FloraWear: Wearable Living Interface

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ABSTRACT

While nature can benefit people both mentally and physically, contemporary society has become increasingly disconnected from nature. To rebuild a stronger connection with nature in our everyday life, we introduce FloraWear, a do-it-yourself, wearable living interface, that enables people to easily and closely connect with plants. This pictorial introduces how knowledge is built and shared with others using hybrid craft and fabrication, illustrates the material experiments and design development for FloraWear, and discusses how it affects wearers. Then we summarize how FloraWear can help catalyze a shift in people's perspectives towards nature. By developing emotional ties to their wearable plants, FloraWear wearers begin to understand that both they and their plants are part of an ecosystem.

Authors Keywords

DIY; flora; nature; plants; wearable; well-being

CSS Concepts

• Human-centered computing → Interaction design.

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Fig. 1. Wearable living interface, FloraWear

1. INTRODUCTION

In urbanized areas, we live in discord with nature. The more our lives are industrialized, the more disconnected we become from nature. FloraWear (Fig. 1), a wearable living interface, is an alternative, craft-based design solution to this disconnection. FloraWear is about getting closer to nature not only by growing plants but also by wearing them.

Wilson's biophilia hypothesis posits that people are naturally inclined to "life and lifelike processes" [41]. Not only do people enjoy being around and interacting with nature, but they also benefit from it (Fig. 2). Studies show that interacting with plants can have positive impacts. Plants can help improve attention levels [18], increase work productivity [24], and speed recovery from stress and injuries [38, 39]. Stress relief can come not only from the nearby presence of real plants, but also from remote views, prints, photographs, and digital renderings of nature [4, 30]. Pretty categorizes three levels of interactions with nature – viewing nature (whether it is live, printed, or digitally displayed), being in or nearby nature, and actively engaging with nature and found that all levels of interactions with nature benefited participants' physical and mental health [29]. However, building and maintaining indoor or outdoor gardens requires space, time, labor, and cost. Therefore, nature may not be present when and where we need it most (Fig. 2).

As an alternative, FloraWear encourages users to be close to nature and provides active engagement with various sensory interactions such as visual, tactile, olfactory, and gustatory experiences. During the pandemic, people have been isolated with limited physical person-to-person interactions and stressed by the precarious times and uncertain future. Our motivation is to improve human well-being through regular interaction with nature via FloraWear. By wearing plants on their bodies, people can feel closer to plants and may build empathy with them. We posit that this wearable device can help its wearers develop intimate physical and empathetic connections to plants so that they benefit from biophilia. Since action and meaning and thus motion and emotion are closely coupled in a feedback loop [7], we hypothesize that wearing FloraWear can both consciously and unconsciously influence the wearer's emotions.

In order to empower users, FloraWear engages them in the design process with a do-it-yourself (DIY), open-source application (florawear.netlify.app) for designing custom jewelry that serves as a reusable wearable substrate for growing plants. Users can go to the FloraWear website, choose a basic type of jewelry such as a necklace, ring, or bracelet (Fig. 3), manipulate parameters to change the form of the jewelry, download their 3D files, and then 3D print their customized wearable. Users then grow plants from seed in the wearable, take care of their plants while wearing the jewelry, and may eventually choose to harvest their plants. FloraWear can be reused and replanted after up to thirty days of wearing (Fig. 4). Findings from interviews with twenty participants who tried FloraWear for up to two weeks reveal how

Fig. 2. Benefits and limits of plants

Fig. 3. Different forms of FloraWear: (a) necklace, (b) ring, and (c) bracelet

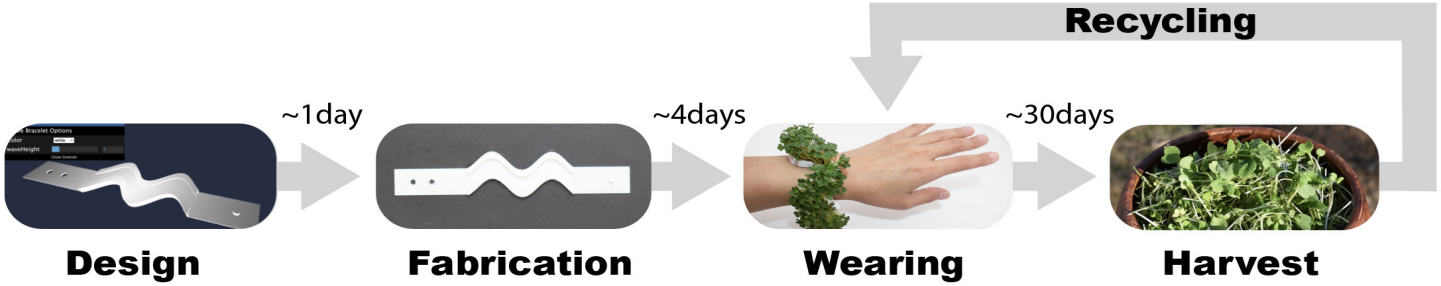


Fig. 4. Cycle of FloraWear

living wearables can build strong physical and emotional connections with nature. Furthermore, the study showed the FloraWear positively influenced participants' emotions and behaviors.

2. BACKGROUND

In this section, we situate our work in prior HCI research exploring the intersection of humans and plants. We describe FloraWear as a form of hybrid craft in which interactions with materials played a significant role in shaping our design process and the FloraWear experience.

2.1 Nature in HCI

HCI researchers and practitioners have investigated ways to enhance the positive impact of nature [19]. Devices have been explored to visualize plants' conditions using digital components to understand plants' emotions and needs, communicate with plants better, and take care of plants effectively [8, 17]. With such devices, plants can display, call, or tweet messages when they need to communicate with humans. These projects enable mostly one-directional communication between plants and humans. Researchers have also utilized nature as input or output devices to enable more organic, dynamic interactions between humans and nature [1, 28, 31, 34, 37]. These researchers have used diverse materials to detect the proximity and intensity of interactions with nature. For example, the BIOdress is a body-worn interface that changes in response to environmental conditions based on sensing via a plant in the physical environment [1]. Researchers have combined conductive materials with plants and measured multiple frequencies from plants. They have presented these sensor values as audio, visual, or physical outputs. These organic interfaces are intriguing due to their intrinsically ambiguous and mysterious design values [13]. Living interfaces are also exemplars of slow design [12, 26], which emphasizes well-being through sustained and extended engagement with, reflection on, and evolution of artifacts. To emphasize the value of living together with other species, design probes for cohabitation and collaborative survival have been introduced to HCI [23, 36]. Tools have been developed to encourage mutually beneficial interactions between humans and non-humans, while reminding us that humans are part of ecology. HCI researchers have recently begun to cast a critical lens on the co-living perspective [5, 6, 9]. To prompt reflection about our relationship with nature, FloraWear explores a direct, immediate way of co-living with nature by wearing plants.

Biodesign is an emerging research area that explores how integrating biological processes and computing technology leads to new interactive experiences [16]. Examples of biodesign in HCI include interactive museum installations that enable participants to playfully use tangible tokens to engineer synthetic bacteria [25, 27] and the MicroAquarium, a digital-biological installation that enables human interaction with photo-tactic organisms by taking advantage of how these organisms respond to light [22]. FloraWear entails an alternative form of biodesign, supporting direct interactions with biological matter and processes rather than mediation through computing technology, such as simulations or virtual constructs. We explore the relationship between physically close interaction with plants and emotional influences on the wearers in the context of biodesign.

2.2 Hybrid Craft

Recently, HCI has taken a significant interest in craft-based inquiries that integrate digital and physical materials in the creation of artifacts. Frankjær and Dalsgaard identify four terms in the literature that describe these integrative processes – hybrid, digital, computational, and technocraft [10]. *Hybrid craft* is "everyday creative practices of using combinations of physical and digital materials, techniques or tools,

to make interactive physical-digital creations" [15]. *Digital craft* is using digital tools, such as CAD, procedural design, and 3D printing, to design and fabricate physical objects. Blauvelt et al. identify *computational craft* as the intersection of two diverse domains, crafting and computation, and their material products, physical artifacts and computational resources [2]. *Technocraft* emerged "from craft practice with relations to Maker culture, taken loosely to mean a crafting approach to digital technology" [10]. At times, these terms are used interchangeably to describe a complex and fuzzy domain. FloraWear exhibits characteristics of hybrid, computational, and digital craft. The open-source application provides a digital tool for computationally designing and digitally fabricating a personal wearable device. In terms of materials FloraWear combines natural media such as seeds and jute fibers with digitally mediated, 3D printed thermoplastic polyurethane (TPU).

2.3 Materials Experience

Material and craft are deeply intertwined. We draw upon Giaccardi and Karana's [14] framework of materials experience to discuss how the organic and inorganic materials of FloraWear shaped our design process and the experiences of our participants. Their framework "provides designers with a vocabulary to describe a materials experience pattern, i.e., the characteristics of the situational whole in which properties of a material, the artifact in which a material is embodied, one's previous experiences and expectations, and social and cultural values affect our encounters and performances with and through objects." They differentiate four levels of experience with materials: sensorial, interpretive, affective, and performative. The *sensorial level* represents the initial encounter with materials formed through vision, touch, smell, and sound. Sensorial experiences are then understood at the *interpretive level* as we develop situated meanings for materials. The resulting interpretations evoke emotional responses at the *affective level*. The combination of senses, interpretations, and emotions directs our interactions with materials at the *performative level*. FloraWear provides strong sensorial experiences with organic plant materials as a core design element. Everyday interactions with FloraWear can provoke thoughts, emotions, and even behaviors at interpretative and affective levels. We envision the living materials of FloraWear acting as co-performers at the performative level.

3. METHODOLOGY

We investigate the effects, implications, and influences of FloraWear through material experiments and user studies.

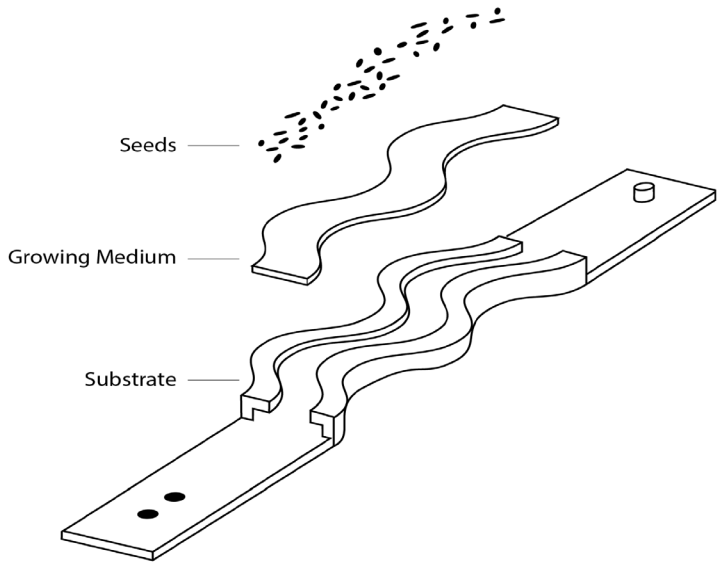


Fig. 5. FloraWear layers

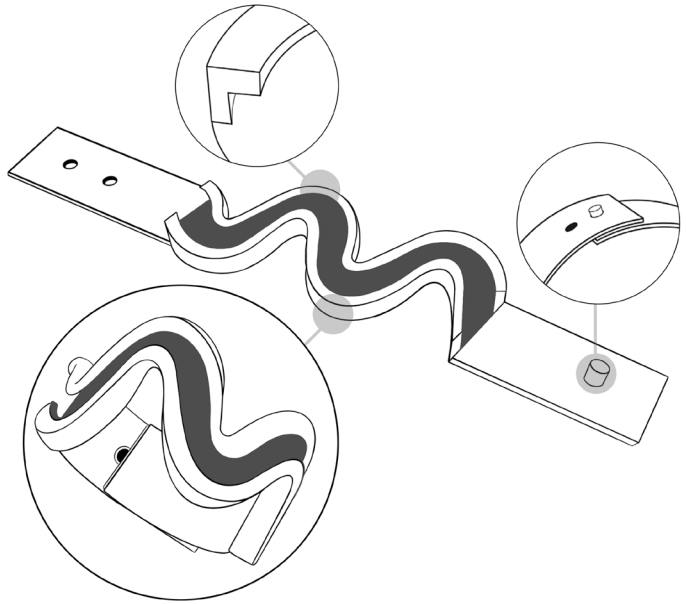


Fig. 6. FloraWear design elements: clasp, rim, and flexible structure

3.1 Material Experiments

In designing FloraWear, we experimented with different materials in an effort to craft intended experiences at sensorial, interpretive, affective, and performative levels. FloraWear consists of substrate material, growing medium, and seeds (Fig.5). We experimented with hard, soft, and organic materials for the substrate. As the substrate has direct contact with the body, it should be flexible, comfortable, water resistant, and safe for the skin. We experimented with fabric, threads, 3d printing filaments, mycelium, and roots [20, 21, 40, 42]. When FloraWear was made out of fabrics, threads, or roots, it became too wet for users' comfort as these materials are not water resistant. The particle size of mycelium proved too coarse and irregular to fabricate the interface as designed. Based on these material experiments we developed FloraWear with TPU filaments to print a flexible, yet sturdy substrate. The substrate has a thin rim to hold the growing medium in place. All details including the rim, clasp, and flexible bending structure were tested for usability (Fig. 6). We experimented with different materials for the growing medium such as coco coir, hemp, and jute. We studied how well these materials supported seed germination and plant growth. Due to the density of the material and its ability to support plant growth, we chose to use jute fiber mats for FloraWear. For planting, we explored

Fig. 7. Lab notebook

* M: Male, F: Female, B: Black, W: White. O: Orange

No.	Age(Gender)	Major	Accessories	FloraWear	Germination
P1	21 (F)	Digital Media	Everyday	Bracelet (B)	Yes
P2	22 (F)	Landscape Architecture	Everyday	Necklace (W)	No
P3	21 (M)	Landscape Architecture	Sometimes	Bracelet (B)	No
P4	22 (M)	Landscape Architecture	Sometimes	Ring (B)	No
P5	31 (M)	Landscape Architecture	Sometimes	Ring (B)	Yes
P6	33 (F)	Architecture	Often	Necklace (W)	Yes
P7	33 (M)	Digital Media	Sometimes	Necklace (W)	Yes
P8	28 (F)	Architecture	Everyday	Necklace (O)	Yes
P9	23 (M)	Mass Communication	Special occasions	Necklace (W)	Yes
P10	21 (M)	Painting	Everyday	Necklace (W)	Yes
P11	27 (F)	Art History	Special occasions	Necklace (W)	Yes
P12	26 (F)	Architecture	Sometimes	Ring (W)	Yes
P13	21 (M)	Computer Science	Often	Necklace (B)	Yes
P14	19 (M)	Computer Science	Often	Ring (O)	Yes
P15	21 (F)	Mathematics	Never	Necklace (W)	Yes
P16	19 (M)	Computer Science	Everyday	Necklace (B)	Yes
P17	19 (F)	Mathematics	Often	Necklace (B)	Yes
P18	19 (F)	Physics	Never	Necklace (W)	Yes
P19	20 (M)	Mathematics	Never	Necklace (W)	Yes
P20	20 (M)	Computer Science	Special occasions	Bracelet (O)	Yes

Fig. 8. Participants' information

different shapes, colors, textures, scents, and tastes from various seeds such as arugula, alfalfa, amaranth, basil, bean, beets, broccoli, chia, chives, cilantro, kale, mint, parsley, peppermint, radish, rosemary, thyme, sage, and wildflowers. Each plant has a unique aesthetic; they all differ in terms of density, height, color, angle, scale, and rate of growth. We observed each plant for up to thirty days to determine its germination period, rate of growth, color variation, height, scent, texture, and taste. Research notes and daily photos were recorded in a lab notebook (Fig. 7).

3.2 User Studies

3.2.1 Participants

We recruited twenty participants (nine female, eleven male) through emails, flyers, and word of mouth on the campus during the summer of 2021 and 2022. Participants were aged nineteen to thirty-three (with a mean of 23.3) (Fig. 8).

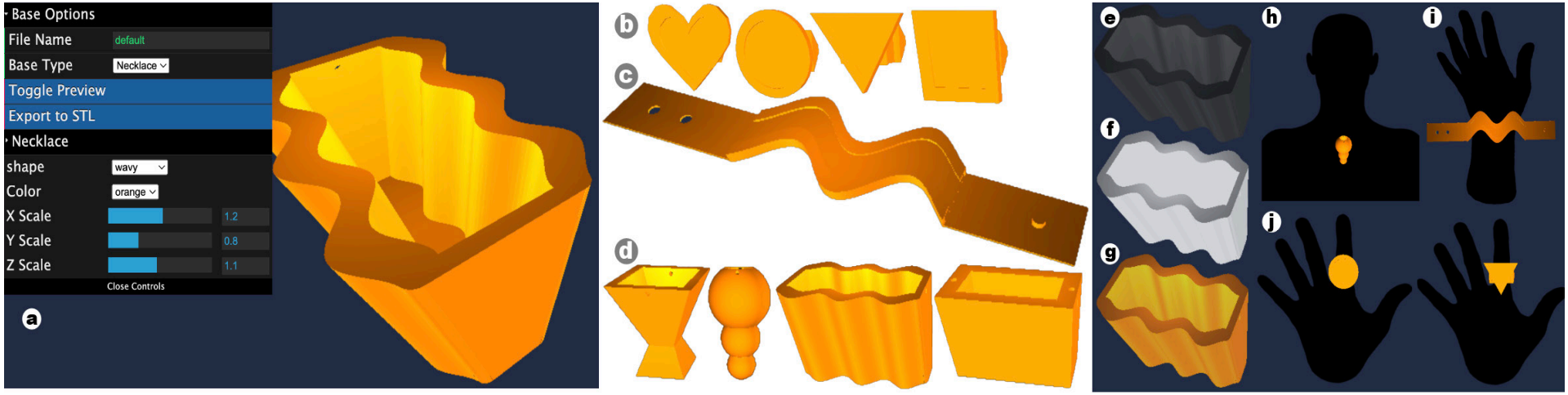


Fig. 9. FloraWear web application: (a) web interface, (b) ring, (c) bracelet, (d) necklace, (e) black filament, (f) white filament, (g) orange filament, (h) necklace preview, (i) bracelet preview, and (j) ring preview

3.2.2 Procedure

Participants experienced FloraWear in three stages – design, growing, and wearing. For the design stage, participants used the web application (florawear.netlify.app) (Fig. 9a), to design a piece of jewelry for their substrate (Fig. 10a). They selected one of three types of jewelry, either a ring, a bracelet, or a necklace. Options for rings include heart, circle, triangle, or square shapes. Bracelets have a wave pattern. Options for necklaces include pyramidal, spherical, wavy, or box-shaped pendants (Fig. 9b-d). After choosing a base type, they manipulated parameters for size and color to generate a custom design. They can choose either a black, white, or orange color filament and then see a visualization of their design being worn (Fig. 9e-j). After participants completed their designs, they exported stereolithography (STL) files from the web application and then 3D printed their interfaces (Fig. 10b).

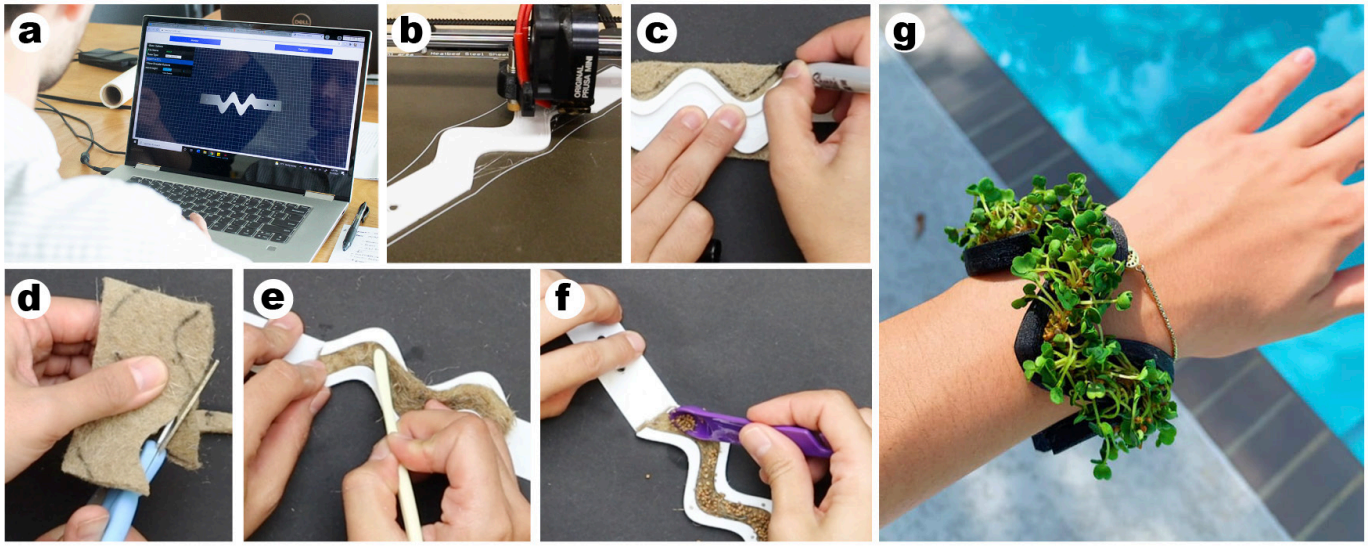


Fig. 10. FloraWear procedure: (a) substrate design, (b) 3D printing, (c-e) growing medium, (f) seeds, and (g) P1 wearing her FloraWear

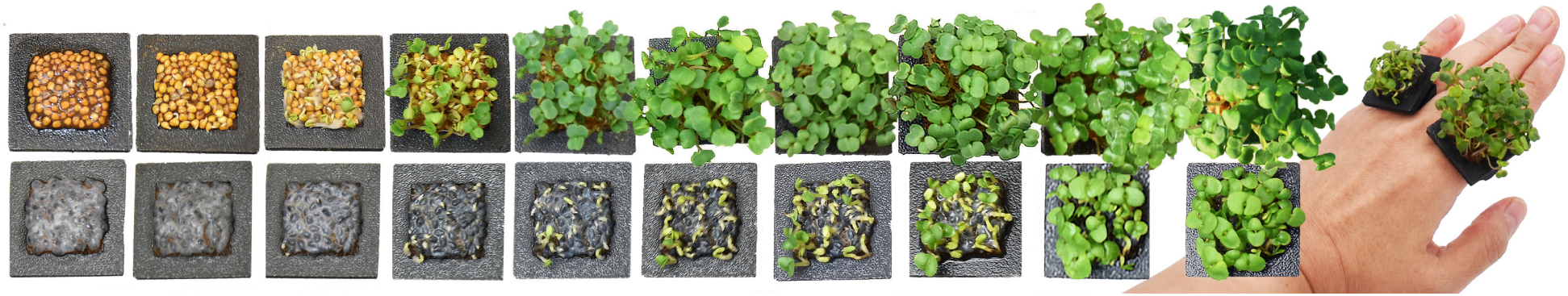


Fig. 11. FloraWear rings with arugula (top) and basil (bottom) for ten days

For the growing stage, participants chose a type of plant guided by photos from the lab notebook depicting recorded growth (Section 3.1). They cut and inserted the growing medium into the substrate (Fig. 10c-e). Then they planted seeds on top of the growing medium (Fig. 10f). Arugula and basil were most popular for their quick germination, fast growing speed, relatively portable size, appealing appearance, taste, and scent (Fig. 11). After sowing seeds on their living interfaces, participants regularly watered their plants and waited a few days until the plants germinated and became securely rooted. Once the plants were secure, participants wore their living wearables for up to thirty days.

3.2.3.Data Collection and Analysis

Participants completed a questionnaire on demographics, ethnicity, and lifestyle at the beginning of the study. We interviewed participants after six to fourteen days of using FloraWear. During the interview, we asked participants about their experiences with, effects from, ease of use with, and suggestions for FloraWear and the web application. Interviews were conducted individually or in small groups of up to four participants. The average length of the interview for each participant was thirty minutes. All interview sessions were videotaped and transcribed.

We performed thematic analysis [3] on interview transcripts. We first familiarized ourselves with the data and coded responses to interview questions. We iteratively organized recurring and unique codes into themes. Finally, we identified three broad categories of themes – emotional connection, well-being, and lifestyle.

4. FINDINGS

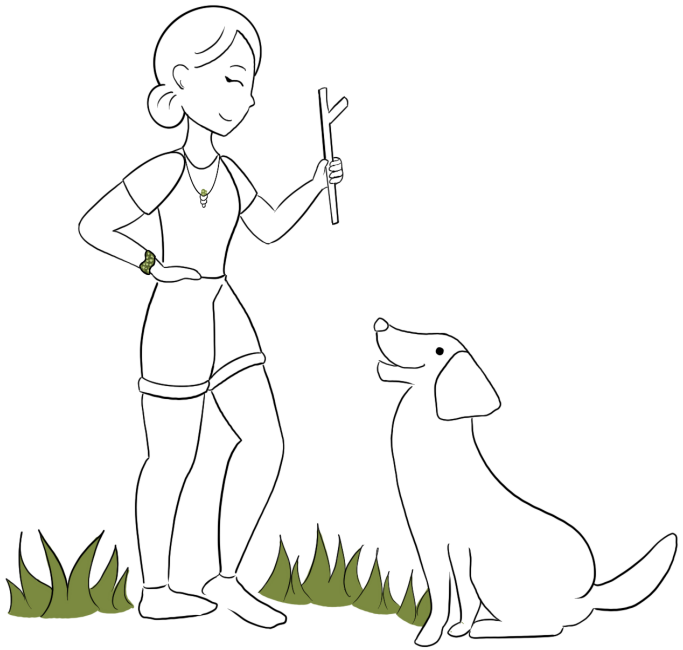
The interview results showed that the participants enjoyed the FloraWear experiment and were positively influenced by it. Germination rates and usage varied by individual. Participants' success rate at growing their living interface was not strongly correlated with their background, major, or previous horticultural experience. Three out of four participants who were landscape architecture majors failed to germinate their seeds, despite having relatively more experience with plants than other participants. Successful germination was a product of their engagement and their attention to what their interfaces' plants needed as they grew. Some participants' seeds failed to germinate when they left their FloraWear at school or at work and inadvertently forgot to water it. Participants waited between one to ten days (5.15 on average) for their plants to take root. On average participants wore FloraWear for 2.1 days. Since three participants did not succeed in germinating their seeds, FloraWear was worn between zero to six days. FloraWear was worn between zero to fifteen hours per day, for an average of 2.95 hours per day. These differences may reflect the level of interactions with and influences from FloraWear in their interviews.

We asked participants about their daily interactions and memorable experiences with FloraWear. Then we questioned them about how wearing FloraWear influenced their everyday life. Nature emerged as a common theme in the interviews. They discussed how their perspective toward nature evolved over the course of the study. In their interviews, participants reflected on how FloraWear helped them build new connections with nature and how that impacted their lifestyle and sense of well-being.

4.1 Emotional Connection

During the interviews, themes of emotional connection naturally occurred based on their embodied experience. Many participants expressed their feelings of connection with FloraWear as if their interfaces were more than mere plants. With regards to nurturing experience, P1 and P12 mentioned FloraWear seem to be family members. P15, P17, and P18 gave their interfaces unique names, while P19 took a walk with his interface as if he walked with a dog.

> P1: *" I felt like I was taking care of a kid. I was very dedicated to see it grow."*
>
> P12: *"It was a child for me because I gave it water, I cared about it. I paid attention. So it started blooming."*
>
> P19: *"When I started doing it, I feel like I am taking care of something...it was kind of a mini dog...I take nightly walks for my health and I would take this (FloraWear) to give it some fresh air."*



P1, P15, and P18 said that their FloraWear made them happy and P13 mentioned that FloraWear helped him become calmer and more relaxed. P6, however, became worried about her interface when she was not with it because she cared so much.

> P1: *"I feel happier seeing something green in there. Something natural so close to you. It really makes my day. Makes me happy."*
>
> P15: *"Even though it's just this tiny thing, but makes you feel a little bit better."*
>
> P13: *"It helped me be more calm because it relieves any stress that I had at the time. I guess having to care for something else does help you distract yourself and relieve stress."*
>
> P6: *"First time it was nice but after some time I really liked it and actually when I was out (without FloraWear), I was worried about it if it needed water."*

To understand participants' emotional attachment, we asked them about memorable experiences with or strong feelings about FloraWear. P11 shared a story about her experience and mindset.

> P11: *"I felt connected to that plant as a living thing. So when it bloomed, I felt it's loving me back. There was an emotional impact...For me, it's a very emotional thing because I'm an international student and here it's very different, also kind of lonely. And when I had that plant, I instantly felt very connected and devoted to something, a part of life. When you are in a different country, you never feel like home. So it gave me a little life in this longest journey."*

They also mentioned that the more they spent time with FloraWear, the more they became attached to it, especially once the seeds had germinated and the seedlings had started growing.

4.2 Well-being

After interacting with FloraWear and reflecting on their feelings towards nature, several participants realized the importance of care. Caring for FloraWear caused P1, P5, and P20 to reflect on how they cared for themselves. By drawing connections between caring for plants and self-care, they realized that they were part of a greater ecosystem.

> P5: *"I think it's strengthened my perception of my body itself as an ecosystem for other living things...thinking about that, and valuing it, those feelings existed previously but this reinforced it of thinking about the interface as being alive, or even reflecting on the life cycle of what was once alive to be part of me...And also the responsibility aspect like, I'm responsible for this plant, gotta take care of it. So, take care of yourself."*
>
> P20: *"Having a plant and taking care of it does reflect how you take care of yourself. I see the connection with my well-being and the plants. And if you have the ability to take care of yourself and you can take care of others."*

FloraWear sometimes physically reminded participants to eat healthy food and vegetables. P5 mentioned the visual presence of the FloraWear interface on his hand served as a reminder to eat healthily, while P12 said that the scent of the FloraWear interface was a motivation to eat more vegetables.

> P5: *"It makes me want to eat healthier when I have to cook for myself, I just want meat and protein and I kind of forget about all the vegetables and it's good to see they're right there (pointing at his FloraWear). If it's literally on you, you'll be kind of reminded to be healthier."*

> P12: *"I like the scent of basil and it's kinda encouraged me to buy more basil and have it in my food. I try to have more plants, more vegetables like basil and parsley."*

4.3 Lifestyle

Because they had developed emotional connections with their plants, while improving their own well-being, participants became more open to and accepting of nature. P1, P12, P15, and P18 said that they would like to have more plants in their daily life and spend more time with them.

> P12: *"It made me more connected to nature, to the plants, because I didn't like planting that much. But now my general perspective has changed."*

> P15: *"It makes me more caring towards nature."*

Over the course of the study, participants gradually became aware that nature can be accessible. Previously, participants had thought that taking care of plants required substantial space and labor. With FloraWear, however, they found that caring for plants can be easy and rewarding. P5, P14, and P18 discussed the convenience and portability of being able to plant on a wearable interface that they can carry everywhere. Because the design was so convenient, P8 and P15 felt more confident taking care of plants.

> P5: ``*It makes me want to grow more edible foods or at least look into it. So I'm assuming a healthier lifestyle, you're getting fresh ingredients, and it's not that hard to do that. You can grow it on jewelry.*"

> P14: *"it made me realize that nature is a lot more accessible than like usually you just think of nature going outside."*

> P8: *"I wasn't that kind of person who cared about plants at all. But after trying these, I felt something inside me. It can be really beneficial to make a relationship between humans and plants."*

These lifestyle changes occurred not only at a cognitive level but also at a behavior level. P1, for example, said that after the experiment she cared more for outdoor plants. Previously she would trample over plants, but once she realized that they were alive, she began to take more care of her environment.

> P1: *"I would just step on the grass, but it just made me not want to do that. Having it (FloraWear) made me realize I'm killing plants."*

Furthermore, FloraWear influenced not only participants in the study but also those around them who observed the experiment. P1's roommate did not care about plants before, but became interested in FloraWear and bought a few plants after the end of the experiment.

> P1: *"I also have a roommate and she was also in the process with this and she usually doesn't like plants, doesn't have any plants. She was actively interested in the process of growth of this plant. So I think it also changed her lifestyle. She even bought a few plants after that."*

5. DISCUSSION

In this section, we discuss knowledge created through our design process by using Frankjær and Dalsgaard's [11] sympoietic framework for articulating and analyzing knowledge creation in craft-based research. Drawing upon Sennett's conceptualization of crafting as a continuous process [33], their framework identifies three key activities that take place in iterative interactions with crafting artifacts: *localizing*, *questioning*, and *opening*. *Localizing* occurs in the lab space where practitioner-researchers come together to frame their design problems around specific objectives while considering the constraints of the problem space and affordances of materials and potential artifacts. *Questioning* occurs when crafted artifacts interact with the outside world. *Opening* occurs through reflection on the crafting process and outcomes of questioning. Opening identifies new concepts, then guide future work. Fig 12 provides an overview of our analysis revealing key concepts for the three activities and connections between concepts.

5.1 Localizing

The research team brought diverse past experiences into the localizing phase. This project was carried out by researchers with backgrounds in fine arts, crafting, computer science, interaction design, and web design. Our primary objective was to *strengthen connections with nature* through a *DIY-crafted living wearable*. This required *identifying appropriate materials*, both organic and inorganic, that would enable *plant growth* and sustain plant life while worn by a human participant. The constraints and affordances of this project were shaped by our objective to support non-expert users with DIY technologies, such as *3D printing*, the biological requirements of plants for growth and survival, and the goal of helping people connect with nature through intimate interactions with plants. Suitable materials were identified through extensive experimentation (Section 3.1).

5.2 Questioning

FloraWear prototypes were evaluated in real-world contexts through the previously described user studies with young adult participants (Section 3.2 and 4). Findings from interviews reveal how FloraWear strengthens the wearer's connection with nature and engagement with plant life. We were surprised by the level of connection and engagement for some of our participants, in particular the forming of close, familial bonds with FloraWear plants. We suspect that the initial care required in growing the plants followed by continual close proximity between human and plant produced these levels of connection. The materials experience of FloraWear plays a critical role in forming these connections and influencing behaviors. Participants directly saw FloraWear at a sensory level while performing their daily activities. The sight of FloraWear provoked reflections and influenced behaviors. The feel of the wearable against the body combined with vision and smell of the plants impacted emotional responses to FloraWear, which correspondingly lead to participants bonding with plants or changing their perspectives on nature.

5.3 Opening

Through reflections on the outcomes of *Questioning*, we identify *human-plant partnerships* as a key design concept for living wearables. *Human-plant partnerships* are symbiotic relationships between humans and plants that emerge through the close, repeated, and sustained physical contact and interaction. Participants described forming bidirectional connections with the plants in their FloraWear. For example, P11 described receiving feelings of love back from the plant. This relationship also evoked reflections by humans on their personal well-being and the need to take care of themselves. These reflections arise in the act of doing, such as while cooking, as a form of Schön's *reflection-in-action* [32]. Further, the notion of human and plants as equitable partners in these relationships aligns with post-anthropocentric viewpoints in recent HCI research [5, 23]. In particular, we find the concept of *collaborative survival*, which describes the entanglements and mutual dependencies of humans and other species [23], salient given the symbiotic relationships expressed by participants. For example, P5 described seeing his body as an ecosystem with other living things. P1 and P12 formed a familial bond with the plants in their FloraWear interfaces. The human-plant partnerships fostered by living wearables offer new ways to influence human attitudes and behaviors towards nature.

During the design process, the research team reflected upon *fashion design* elements and the aesthetics of living wearables, specifically focused on sensory characteristics for vision, smell, and taste. We considered *somaeshetics* [35] looking at the intersections of sensory experiences, embodiment, and emotional response. Many participants report how sensory experiences impacted emotional attachment to their living wearable. Further, we suspect that different types of wearables and plants may influence embodied experiences and correspondingly the types and depth of human-plant partnership. We hope this work will inspire others to investigate how the somaesthetics of living wearables fosters human-plant partnerships.

5.4 Design Recommendations

We provide the following design recommendations for living wearables. For the materials of a living wearable, designers need to consider both somaesthetics and biological constraints. A living wearable's material is often in direct contact with the wearer's skin producing a particular tactile experience. Further, the material needs

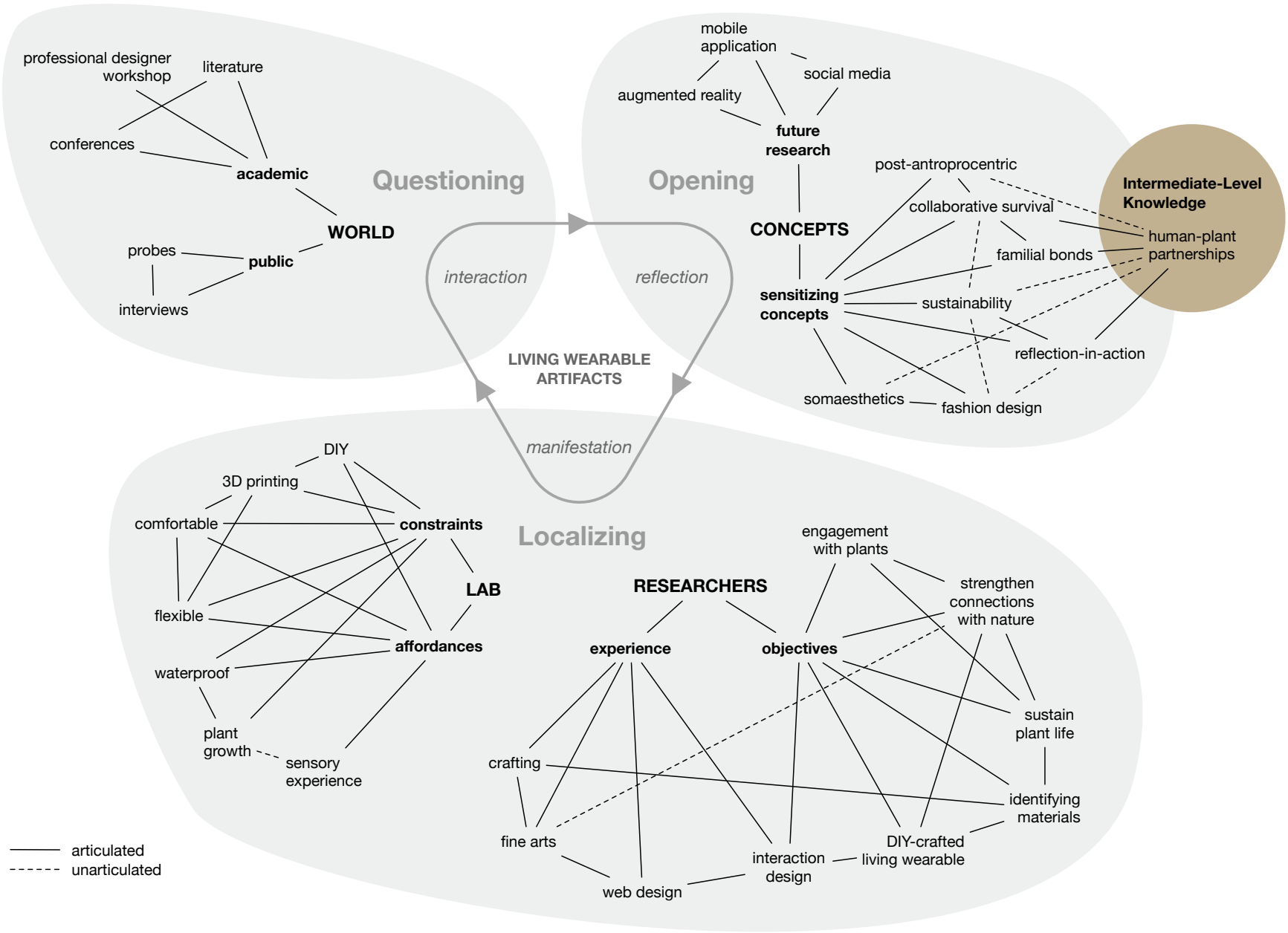


Fig. 12. Diagram of the research process of living wearables using Frankjær and Dalsgaard's framework

to contain the moisture required for plant growth. Any material that absorbs moisture, despite the richness of its tactile experience, is not recommended as this will impact plant growth and provide discomfort for the wearer if the moisture soaks through to the skin. Through our material experiments (Section 3.1), we selected TPU, which is a flexible and impermeable 3D printed material.

For young college students, we find that living wearables need to be easy to put on and take off, comfortable to wear, and less visible or flashy than other accessories. Many participants selected the necklace for their FloraWear as they did not want to have items near or on their hands as that would interfere with certain hand-based activities, such as typing or eating. We note that some participants expressed self-conscious feelings about wearing FloraWear in certain public contexts. The ability to quickly take off the wearable was appreciated.

Living wearables require clear instruction and feedback to ensure successful experiences. Plant growth is a slow process that requires daily attention. FloraWear itself does not provide any affordances or feedback to indicate when to water and with how much water. Instead, designers of living wearables need to provide adequate instructions to wearers. In the following section, we discuss how mobile applications and moisture sensors could support better feedback and instruction.

5.5 Limitations & Future Work

Our design recommendations and findings have limitations. We studied the experiences of college students wearing FloraWear. Without studying further age and socioeconomic groups, we cannot confidently state that the impacts of FloraWear are generalizable to a broad audience. Further, we only studied limited types of plants. Future studies are needed to assess if other types of plants, such as ones with more vibrant colors or stronger smells, like flowers, will affect emotional connections. We studied a narrow set of wearables – necklaces, bracelets, and rings – made from TPU. Our materials experience guided us towards an appropriate DIY solution, but we need further studies that look at more sustainable materials besides TPU and other types of wearables, such as earrings, purses, or belts. Additionally, participants only wore one type of FloraWear for one lifecycle. We do not know how multiple interfaces (Fig. 13) or several lifecyles of plants will affect the connections and relationships wearers feel towards the plants.

In future work, we plan to design and study the role of computing technology in augmenting human-plant partnerships. In particular, we are interested in a mobile app where users can design their wearables, receive instructions about how to care for their FloraWear including notifications on when to water, and use the phone's camera to identify the health of their FloraWear. We will use computer vision approaches for detecting when seeds germinate and plants begin to grow. Based on the type of plant, we will notify users if plant growth is behind schedule and instruct them on what steps they need to take. We are considering how to integrate moisture sensors into the wearables in order to provide feedback when not enough or too much water is provided. These sensors would directly connect to the mobile app, which could provide status alerts to the wearer. To support the fashion interests of wearers in the initial design phase, we are exploring an augmented reality visualization that will convey how a particular FloraWear design with a specific plant will appear on their body at different stages of growth.

6. CONCLUSION

From the experiment and studies, we found several participants and their family and friends were positively influenced by FloraWear. Our participants expressed strong emotional attachments to and mindfulness of nature through the embodied activities and caring experience. Furthermore, several participants shared stories on how these experience influenced their daily thoughts on, mundane behaviors towards, and repeated habits related to nature. The metaphor of the relationship between human and nature has shifted from two discrete elements towards an interconnected ecosystem. Accordingly, FloraWear has shifted the concept of nature in HCI from a mere tool in a hierarchical relationship to a mutual relationship between companions. Based on these preliminary studies, we plan to develop FloraWear to be more comfortable, sustainable, versatile, and engaging in the future to help people become healthier, more positive, and more resilient. Participants in the study appreciated that they could interact more closely with nature using a unique wearable interface.

Fig. 13. Multiple FloraWear interfaces (one ring and three bracelets)

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