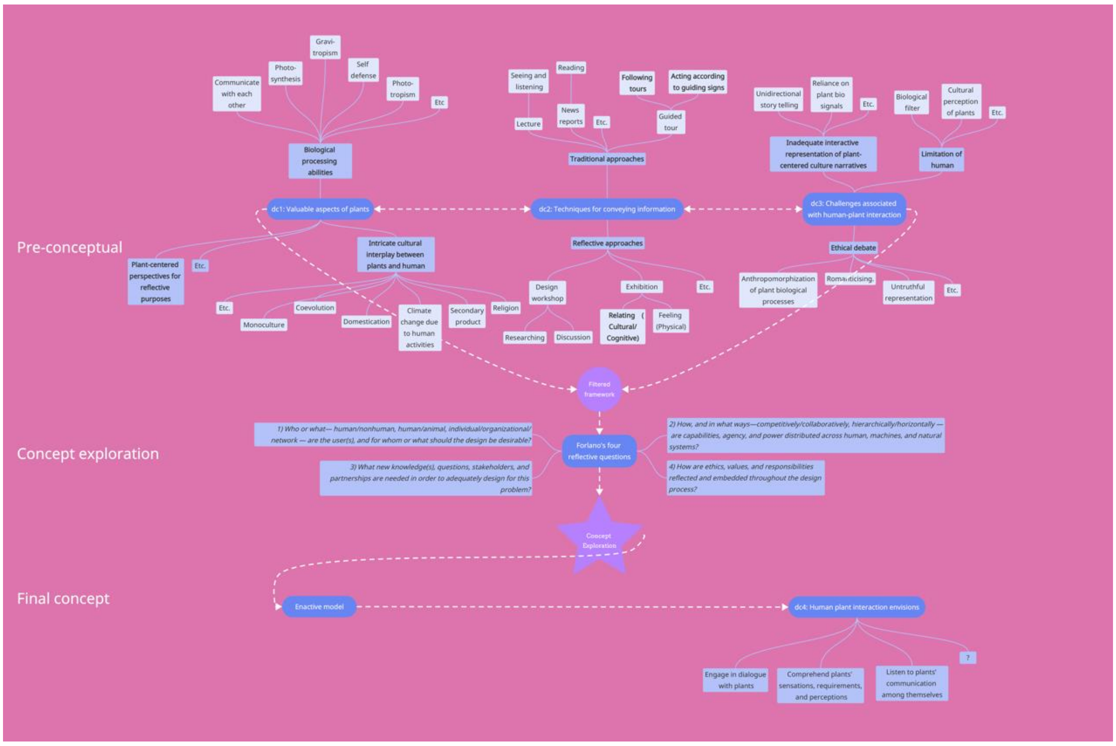

Figure 3. Methodological framework for concept exploration.

In this framework, a foundational narrative can be established through a mind-mapping process, which helps to form the core concept for subsequent prototypes involving the integration of soft robots. The visual framework serves as an effective mind map for simplifying the pre-conceptualization of human-plant interactions, systematically considering three deductive codes (dc). For instance, dc1 involves identifying a significant aspect of plants or a specific plant as the central message. Next, I move on to evaluate existing techniques for conveying this aspect. Subsequently, I assess the challenges associated with human-plant interactions within this specific context, particularly concerning this central message. Afterward, I iterate on the first two deductive codes to refine the essential codes required to address Forlano's four reflective questions.

The cross examination of the presented codes and available resources indicate a lack of attention to cultural narratives in HPI and excessive attention on abstract interactions. Moreover, the trips to two botanical gardens show a rare application of interactive technology in plant information communication - a potential method for raising public awareness and empathy. With these findings in mind, I began to wonder whether I could build a prototype that conveys both human plant interaction and meaningful cultural narratives?

4.2.1. Final concept: About Elms

The initial inspiration for this concept stemmed from my visit to Hortus Botanicus Amsterdam and Leiden. While observing the semantic behavioral signs and secondary product indicators placed alongside the plants, I contemplated employing soft robots to create dynamic signs with a similar purpose. However, I abandoned this idea as it ultimately perpetuated the perception of plants as mere resources, failing to acknowledge their inherent agency.

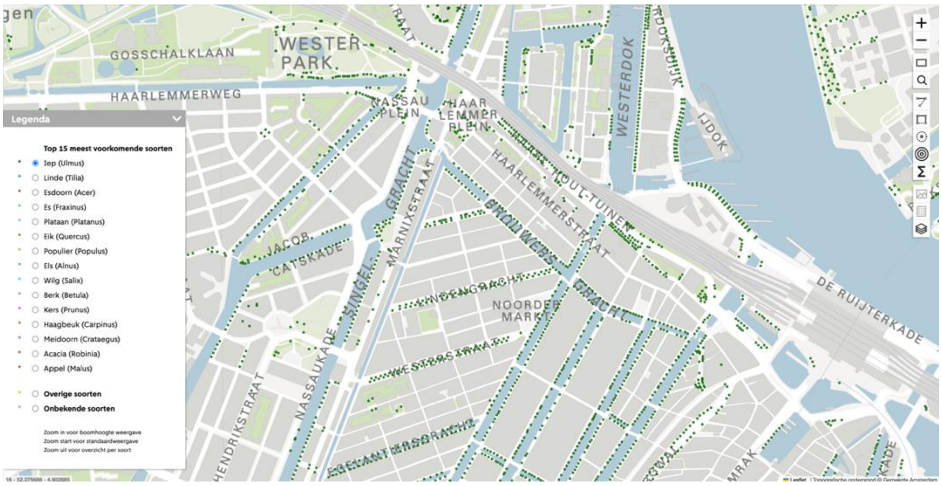

Figure 4. Amsterdam tree map

A important shift in my thinking occurred when I encountered a map delineating the distribution of trees in Amsterdam during my research into the most culturally significant plant species in the Netherlands. Figure 5 shows the map detail. This discovery led to two fundamental questions: What relationships exist between trees and the residents residing in their vicinity? And what sensory input do trees experience in the city environment? These questions prompted two potential directions of cultural narrative exploration: conducting interviews with local residents and undertaking thing ethnographic investigations of the chosen trees within a certain neighborhood.

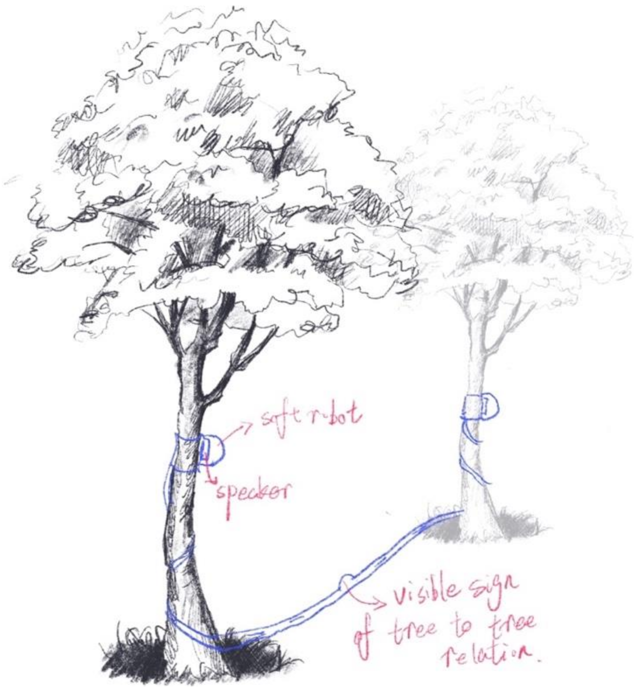

Figure 5. Concept sketch

With these directions in mind, I made my first sketch of the prototype concept, shown in Figure 5. The interview data helps to enrich the final cultural narrative which can then be transformed into a audio file for playback. Thing ethnography would enhance my understanding of the biological change of trees through observing their electrophysiological signal changes. Soft robots here, then play a side role that helps to transform the electrophysiological signals of the corresponding trees into tactile feelings that can be perceived by humans. Participants, by approaching trees and listening to the narratives emanating from them, along with sensing the trees' pulses, could be provided with a unique perspective on perceiving the greenbelt trees.

The primary tree species chosen for gathering stories is the Elm, they serve as the city's signature tree and is also the most commonly planted tree in Amsterdam. This makes them easy to spot and makes it convenient for the later user tests. With the primary trees being confirmed, the research question also becomes clear: How does the integration of soft robot, actuated by bio-signals from Amsterdam Elms, in the context of cultural stories shared between residents and nearby Elms, impact people’s perception of trees in urban greenbelts?

5. Research Statement

Up to this point, we have progressed from foundational philosophical and theoretical underpinnings that emphasize the need to surpass anthropocentric viewpoints. This calls for greater attention toward non-human organisms and MTH development. Moreover, insights collected from Umwelt have yielded a more tangible comprehension of the shared traits and distinctions between human beings and plants. Showing the possibilities of forwarding a MTH future that goes beyond linear progresses, promoting diverse experiences and a co-habitating living style.

Furthermore, the utilization of alternative technology and soft robot technology in the exploration of meaningful interactions with plants has been successfully showcased. This demonstration underscores how these technologically mediated experiences hold the potential to reshape our conceptualization of commonplace artifacts, potentially giving rise to novel behaviors. Concurrently, these experiences have revealed that modifying the agency dynamics between humans and plants, as well as rendering imperceptible aspects of plants visible, can induce heightened empathy and a greater perception of plants' vitality among human observers.

Subsequently, I adopted the abstract strategy of the art of noticing and conducted expert interviews, along with field observations, to comprehend how information about plants is communicated within the realms of human-computer interaction and botany. This involved expert interviews and field observations. The ethnographic data gathered from these interactions revealed a shared interest among experts in conveying the vibrancy and deep cultural and ecological connections between humans and plants. My prior analysis of technologically mediated human-plant interaction and visits to botanical gardens in Amsterdam and Leiden further demonstrated the traditional and interactive methods through which this information is communicated. Ethnographic findings indicate that knowledge regarding plant culture and vitality is often presented in distinct manners. Traditional approaches rely on textual and cinematic methods, while interactive methods emphasize physical embodiment. This duality provides an opportunity for this thesis to explore the communicative impact when both forms of knowledge are conveyed through traditional storytelling and technologically mediated interaction.

The central focus of this thesis lies in the exploration of human-plant interaction through the integration of soft robotic technology. Drawing inspiration from MTH design strategies, previous human plant interactions, and soft robot human computer interactions, this thesis aims to construct an interactive prototype following the methodology of Research for Design (RfD) and Research through Design (RtD). Through the analysis of collected ethnographic codes, "About Elms" emerges as the final prototype concept, along with a clear research question. That is, *how does the integration of soft robot, actuated by bio-signals of Amsterdam Elms, within the framework of cultural narratives shared among residents and the nearby Elms, influence individuals' awareness of trees within urban greenbelts?* Simultaneously, by concentrating on the visiting experience, the project seeks to uncover potential applications of soft robots as educational tools, going beyond their mechanical utility. This approach functions as a means to better understand the complex entanglement between humans and plants. Through an analysis of the dynamic interplay facilitated by soft robot-assisted human-plant interactions, this research contributes to the evolving landscape of human-plant relationships and broader ecological awareness.

6. Design process

6.1. Collecting Cultural Stories Between Residents and Nearby Elms

6.2. Material Tinkering

6.3. Thing Ethnography, Prototyping, and Control System

6.1. Collecting Cultural Stories Between Residents and Nearby Elms

In preparation for narrating cultural stories linked to elm trees through audio means, qualitative interviews were utilized to collect relevant data. Initially, over 150 leaflets were distributed in the selected neighborhood to attract potential interviewees. Regrettably, there was no active response to this method. Consequently, a revised strategy was implemented, involving direct outreach through phone calls and emails to invite individuals to share their stories. Ultimately, four participants were interviewed, each contributing unique perspectives. Three of these participants were female, all engaged in artistic practices related to nature, two of which have especially close relationship with elm trees. The fourth participant was a male, employed as a tour guide in Amsterdam. Their responses were synthesized to construct a comprehensive narrative depicting the relationship between Amsterdam residents and elm trees.

During the interview process, both non-directive and directive questions were constructed following the structural guide from J.P. Spradley's work, "The Ethnographic Interview" (2016). Given the interview's aim to collect stories involving a personal connection with elm trees, questions were semi-open to guide interviewees in openly sharing their experiences related to the trees. The interview commenced with a research introduction, followed by four key questions:

1. Could you first introduce yourself? What do you do, which area do you usually stay in Amsterdam? For how long or how often are you at these areas, or have you lived in these areas?
2. Before this interview, we have confirmed that you have some personal stories to share with me between people and Elm trees, would you please tell me about these stories?
3. Do you notice any elm trees planted nearby the areas that you are usually at? Or just when you walk on the street?
4. If the answer to the third question is yes. Ask: Close your eyes and imagine a familiar scene with you and the elm trees you noticed in the past, could you describe your thought at that time to me? If the answer to the third question is no. Ask: After reviewing connected stories between residents and the tree of Amsterdam city, what do you feel about elm trees planted along the streets?

6.2. Material Tinkering

Materials are ubiquitous and play vital role in our daily lives, including their significance in the context of this thesis. In this study, the influence of materials on participants' experiences in haptic interactions, facilitated by soft robots, takes centre stage. Material Driven Design (MDD), as introduced by Elvin Karana et al. offers a methodological framework to guide material development based on experiential goals (2015). To augment understanding, I will first provide a concise analysis of important parameters and the application of materials in soft robotics, elucidating the rationale behind my material selection. Then in pursuit of an optimal form for the "About Elms" prototype of a soft robot, this thesis also adopts partial principles of MDD. The primary focus here lies in the processes of material experimentation.

6.2.1 Shape changing parameters

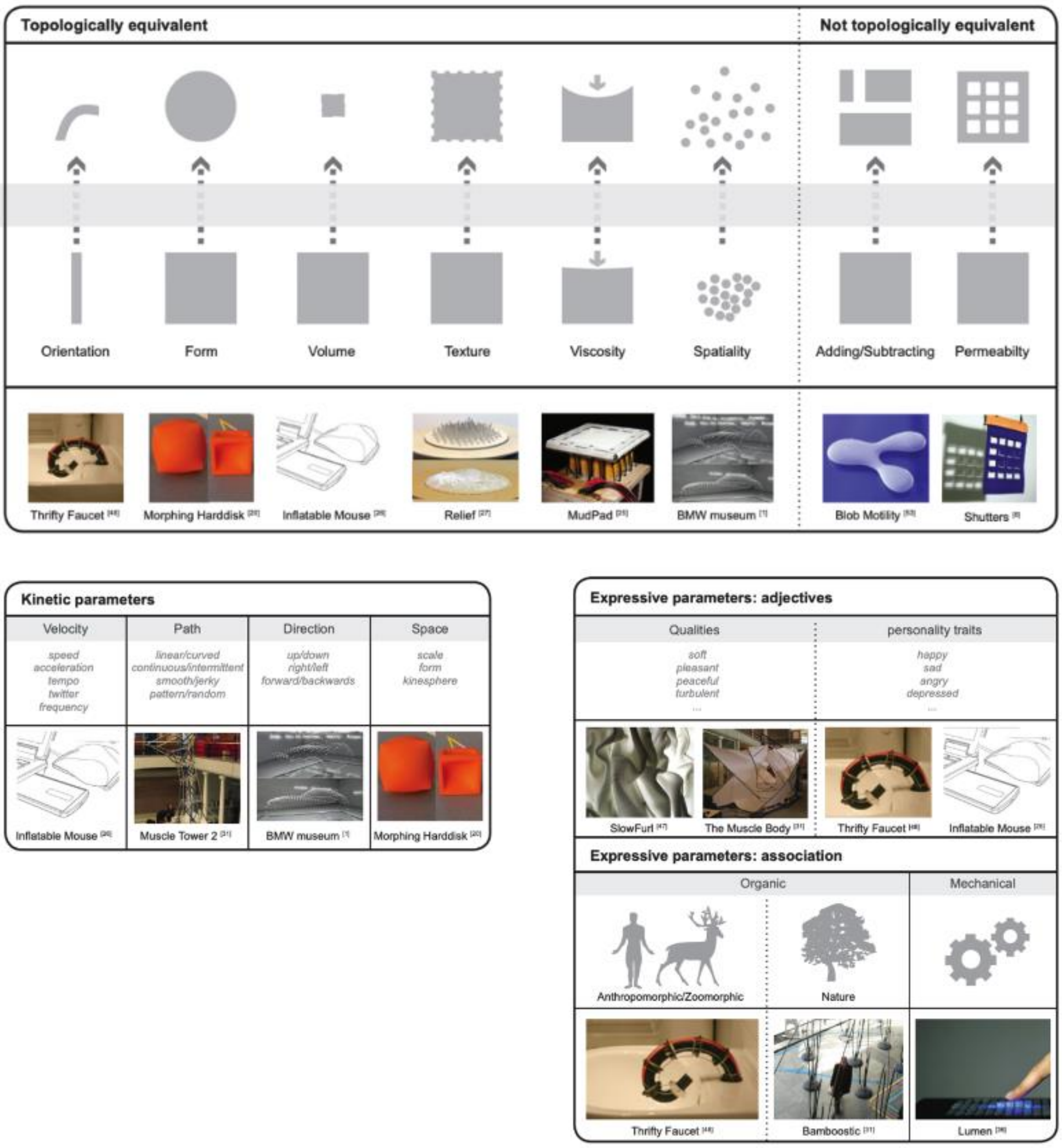

Figure 6. Types of Shape Change (Rasmussen et al., 2012)

In his 2021 master's thesis, Martinez Castro examined the developmental aspects of employing MDD. His research investigated how shape-changing interfaces influence the perception of liveliness, encompassing both spatial-temporal attributes and material characteristics. Castro's study also emphasized the interconnectedness of spatial and kinetic parameters with the expressive parameters they could induce. This assertion was drawn from a meta-analysis of a 2012 conference paper authored by Rasmussen et al., which explored the utilization of shape-changing interfaces in design, shown in Figure 6 (2012).

Rasmussen et al. conducted a comprehensive review encompassing 44 studies on shape-changing mechanisms. Their analysis led to the identification of three key parameters: 1) Types of Shape Change, 2) Kinetic Parameters, and 3) Expressive Parameters. The classification of shape changes is primarily based on whether they are topologically equivalent or not. It is essential to note that the extent of deformation is significantly influenced by the materials used in the construction, as pointed out by Martínez Castro (2021). Kinetic parameters were further investigated in four distinct dimensions, specifically focusing on the prototype's velocity, trajectory, direction, and spatial characteristics. It is revealed that the changes of kinetic parameters often directly associate with the expressive parameters, i.e. how the shape transformation is perceived. For example, a repeating rotation with jerky movements can be perceived as mechanical instead of reflecting personal traits. This research only experimented with volume and velocity change.

6.2.2. Material choice

In this context, an essential aspect to grasp is the application of soft robot materials. These materials can be categorized as heat-sensitive, liquid-sensitive, pneumatic, and mechanically actuated materials (Martínez Castro, 2021). Among these, pneumatic and mechanical materials offer greater control and rapid reversibility. As this thesis focuses on comprehending soft robot movement rather than exploring a wide array of methods and materials for shape-changing, I will exclusively provide an overview of Martínez Castro's analysis of pneumatic materials instead of diving deep into technical jargon.

Pneumatic materials primarily comprise expandable substances, such as those silicone casted product using 3D-printed models, liquid 3D print, TPU-coated fabric, or other airtight materials in conjunction with textiles (Ibid.). The transformation of their shape is typically triggered by inflating internal channels, and can be utilized independently or in conjunction with other materials. In the case of TEX(alive), Martínez Castro et al. employed 3D-printed pneumatic materials as modular actuators to govern the overall movement of lifeless fabrics, showcasing the concept of "liveness" (2022).

Among the various materials available, many necessitate fabrication within a controlled laboratory setting with precise measurements, which can be challenging to access. Consequently, TPU-coated fabric and silicone casting have emerged as noteworthy choices due to their simplicity and rapid prototyping suitability, particularly for do-it-yourself (DIY) projects.

6.2.3. Tinker: material familiarisation

TPU 71106

TPU-coated fabric represents an additive textile that employs innovative polymer blending techniques to create a highly durable thermoplastic polyurethane (TPU) coating atop a base fabric such as polyester or nylon. By heating the TPU layers face to face at high temperatures, two pieces of fabric can be seamlessly bound, forming an airtight chamber for pneumatic applications.

During the tinker process, I have chosen TPU 71106 purchased from the extremtextil website[1] as the TPU source material. To seal the fabric, I have attempted to use iron, hair curler, and a soldering machine. In the end, I have decided to use the soldering machine as the final sealing method due to its flexibility. A flat solder head is applied, and a solder temperature of 240 celsius is considered the optimal temperature after a few experiments. It is important to have an protective layer in between the solder head and the TPU fabric, because direct sealing can easily lead to damage of the fabric. In my case, I used baking paper as the protective layer.

Silicone

Silicone, renowned in the realm of soft robotics research, is esteemed for its strong sealing and elastic properties. While more professional applications might necessitate 3D printing models or precise curing equipment, silicone rubbers are readily available to hobbyists. Typically, the curing process involves pouring a mixture of platinum poly-addition casting silicone A and B gels into a mold and allowing it to cure for twenty-four hours.

During the tinkering process, I have bought a hobby silicone kit gel as the silicone source material. Through experiments, I have found that the proportion of the A, B gel result directly on the elasticity of the final material. The proportion of 1/3 B gel and 2/3 A gel delivered a rather good elasticity. Moreover, by curing the gel in an 40 celsius degree oven, the material can be quickly cured within an hour, which substantially reduces the curing time.

6.2.4. Material decision

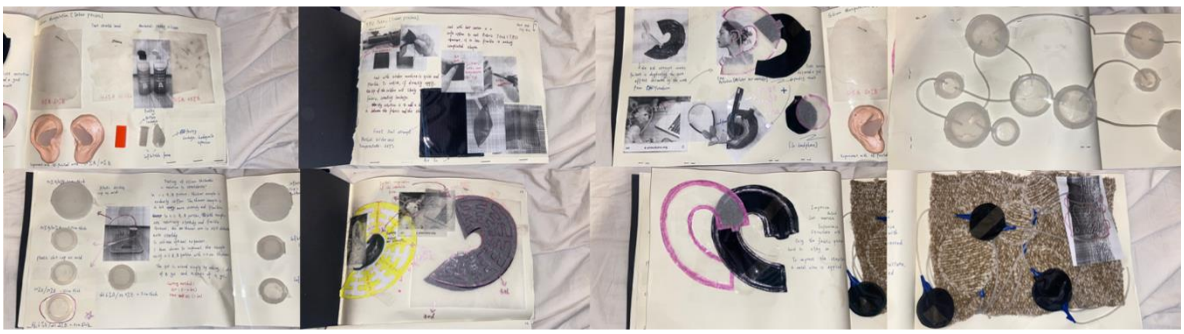

Figure 7. Material tinker process

Figure 7 shows partial tinker process. During the tinker process, inflatable modules made of TPU 71106 fabric and hobby silicone were tested for their air seal ability and expansion

[1] Purchasing website URL. https://www.extremtextil.de/en/nylon-70den-tpu-coated-one-side-170g-sqm-heat-sealable.html

performance. Both exhibited good expansion performance with noticeable volume changes when tested individually. However, when tested with multiple modules, silicone modules performed significantly worse than those made of TPU fabric, this could be because silicone modules required higher air pressure for further expansion. Both types of modules experienced air leak issues due to the limitations of the kitchen lab environment. Although this problem can be easily addressed by applying UV gel to the leaking areas for both materials, it was later discovered that UV gel does not adhere well to silicone, posing a higher risk of leaks. Therefore, TPU fabric became the natural choice for the final prototype.

6.3. Thing Ethnography, Prototyping, and Control System

6.3.1. Thing ethnography

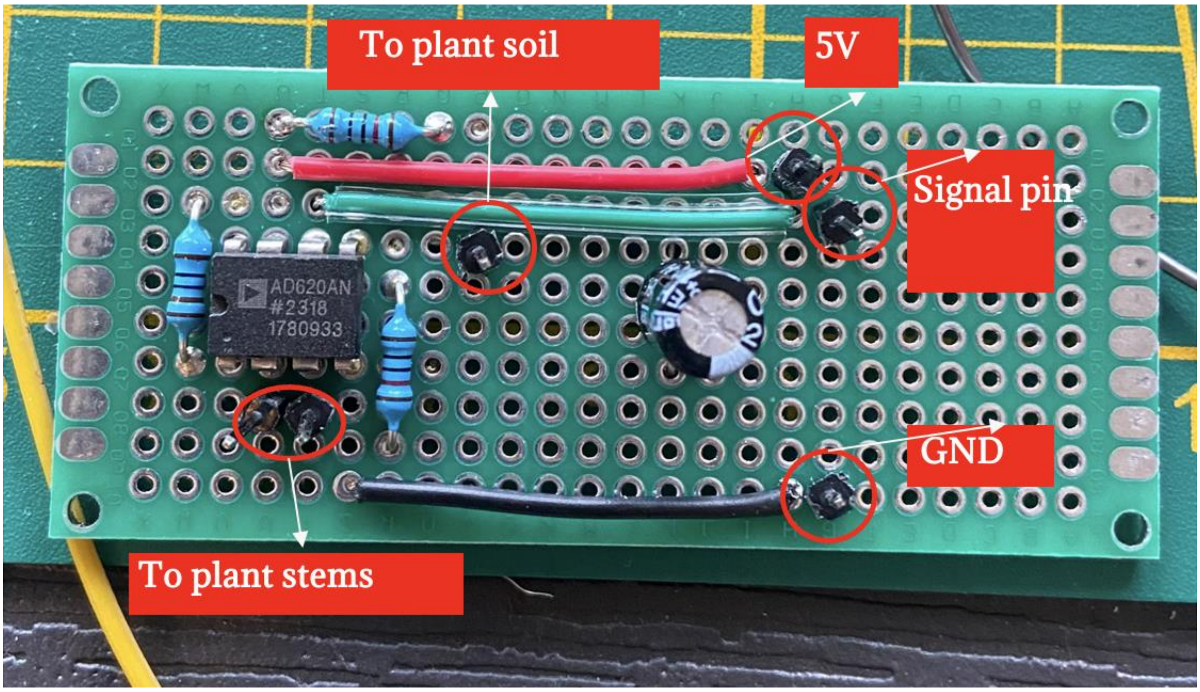

Figure 8. Self-made electrophysiological sensor

This study employs ethnography as a design practice to comprehend how trees respond to environmental changes. Figure 8 shows a self-constructed electro-physiological sensor utilized to capture and amplify plant signals. While not as intricate as animal nerves, plants possess a nerve-like cellular system enabling them to transmit electrical signals in response to environmental stressors (Fromm, 2006). Put simply, plant cells actively react to changes such as temperature, light, and touch, leading to detectable alterations in electrical signals. However, these changes result from a combination of external stimuli, and their correlation to specific environmental factors remains open to interpretation.

To understand the influence of human interactions on plant responses, preliminary experiments were conducted on diverse house plants, namely Dracaena Marginata, Calathea medallion, and Gynura aurantiaca. Each plant demonstrated unique responses to touch, with Gynura aurantiaca manifesting the highest sensitivity. Conversely, Dracaena Marginata consistently exhibited a delay of twenty to thirty seconds in its responsive behavior to tactile stimuli. Following these indoor trials, a series of three one-hour outdoor tests were conducted on a nearby Elm tree. While the tree did exhibit signal variations, it is notably more stable compared to the indoor house plants. Also because the insulating property of its outer bark, no signal changes were triggered by regular human interaction like touching or hugging.

The acquisition of tree electrical signals via ethnographic methods underscores the challenges inherent in developing a responsive system that reacts to human interactions with the tree. Another potential signal of interest involves capturing real-time sap flow sounds within the trunk using a contact microphone attached to a sound-transmitting object inserted into the tree trunk. The frequency of sap flow sound can then be used to drive the movement of a soft robot. However, due to time constraints, I opted to simulate the signals to induce movement in a soft robot, with the aim to observe and analyze the resulting interactions.

6.3.2. Prototyping and control system

The initial concept involved incorporating an ear pocket into the headphone design, accompanied by an external wearable air pocket for the outer ear. However, the in-headphone ear pocket was later eliminated due to the noticeable noise transmitted through the air pipe. To enhance interactivity, a soft material fabric was designed and manufactured. This fabric not only facilitates participants in concentrating on their listening experience but also encourages active engagement with both the tree and the soft material. Figure 9 shows the details of prototype and control system.

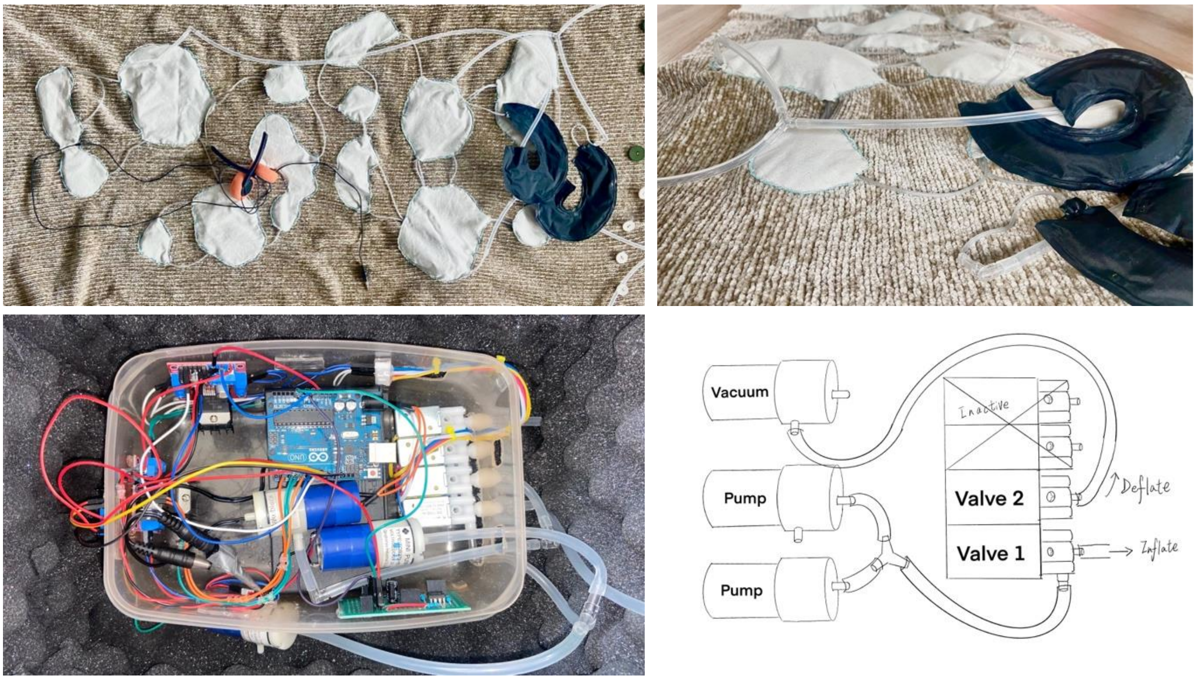

Figure 9. Prototype appearance and control system

The soft robot is composed of a fabric with variable-sized air pockets and two outer wearable earpieces. All air pockets are interconnected through hollow air pipe channels, streamlining the need for a single air source in the control system. The soft robot's movement has been programmed to show three patterns: stable, unstable, and super-unstable, each characterized by a progressively faster pulsing rhythm. These patterns correspond to the house plants' signal responses to various human interactions, such as touching, plucking, and blowing air. In interactions with house plants, gentle stimuli typically lead to minor signal fluctuations, whereas significant tissue damage elicits more pronounced spikes.

7. User Evaluation

7.1. Method

7.2. Results

7.3. Analysis

7.1. Method

Participants

To assess the impact of a prototype on individuals' awarenessof urban greenbelt trees, fifteen participants were recruited for the study, with five individuals assigned to each of three different groups. Namely, the cultural narrative group (CG), the soft robot group (SG), and the soft robot and cultural narrative group (SCG). Due to constraints in time and resources, the majority of participants were drawn from my social network, while two participants were recruited from public spaces—an individual from the library and another from a café. The participants, comprising six males and nine females, ranging from 18 to 50 years old. Tests for each participant were conducted based on their availability. Similarly, tests for each group were conducted in the following order, beginning with the CG, followed by the SCG, and concluding with the SG.

Task

The original plan to test the prototype was to recruit pedestrians on the street at the ferry across Amsterdam central station. This was soon proven to be difficult considering the relatively long amount of time required from each participant. In the end, all tests are conducted at a tree nearby each recruited interviewee's preferred location as shown in Figure 10 below.

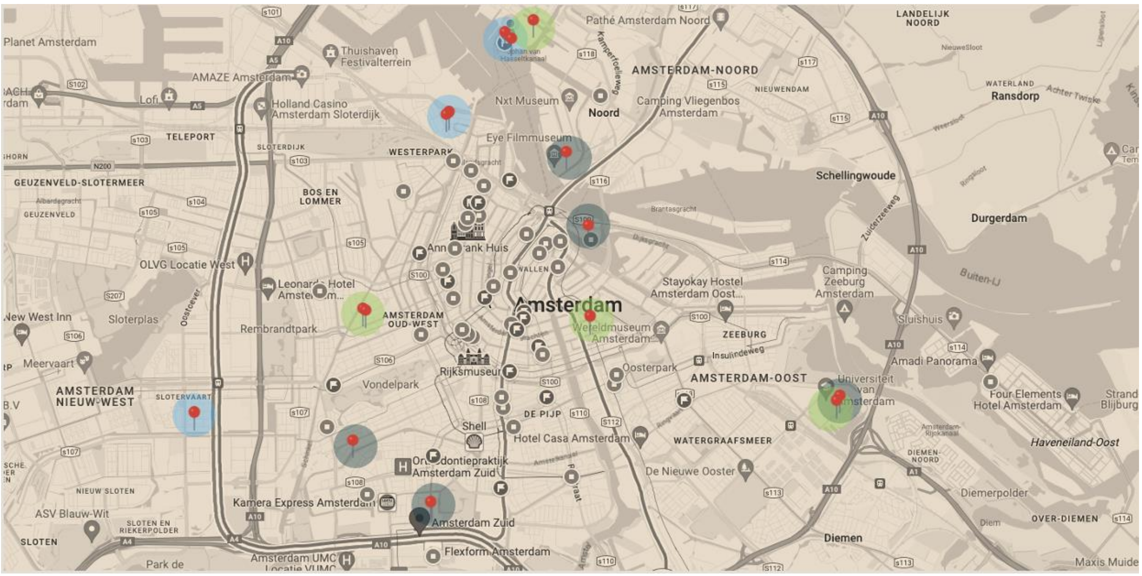

Figure 10. Test locations in Amsterdam.

Before experiencing the prototype, all participants are interviewed to share their knowledge and awareness of urban green belt trees with a rating between 0 to 5, with 0 being the lowest knowledge level and awareness, and 5 the highest. Moreover, they are asked to share the ways they have obtained knowledge about plants, either passively or actively.

Figure 11. SCG test set up and observed interaction.

After the pre-experience interview, participants of each group are guided to begin their interaction with the prototype. Figure 11 depicts the SCG test set up and partial behaviors exhibited during the tests. All tests are done next to an Elm tree. CG participants are asked to listen to the cultural narrative while observing and interacting with the tree. SCG participants are asked to listen to the cultural narratives with the soft ear wearable on while interacting with the tree and both soft robots around their ears and the tree. SG participants are asked to put on the soft ear wearable and interact with the tree and both soft robots around their ears and the tree. To notice, both SG and SCG participants are told that the soft robots are actuated by the biosignal of the Elm tree before interacting. The fact that the signal was simulated was revealed only after the post-experience interview.

After experiencing the prototype, all participants were again asked about their awareness of urban green belt trees with a rating between 0 and 5. On top of that, they are asked to share their opinion on the overall experience as well as the elements involved in the prototype. Finally, they are requested to fill in the experiential characterization map to give a clearer overview of their description of the experience, which consists of interpretive level, affective level, and reflection. The interpretive level of the prototype is omitted for the CG due to its focus on the audio experience.

Evaluation method

Evaluation of the prototype effect is based on a general analysis of all tests. The analysis takes four elements into consideration. The result of experiential characterization maps, ethnographical observation, awareness ratings, and semi-structured interviews. Results of experiential characterization maps entail the level of various positive and disturbing feelings participants experience in each group, as well as the corresponding elements with effect (Camere & Karana, 2022). Ethnographical observation offers an overview of different behaviors participants elicit. Awareness rating allows a more straight forward comparison between each group. Finally, descriptive answers of semi-structured interviews are to analyze deeper, and more personal reflections.

7.2. Results

Among all participants, four individuals maintain a close relationship with plants, engaging in activities related to the Internet of Things (IoT) in agriculture, writing essays about trees, specializing in plant biology, or working in municipal urban planning. Additionally, eight participants possess varying degrees of experience with interactive installations, and six lack extensive knowledge of both urban green belt trees and interactive installations. This section discusses the results of the awareness rating, experiential characterization map and ethnographical observation separately. Each part will also incorporate valuable answers from semi-structured interviews before and after the experience.

7.2.1. Awareness rating

Group 1: Soft robot group (SG)

User	User information	Knowledge level of urban green belt trees	Pre and post experience awareness	Interpretive level result
User 1	43, male, software engineer, IoT hobbyist	1 [between 0-5]	3 VS 4	Cozy, curiosity, playful
User 2	22, female, financial consultant, Christian	1.5 [between 0-5]	1.5 VS 4	Spiritual, intellectual, urbanization
User 3	31, male, Interaction design student	2 [between 0-5]	3 VS 4	Calm, nostalgic, natural but also futuristic
User 4	23, female, biologist with focus on fungi and plants	4 [between 0-5]	4.5 VS 4.5	Alive, strange, playful
User 5	18, female, media and art student	0.5 [between 0-5]	0 VS 3	Feminine, scientific, inspirational

Figure 12. SG directive question and partial experiential characterization result

Indicated in Figure 12, SG comprises an individual actively engaged in agricultural Internet of Things (IOT), a plant biologist, an interaction design student, and two individuals with limited knowledge of plants or interactive installations. Among the five participants, four demonstrated an increased awareness of green belt trees following the experience. The plant biologist's awareness remained unchanged, but she already possessed a high pre-experience awareness score of 4.5. She was also the only one who suspected that the signal was simulated, but she still thought the experience made the tree more alive to her. In total four participants verbally expressed their surprise in feeling the liveness of the tree. Notably, two participants, initially lacking awareness of urban green belt trees, reported a post-experience awareness increase exceeding two points. The later interview showed that the enhanced perception of both participants referred more to their attention to urban greenbelts as living creatures, and neither of them showed intention to actively learn more about this field.

Group 2: Cultural narrative group (CG)

User	User information	Knowledge level of urban green belt trees	Pre and post experience awareness
User 1	26, male, lawyer, read a book about trees	2 [between 0-5]	2 VS 3
User 2	29, male, lawyer	3 [between 0-5]	3 VS 4
User 3	24, female, media technology student, musician	2 [between 0-5]	3 VS 4
User 4	29, female, lawyer, have house plants	2 [between 0-5]	4 VS 4
User 5	50, female, city program manager, managed urban planning	3 [between 0-5]	4 VS 4

Figure 13. CG directive question result

Group 2 comprises individuals solely exposed to the cultural narrative. Three participants showed limited knowledge of urban green belt trees before the experience. Between the other two participants, one had written an essay on noise pollution related to trees and possessed experience with interactive installations, while the other was employed in municipal urban planning. Post-experience awareness of urban green belt trees, as shown in Figure 13, revealed that three participants demonstrated a one-point increase in awareness. The remaining two participants maintained their pre-experience awareness levels but acknowledged that the narrative provided new insights into urban green belt trees. In later interviews, three participants expressed a newfound interest either in elm trees or urban planning of trees. Two participants brought up the word co-living, indicating their perception of trees being living co-habitant in the city.

Group 3: Soft robot and cultural narrative group (SCG)

User	User information	Knowledge level of urban green belt trees	Pre and post experience awareness	Interpretive level result
User 1	25, male, media technology student, TA in neuroscience	1 [between 0-5]	3 VS 4	Informative, cozy, strange
User 2	28, male, HCI student	1.5 [between 0-5]	3.5 VS 3.5	Calm, spiritual, wavey
User 3	28, female, linguistic Ph.D.	2 [between 0-5]	2 VS 3	Intriguing, interactive, delicate
User 4	25, female, media technology student, technician in a dance group	2 [between 0-5]	3.5 VS 4	Cozy, toy-like, handcrafted
User 5	25, female, media technology student, psychobiology Bachelor	2 [between 0-5]	2 VS 3	Calm, handcrafted, natural

Figure 14. SCG directive question and partial experiential characterization result

Finally, Figure 14 demonstrate the result of SCG. Among the five participants in SCG, who encountered both the soft robot interaction and cultural narrative, four demonstrated a good understanding of interactive installations during pre-experience interviews, and none possessed extensive knowledge of urban green belt trees. Following the experience, four participants exhibited increased awareness of urban green belt trees, two of them expressed newfound insights into this aspect of Amsterdam. The same two also expressed their interest in learning more about urban green belts actively through research. Three of them explicitly mentioned the liveness of the tree. Three participants, all are media technology students, suspected that the signal was simulated during later interviews.

7.2.2. Experiential characterization map

Figure 15 below shows the results of all three groups' experiential characterization map. Each participant's answers are color coded. The vertical line corresponds to the intensity of the feelings, and the horizontal line corresponds to the spectrum between the unpleasant and pleasant level of the feelings. The position of the word therefore indicates the quality and intensity of the feeling. For example, an extreme joyfulness would be positioned on the top right corner.

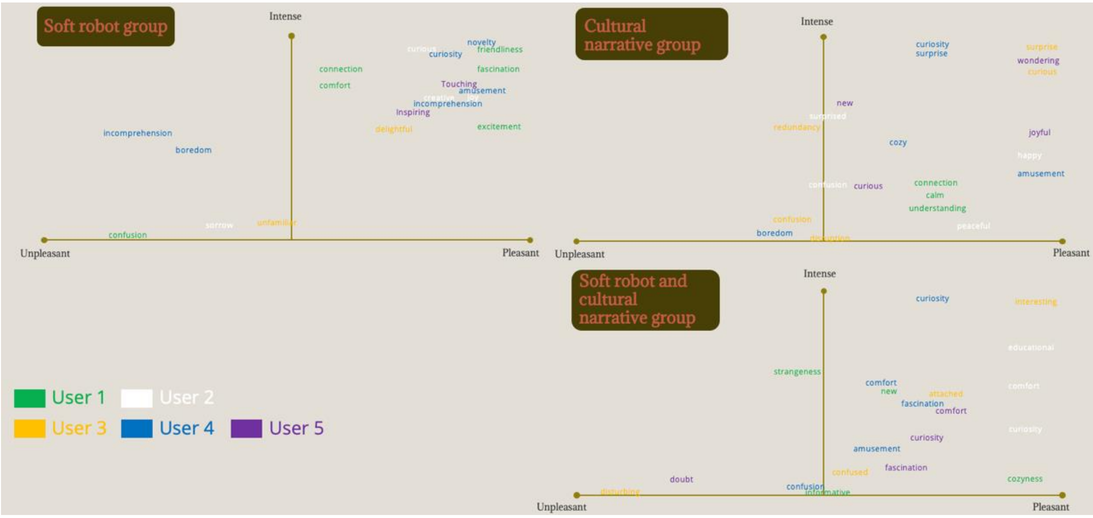

Figure 15. Experiential characterization maps of all three groups

SG's responses to the experiential characterization map formed a cluster on the top right corner, indicating stronger pleasant experiences. However, it also elicited the most intense unpleasant feelings, which was explained during the post-experience interview as associated to a deeper personal reflection to the state of trees. Besides the feeling of curiosity and playfulness some participants express, the majority highlighted the unique sensation of pulsing movements around the ear, signifying a heightened perception of the tree's vitality. Interview answers show that participants in this group exhibited a closer connection to their past experiences. For instance, the individual working with IOT devices displayed a particular interest in the installation's mechanism, while the religious American tourist repeatedly emphasized how the experience evoked feelings of spirituality and meditation.

The experiential characterization map of CG depicts a scattered pleasant emotions, with curiosity being highlighted by three participants. The answer also represented more neutral feelings in comparison to the other two groups. Two individuals reported feeling a sense of peace while listening to the audio and expressed surprise at discovering information about elms in Amsterdam. However, two participants perceived the narrative as slightly lengthy, with one indicating a moderate degree of redundancy and another noting a mild level of boredom. Furthermore, two participants identified certain parts of the story as unclear or not relatable, contributing to a somewhat confusing experience. Responses from post-experience interviews underscored the significance of staying next to the tree to establish a meaningful connection during the audio experience.

The experiential characterization map of SCG showed a similar position distribution of various pleasant feelings to the CG, and similar number of unpleasant feelings to the SG. Two participants initially reported feelings of doubt and confusion. They clarified that uncertainty arose from a lack of clarity regarding the connection between the soft robot's movement and the tree. Perceptions of the experience varied among participants. One participant expressed a preference for initially interacting with the tree before engaging with the audio file, as simultaneous interaction seemed distracting. In contrast, the other two participants found the combination beneficial for focusing on the audio experience. Notably, all participants regarded the interaction with the soft robot and the tree as a unique experience, with one participant emphasizing the pleasing integration of this soft robot and tree interaction with the audio story.

7.2.3. Ethnographical observation

Ethnographical observation includes my own observation of all participants' behavior and facial expression during both interviews and their interaction with the prototype and tree. A noteworthy trend observed across all groups is the impact of the testing environment on participants' reactions. For instance, a participant in the SCG expressed self-consciousness about conducting the test in public, a CG participant mentioned dissatisfaction with the weather, and an SG participant complained about being approached by a neighbor during the test.

Among all three groups, participants in CG exhibited the least physical interaction with the tree, despite they were suggested to interact with the tree and observe the environment. However, two of them approached to smell the tree, possibly due to the information about the smell of Elm trees in the cultural narrative. Participants from SG and SCG were more active during the experience, probably due to the seemingly reactive movements of the soft robots. They caressed and pressed the soft robot and tree trunk, hugged the tree, and jumped around, trying to figure out the connection between the soft robots and their interaction to the trees. No strong behavioral differences were recognized between these two groups. Additionally, despite the simulated signal, half of the participants in both SG and SCG sensed a connection between the tree and soft robots. It is plausible that my pre-experience explanation of the movement mechanism, later revealed to be false during the final interview, subconsciously influenced their perceptions.

Seeing from participants' facial expressions, micro gestures like nodding and raising eyebrows are noticed among participants across all groups, indicating their understanding of the narrative. However, two CG participants showed a bit of impatience as they began to look around and appeared to be unsettled, which was not recognized in the other two groups. One SG participant showed a strong surprised face with her mouth wide open for long. Another SG participant giggled and wiped her eyes during the interaction, she reported shedding tears while engaging with the robot and touching the tree. Giggling and laughing were observed both the SG and SCG, but this lasted only for a short time after the participants' first contact with the soft robot earpieces. Another interesting expression observed was frowning and looking back to me with a face full of questions, this appeared on two participants each from the SG and SCG, which I interpreted as a sign of confusion and intrigue.

7.3. Analysis

In summary, the outcomes of experiential characterization mapping, interviews and ethnographic observations among the three groups underscore the entertainment value associated with active interaction and exploration of the tree, as opposed to solely listening to cultural narratives. Positive feedback regarding interactive communication was received from all three groups' interview results compared to traditional methods involving books or simple explanatory signs. Notably, interaction with the soft robot, devoid of cultural narratives, emerged as the most emotionally evocative. In contrast, individuals exposed solely to cultural narratives tended to exhibit more rational reactions during their experiences. Participants' feedback on the integration of soft robots and cultural narratives tends to lend in between the other two groups.

Test results reveal that SG participants experienced the most positive effects, attaining heightened awareness and deep reflections. Nevertheless, these reflections remain broad and abstract, lacking concrete practices. In contrast, CG participants maintained a more rational stance, displaying lower increased awareness and minimal reflections. However, CG participants exhibited an interest in actively seeking more information about Elm trees.

SCG participants, who encountered the integration of a soft robot and cultural narratives, achieved higher awareness and deeper reflections than CG participants regarding the current social awareness of greenbelts. Many of them also were happy about the information brought by the cultural narratives and wanted to learn more. Despite this, their reactions appeared relatively calm, resembling the intensity observed in the CG group according to experiential characterization mapping and interviews.

It is crucial to acknowledge that the variety and intensity of emotions observed may be intricately linked to participants' life circumstances, their familiarity with the context as well as the testing environment. While there may be a personal bias, it is noteworthy that participants in the SCG, most of them being familiar with the underlying mechanism of simple interactive installations, potentially displayed less intense emotions due to their existing knowledge. This underscores the necessity for additional post-experiment explanations to facilitate a more balanced participant structures across groups in a better controlled environment.

8. Discussion

8.1. Reflection on the Research Process

8.2. Value of this Research

8.1. Reflection on the Research Process

While the integrated experience of soft robot interaction and audio cultural narratives generally heightened awareness of urban greenbelts and enhanced knowledge of Elm trees, determining its exact impact on public awareness remains challenging. Research results indicate that participant reactions to the prototype varied based on factors such as prior awareness, knowledge of the target plant and the prototype's placement.

First, all experiments were conducted under clear guidance, including explicit instructions. However, this might create potential biases in participant responses during semi-structured interviews, as the interview format inevitably contains suggestive elements. This was taken into consideration and compensated for conducting ethnographical observations, which helped to provide a more balanced perspective. It is important to be aware that potential biases cannot be eliminated in both social science and design, therefore more test iterations in this research are needed. For example, conducting solely a thing ethnography using a hidden camera in a better-controlled environment like a botanical garden could render very different results than the current evaluation method.

Additionally, it is unknown how this experience would affect the participant's long-term attitude to the urban greenbelts. Yet understanding the potential long-term effects of the prototype on people's attitudes towards the urban greenbelts could contribute to a more holistic understanding of its societal implications. If time allows, I will conduct follow-up interviews to see how the experience influences different participants.

Finally, the prototype requires improvement. While some participants appreciated the handcrafted nature and perceived the material as soft and engaging, a refined structure could facilitate a more natural and serious interactive communication process. Unfortunately, a notable limitation was the inability to control the soft robot using actual bio signals from Elm trees, which is crucial for achieving true retroactive interaction. If continuing with the electro-physiological signal, then the behavior of the soft robots needs to be adjusted to provide a noticeable reaction that corresponds to the stable signal of trees. Otherwise, making a predicting algorithm that interprets various physiological changes in the environment based on theory can also serve a similar purpose.

8.2. Value of this Research

To users

Partial motivation for making this prototype come from my own frustration during my tour in botanical gardens and nature-themed art exhibitions. This prototype was made with the hope to create a more inviting way to learn and care about nature while also creating a surprising effect to stimulate deeper reflection. From participants' reaction to their experiences, the prototype with the involvement of soft robots appear to have quite positive entertainment value, and the cultural narratives then helped to provide a concrete context to stimulate active exploration of the topic afterwards. It therefore could be considered as a potential way for museums or botanical gardens to incorporate installations alike for a better learning experience for visitors that want to learn about plants.

To academics

This research introduces an explorative design method for academics commencing research with abstract theories, particularly in the More-Than-Human domain. Historically, the More-Than-Human concept has primarily existed as an abstract philosophy, offering limited guidance on its practical integration into research methodologies. This stands in stark contrast to prevailing academic research approaches, which often advocate for applied methods characterized by rigid frameworks.

By combining three distinct More-Than-Human design strategies, I developed research methodologies tailored to my specific requirements, while ensuring their academic validity. The exploratory research procedures ultimately brought attention to the deficiency in effectively communicating cultural aspects of plant information through interactive means. This highlights the efficacy of the More-Than-Human design approach in identifying potential research goals.

This paper not only identifies a novel research topic but also goes a step further by making and evaluating a prototype. It serves as both an example of the evaluation process and a practical tool for designers and social researchers interested in exploring the impact of integrating soft robot technology for communicating biological information.

To myself

To myself, the various strategies employed, though not necessarily the most efficient, offered a unique lens to observe and understand the intricate relationship between humans and plants. Particularly noteworthy is the ethnographic approach. Through observing the signals collected from various plants, I realized that plants react to environmental changes differently depending on their specie, age, and size. Despite the absence of signal changes in the trees tested during my interactions, my respect for them grew, acknowledging their autonomy and robust, independent living systems.

The research process also played a role in my personal growth in taking on a research project independently. Without solid design or biology knowledge in the past, I took quite a challenge in learning and integrating design strategies into practice, to relying on the process of RfD and RtD. Although it was a struggle to dig through a large amount of broad information and to make proper connections, this practice has used proven design methodologies in exploring and constructing yet-to-be-found research contexts. It taught me to live with flaws and imperfection and be resilient throughout the process.

To More-Than-Humans

Being in the field of More-Than-Human design, I would of course like to also discuss the value of this research to plants. Although this research result focuses mostly on the effect of the interaction project on human participants, the overall aim is to find a more engaging way to communicate plant information. In the long term, improved societal perception and heightened awareness of both urban greenbelts and plants could help plants to be considered throughout a decision-making process, or even influence people's decision on who to vote for. Positive feedback from participants therefore highlights the potential of this research in bringing society a step closer to the More-Than-Human wish.

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Appendix A

Sensibility differences between human and plants

Sense of touch

Our sense of touch, facilitated by various receptors in our skin, not only allows us to perceive sensations such as pressure, temperature, vibration, pain, and texture, but also plays a crucial role in decision-making and is closely linked to feelings of compassion (Keltner, 2010; Hsu, 2010). While plants cannot feel touch sensations as humans do, they can respond to mechanical stimulation in unique ways, adapting to their environment. Interestingly, mechanical stimuli not only act locally but also trigger the transmission of electrical signals to different parts of the plant (Chamovitz, 2013).

Sense of sight

For most human, our sight is the main information source to understand the world. The visual system provides us with rich information by enabling us to translate light signals ranging from 380 to 720 nanometers into images (Hadhazy, 2022). Unlike human vision, plants do not convert light signals into images; instead, they translate light impulses into growth-related stimuli. They also perceive a broad range of light spectra, including UV light and radio waves, beyond human perception. Despite biological differences, both humans and plants are influenced by circadian clocks, regulated by their respective blue light receptors (Ibid.).

Auditory system

Humans' auditory system, in conjunction with brain processing, enables us to experience a wide array of sounds and frequencies ranging from 20 to 20,000 Hz, with the spectrum between 2,000 and 5,000 Hz being most sensitive to our ears (Gelfand & Calandruccio, 2023). While many of us tend to immediately relate sound to music, studies have shown that plants do not seem to react to music (Scott, 2008). Plants reaction to sound link closer to their evolutionary needs, a study has shown that plants' roots bend to the 200 Hz frequency transmitted through water, suggest that plants might be searching water by detecting sound (Rodrigo-Moreno et al., 2017). A recent research also found that many plants emit ultrasound undetectable by humans when under stress, though the effect of such behaviour on their neighbouring plants are not yet discussed (Caton, 2023).

Sense of taste

Our senses of taste and smell, activated by receptors in the mouth and nasal passages, contribute another layer of perception to our experiences. Taste buds allow us to distinguish between sweet, sour, bitter, salty, and savoury flavours, while our olfactory system detects numerous chemical compounds (odorants), even in minute quantities, closely tied to our emotions and hormone levels (Sharma et al., 2019; Chamovitz, 2013). Plants of course can not taste flavours the same way as a human do, instead they sense the amount of perceivable chemicals to decide weather to root deeper for more nutrients and to communicate with other organisms by emitting unique substances. In terms of olfaction, plants can quite literally smell pest attacks or potential nearby host plants by sensing volatile chemicals emitted by neighbouring plants, allowing them to react to environmental changes (Chamovitz, 2013).

Sense of space

Lastly, for humans, the sense of space and gravity provides spatial cues like distance and depth, aiding our movement and environmental orientation. As for plants, gravity force induces not only phototropism in their root and stem growth but also the period and speed of their circumnutation behaviour during growth. Studies indicate that plants orient their growth direction according to gravity, while stems grow in the opposite direction while roots grow in the same direction as the gravitational force (Ibid.).

Appendix B

Case summaries

Homo Viridis (Christiansen et al., 2020)

Figure 16. Homo Viridis prototype

Homo Viridis (Christiansen et al., 2020) embodies a hybrid environment in which the traditional demarcations among humans, technology, and plant life have become increasingly indistinct. This exposition delves into the human perception of our surroundings, probing the capacity for us to comprehend the potential experiences of other living organisms. Conceptually, the researcher interlinks the term 'entity' with the posthuman concept, aimed at understanding the effect of mediating human and plant entities through the application of soft robotics. This exploration of a 'posthuman entity' not only refers to the material unit involving human visitors, the Monstera Deliciosa plant, and the prototype of the soft robot sleeve exhibited (see Figure 16), but also encompasses the abstract discourse elicited by the presented experience.

Here, the soft robot is used as a wearable sleeve to provide a new layer of haptic feeling to the human visitors. The aim is to enable plants to influence the human physically so to blur the boundary between the humans and plants. As a result shown by the analysis of ten interviewees who visited the installation, an increased level of empathy was expressed by some. Moreover, many formed a deeper realization of the different sensibilities plants and human possess. As for the material characteristic, many considered it uncomfortable to wear, while some noted the organicity brought by the soft silicone. The unexpected movement of the soft sleeve also enhances its creature-like feature.

Entangled Habitation: the second organs (Xiying, 2023)

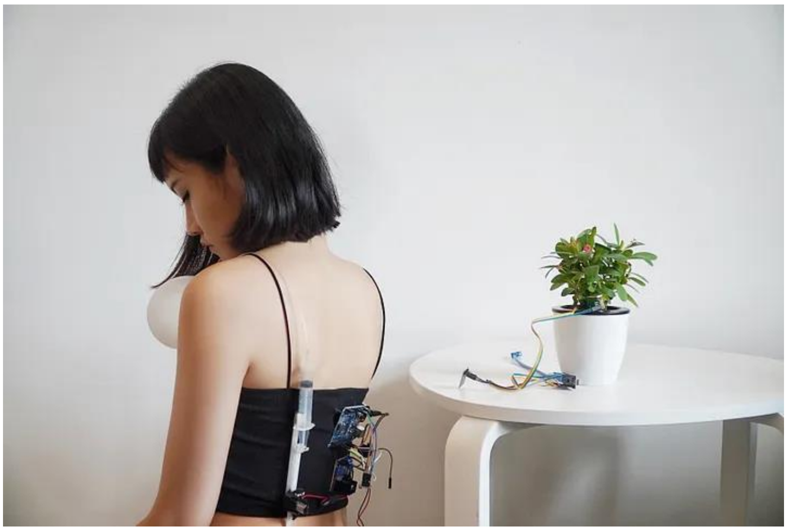

Figure 17. The placement of the air bag

Entangled habitation looks into the potential of shifting from a mere aesthetic focus towards a more interconnected and engaged experience of plant care. The research delves into the impact of a plant-human cohabitative relationship on perceptions. The investigation begins with the practice of art of noticing, which involves detailed plant observation facilitated by multiple sensors from humidity, temperature, heat, photosynthesis, to motion, revealing concealed plant behaviors often unnoticed by humans. The researcher took an auto-ethnographical approach and came up with three speculative artifacts to facilitate interaction with plants, acting as conduits for studying the evolving dynamics of plant-human relationships.

The third artifact shown in Figure 17, "Breathe Together", uses soft material to materializes the concept of shared respiration. The author emphasizes the entanglement of both human and plant needs for air, and designed the wearable based on the O2 and CO2 exchange happening between plants and humans. Soft robots play a crucial role in rendering the otherwise imperceptible air exchange processes visible to humans. While the precise magnitude of carbon dioxide (CO2) transformation into oxygen (O2) by plants remains uncertain, a smart utilization of fluctuating CO2 levels contributes to a comprehensive narrative. This narrative suggests that every exhalation we do is absorbed by nearby vegetation for its sustenance. The synchronization between our exhalations and the inflation of an air sac creates the illusion of shared respiration with the plant.

Symbiome (Spačal, 2016)

Symbiome embodies a biotechnological sound installation that delves into the intricate realm of symbiotic relationships across diverse species. These relationships perpetually adapt to trophic demands and environmental circumstances. Saša Spačal defines symbiosis as a profound, enduring biological interaction among diverse organisms, encompassing mutualism, commensalism, and parasitism. Drawing an analogy, she likens this endeavor to a streamlined economic system founded upon symbiosis, accentuating successful interspecies evolutionary processes characterized by mutualism, cooperation, and negotiation.

Figure 18. Symbiome in exhibition

To bring this concept to fruition, Spačal constructs a miniature ecosystem housing a red clover plant (*Trifolium pratense*) and bacteria from the genus *Rhizobium* (see Figure 18). These selections are predicated on their reciprocal advantages and their role in the human symbiotic relationship within food production. The red clover's association with rhizobia proves pivotal for crop rotation, given the nitrogen-enriching capabilities of rhizobia that rejuvenate depleted soil. Rhizobia produce atmospheric nitrogen, inducing acidification around the clover's roots, which is indispensable for plant growth, amino acid, protein, and DNA production due to the inherent scarcity of atmospheric nitrogen in nature.

Within this installation, the survival of both species is facilitated through a biological feedback mechanism. Nitrogen fixation levels in the hydroponic solution indirectly impact water dripping speed. Elevated symbiosis results in swifter water flow and more pronounced ripples on the water surface caused by droplets. A light sensor discerns these ripples, translating the symbiotic process into sound through an interface. The generation and filtration of real-time sound transpire via phase modulation, which maps temporal and spatial symbiotic nuances, yielding a sonic representation. Consequently, the sonic output becomes an abstract cultural representation of the ongoing negotiation between the clover and rhizobia, inviting interpretation and contemplation from visitors.

Flora Luma - an Agential Provotype (Frankjaer, 2017).

To cultivate a dialectical process of critical examination regarding the foundational assumptions and beliefs that underlie our prevailing exploitative and anthropocentric value system, Raune Frankjaer introduces the concept of "agential provotypes." Initially introduced by Mogensen in the early 1990s, provotypes serve as tools during the initial stages of innovation to comprehend individuals' accustomed experiences of various phenomena. Their objective is to reveal and illuminate disparities within current practices that may not be readily identified as problematic. Instead, they are viewed as a starting point and a potential catalyst for transformation (Mogensen, 1992). Expanding upon this framework, the concept of agential provotyping broadens its application by utilizing provotypes to unveil overlooked yet pivotal aspects of reality.

In this pursuit, the author presents "Flora Luma" (see Figure 19) as an interactive installation designed for public engagement and interaction with plants, whose imperceptible activities evade human awareness. This project employs EMG sensing technology to collect the electrical activity data of the respective plants, directly influencing the changing speed and colour of each lighting element within the Flora Luma installation. Subsequently, these changes are visually manifested to enthral the audience through aesthetic brilliance upon their haptic interaction with the plants. Additionally, Frankjaer introduces the concept of "tactics of aesthetics," suggesting that engagement fuelled by experiential beauty possesses significant potential in nurturing empathy and cultivating care.

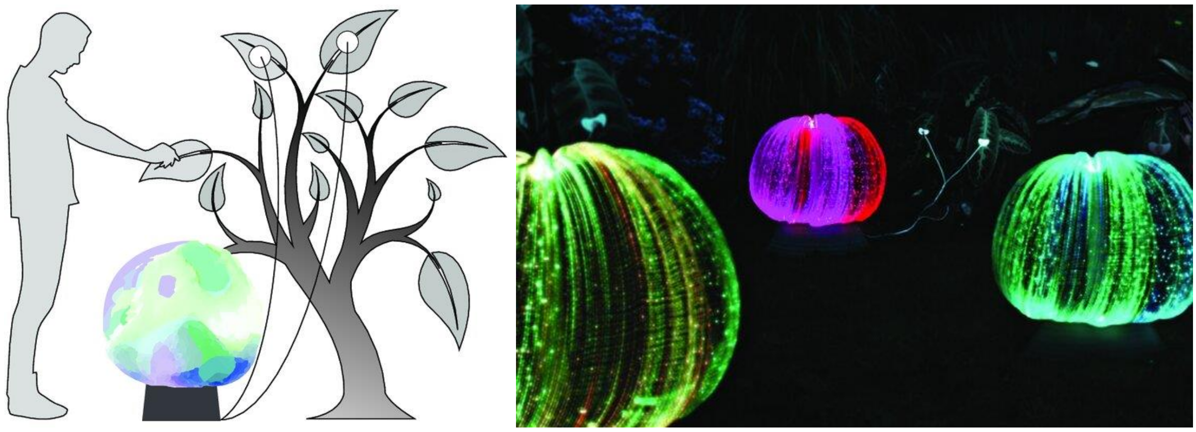
Figure 19. Interaction sketch and display of Flora Luma

The objective of this project is to challenge prevailing notions of the vegetal world, which often depict plants as passive entities, by employing visual aesthetics facilitated through haptic interaction. This project was unveiled at Nizza Park, where scientists and designers engaged in meaningful discussions with the visitors. The lighting elements served as a visual attraction, enticing close-up observations. Additionally, the connected hardware, affixed to the plants, piqued visitors' curiosity and encouraged them to engage in interactive experiences. The collective outcome demonstrated a considerable level of public interest and curiosity, primarily driven by the visual appeal of Flora Luma. However, it is noteworthy that the audience's fascination with plants appears to be more profoundly influenced by the explanations provided by the on-site scientists.

Furl (Galperina, 2014)

Mangion and Zhang undertook an investigation into the integration of soft robotics and kinetic designs within an architectural context, aiming to engender a distinctive spatial experience (Chung, 2014). Drawing inspiration from the work of the Whitesides Research Group at Harvard, particularly their development of PneuNets (pneumatic networks), the researchers fabricated a series of transparent soft silicone actuators characterized by their minimalist design.

Subsequently, they harnessed advancements in pliable silicone casting techniques for "air muscles" in conjunction with Electroencephalography (EEG) technology. This innovative amalgamation enabled the construction of an architectural structure capable of responding to human brain activity. In effect, this approach forged an emergent interplay between architectural elements and human occupants. The previously inert and static nature of the constructed materials yielded to a state of vitality, becoming responsive to fluctuations in human brainwave patterns.

Figure 20. Furl EEG reaction

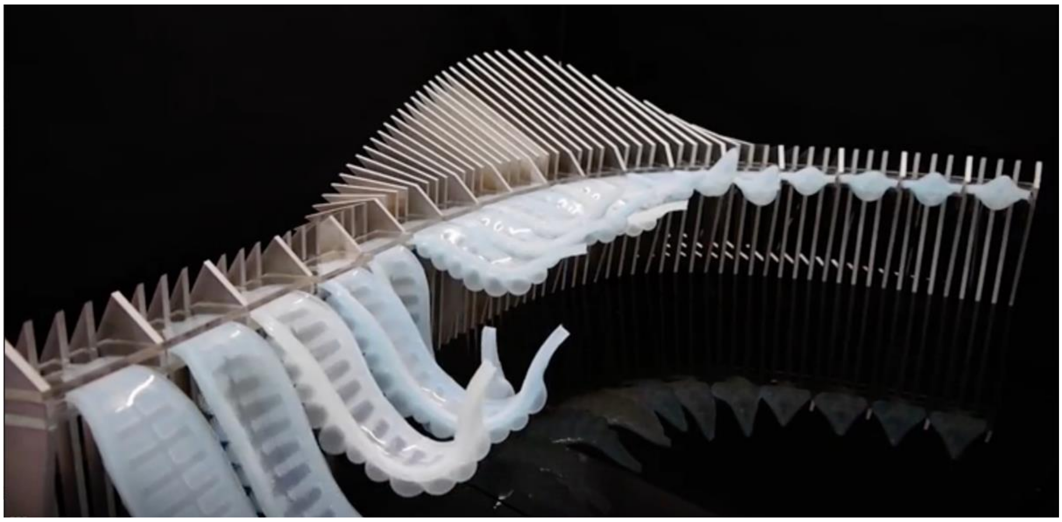

Figure 20 shows that the design of soft materials forming into small tentacles affixed to the metallic base. The installation draw a distinct parallel between the organic motion exhibited by the harmonic composition of soft tentacles and its static silver supporting framework. This arrangement of soft tentacles surrounding the visitor fosters a genuine immersive experience, evoking the sensation of inhabiting a living architecture synchronized with one's thoughts.

Sarotis (Aghakouchak, 2016)

Within the realm of human cognition, screens emerge as a profoundly influential and potent instrument, assuming a cybernetic role that transcends the mere facilitation of positive user interactions with technology (Aghakouchak, 2016). In light of this phenomenon, Paneta and Aghakouchak have undertaken an investigation into the concept of "Sarotis." Derived from Greek, "Sarotis" denotes a scanner or an apparatus designed to assimilate comprehensive information. In their research, Paneta and Aghakouchak have orchestrated diverse experimental prototypes, guided by an inquiry into the transformative potential of technology on human-world interactions.

Figure 21. Sarotis appearance and mechanism

Their study delves into the prospect of heightening human spatial awareness through the integration of real-time 3D scanning in conjunction with soft robotic wearable technology. Figure 21 shows the system design of the prototype. Sarotis harnesses the capabilities of soft robotic to emulate the tactile qualities of human skin. The aesthetic dimension is carefully addressed, encompassing nuanced explorations of color intensity, elasticity, and the visual manifestations of inflated pneumatic networks. The empirical findings from their effort suggest the viability of deploying this design either for individuals with visual impairments or as an instrumental apparatus in the construction of virtual domains endowed with physical actualization (Paneta & Aghakouchak, 2016).

Appendix C

Explanation of collected codes through the art of noticing

dc1: Valuable aspects of plants

Biological processing abilities

In regards the biological processing abilities of plants, many interesting thoughts are mentioned during the interviews. There are two main aspects can be differentiated from all the answers. The first aspect, concluded from two botanists' response, points to the general importance of plants to human and ecosystems due to their biological processing abilities. Whilst the second aspect relates more to the surprising similarities of various biological processing abilities of plants as almost motionless beings to humans and other animals. Here the biological processing abilities of plants serves not only as a reminder of plants as living beings. Its correlations and interactions to the changing surrounding also explain the importance of these biological abilities in regards to human and the broader ecosystem.

Plants' importance to the broader ecosystem is reflected in the answer of one of the interviewees as follows: "I think that's the most admirable about plants, and their ability to also establish all sorts of partnerships and relationships with other species, like, obviously, fungus and insects … understanding how another organism can perform in such a level that we can never achieve in itself extends our own kind of perspective towards the world". To further clarify, I took inspiration from both the suggested plants biological processing abilities by interviewees and the plant sensing abilities discussed previously in Appendix A, "Sensibility differences between human and plants". They are respectively sensing abilities including seeing, smelling, tasting, hearing, touching, and the sense of gravity; the ability to establish negotiable relationship with other species; the adaptation ability to the changing environment.

Intricate cultural interplay between plants and human

The second category, overlooked in the desk research, pertains to the cultural significance of plants. Like the biological processing capabilities of plants, this category also encompasses two primary aspects. First, it includes the historical colonization linked to the utilization of valuable plant resources. Second, it involves the human influence on the evolutionary advancement of specific plants. These aspects sway a bit away from the plant centered view, but nevertheless brought up really interesting ideas on how the cultural interpretations around plants have played a role in the history of both human society and plants evolution. Although both aspects see plants as rather a passive subject to be interpreted and controlled by humans, which do not fit with the message this thesis wants to convey, they nonetheless provide a compelling narrative framework that facilitates profound contemplation. One good story mentioned by one of the interviewees was the cloning of identical trees to fit the market's ideal image of a Chirstmas tree.

dc2: Techniques for conveying information

Traditional approaches

Botanical experts typically adopt traditional approaches, employing methods such as courses, lectures, news reports, and guided tours to communicate definitive information to the public. While digital technologies like GPS and mobile apps are accessible to visitors, interactions predominantly remain unidirectional, with visitors positioned as passive recipients of information. In addition, information is also communicated for research purposes. One interviewee mentioned "we are actively looking for citizens who are helping us in generating or looking for data for the PhD … we are also using some newly developed things like identify apps, so apps identify whatsoever they are used for". In general, these technologies seem to primarily serve to either substitute human indicators to enhance the overall visitor experience with greater efficiency, or to be used as a tool for more practical use.

Reflective approaches

Conversely, designer interviewees gravitate towards a more reflective approach, aiming to convey abstract concepts that encourage extended exploration. They achieve this through avenues such as small group workshops or the creation of wearables that facilitate novel forms of physical perception and nurturing interactions. Additionally, they tend to present speculative projects artistically, fostering discussions and stimulating discourse. Though all designers have reflective practices as the foundation of their communication technique, these practices serve different goals for different designers. Comparison between the answers of a product designer and a interaction designer shows that for the product designer the goal of the practice is to generate innovative product concepts, while for the interaction designer the aim is to explore what kind of interaction or reflection their prototype can bring out.

In line with the objective of this thesis, which seeks to develop a new form of HPI to communicate plant information, a reflective approach emerges as particularly advantageous. However, there is a limitation in this technique, as it could appear to be too abstract to grasp under an inadequate context. Same can be applied on the more traditional information distribution techniques mentioned by the botanical experts. If more connections are made between the definitive facts over plants and its relation to our life, we might be able to trigger a more meaningful discussion. This can be concluded by another interviewee's answer, "I usually will try to first learn their (refers to the workshop participants) language, and then seamlessly to introduce a non-human perspective into their practice. And I see that is more convincing or make people have more comfortable to, to start to change your perspective a bit".

dc3: Challenges associated with human-plant interaction

Ethical debate

I was pleasantly surprised by the variety of responses provided by interviewees regarding the challenges linked to human-plant interaction. Similar to interactions between humans and animals, the ethical discourse emerges as a prominent concern in the realm of human-plant interaction. Half of the interviewees emphasized that plants have traditionally been perceived merely as resources for human exploitation, often disregarding their status as living organisms. One of the botanical experts explains that unlike animals, which can express their preferences based on their circumstances, plants lack the ability to exhibit such behavioral responses.

Furthermore, the absence of pain receptors in plants complicates the ethical deliberation, as these living entities can endure damage without experiencing pain.

Limitation of humans

Another challenge agreed on by many interviewees are the limitations of humans. One of the designer interviewee states “no matter how we discussed right now, we are still human. I think because the plant doesn't have facial expressions. So we don't actually empathize or we don't feel sad for those dying plants”. While humans possess the distinctive capability of empathy, this attribute is not without constraints. Our responsiveness is confined to the semantics within our own linguistic and symbolic framework. Moreover, delving into the imperative of extending empathy towards plants introduces a quandary; the inclination to romanticize the scenario further underscores the intricate emotional nature of human beings.

Inadequate interactive representation of plant-centred narratives

The final challenge mentioned is the excessive technical focus in the field of human plant interaction in recent years. A wearable designer answers like such, “once there are some technical examples that came out or early designs that came out, and which lots of later project follow suit. There is a lack of understood exploration into a non technical way of relating to the plant, … those rich relations, entanglement between plant and human societies, it's never really able to, to be explored by merely, you know, looking into some signals of the plant”. This answer drives us back to the gap between the traditional technique and the reflective technique of communicating plants information to the public under the category of dc1.

As previously analyzed, during interviews, botanical experts primarily utilize a unidirectional traditional approach, offering precise information and a linear narrative. In contrast, designers often employ a reflective method characterized by interactivity and the exploration of abstract concepts. In my view, the final challenge, to conclude the wearable designer’s answer, revolves around the underrepresentation of thoroughly researched plant narratives and well-defined information in a compelling interactive format.

Processing codes

Reading

Figure 22. From left to right: Booklet guides/ A man reading a small sign/ Background explanation.

From the left picture to the right one in Figure 22, each presents a different form of information displayed in texts. On the left picture, is the booklets shelf, it is placed right at the entrance. There are five kinds of booklets available to different visitors. Two of them are in English, one calls for the use of the Hortus mobile app, and the other one provides general information about Hortus Botanicus Amsterdam with its visiting routes mapped out. The remaining three booklets are all in Dutch, one describes plant attractiveness more extensively, and the other two are about a general insights relating to Hortus Botanicus Amsterdam. On the middle picture, we see a visitor checking the sign of a corn plant. According to the staff I have interviewed, these signs are all written in Dutch, and are kept small deliberately to avoid distraction from focusing on the plants themselves. The picture on the right, explains the historical and geographical relation of cycads and the Netherlands, it is presented both in Dutch and English.

Seeing and Listening



Figure 23. From left to right: A woman check a butterfly/ A man seek the direction of chirps/ Visitors check bee activities.

In their collaborative publication, educational psychologist Wandersee and biologist Schussler elucidate the human inclination to perceive non-flowering plants primarily as an undistinguished green mass, particularly when in motion or observing moving objects (Knapp, 2019). Walk inside the botanical garden, it is not hard to notice that most visitors are more often intrigued by moving creatures like butterflies and bees, while paid little attention on the surrounding plants. In the middle picture of Figure 23, we see a man looking upwards seeking for the trace of bird that was making chirps. Occasionally, I would see people carefully observe a flower due to its unique appearance. Not only the visitors, being surrounded by the green environments, I also find myself easily distracted by external factors like sudden movement, vibrant colours, and distinctive sounds.

Following tours


Figure 24. From left to right: A tour group/ A woman holding the tip of a tree branch.

During my observation, I noticed that the majority of visitors in the botanical garden engage in casual conversations while walking. Only a limited number of individuals pause to genuinely engage with the plants, utilizing senses beyond just sight. An exception to the norm was exemplified by a tour group I encountered (see Figure 24). In the accompanying image, the lecturer is depicted holding the tip of a tree branch, providing explanations to the participants. While I may not have comprehended the specifics of the discourse, the actions of the tour members conveyed their intent. They sought a heightened understanding of the tree in question, not solely through visual observation, but also by engaging their sense of touch and smell, guided by the lecturer's verbal instructions.

Acting by the guiding signs

Figure 25. From left to right: A Kalanchoe Beharensis Drake with a touch sign/ Two visitors touching the plant/ An Acorus gramineus Aiton with a pluck and taste sign/ A visitor plucking the leaves.

In Figure 25, a variety of plants are showcased alongside informative signs, aimed at fostering meaningful interaction between visitors and the plants. The photos feature a Kalanchoe Beharensis Drake and an Acorus gramineus Aiton, each residing in separate pots with dedicated labels. These supplementary signs act as guides, directing visitors to explore the unique characteristics inherent to each plant. Unlike the small descriptive signs scattered around the open area, these signs introduce a tangible dimension to the visiting experience. They offer a distinct opportunity for visitors to engage with the plants physically, facilitating a hands-on learning experience.

Relating

Figure 26. From left to right: A pineapple plant with the image of its relevant food product/ Plants with the images of their relevant food products/ An old picture of Cycas plant marked with American scenery.

In our contemporary society, the practice of cultivating our own food has become increasingly uncommon. Despite the fact that a significant portion of our essential nutrients is derived from plants, the prevalence of a highly industrialized food industry has led to a notable detachment from experiencing these food sources in their unprocessed entirety. While we possess knowledge regarding the origins of our sustenance and the pivotal role that plants play in providing us with vital nutrients, there exists, at least in my personal experience, a distinct emotional response upon encountering these crops in real life. In Figure 26, the first two pictures above depict the raw state of plants at their source, alongside their final products as displayed in a supermarket. The third picture, on the other hand, was taken through the lense of an old image display box, showing how this archived plant image was exhibited few decades ago.