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‘Does phosphorus want to sound like that?’: Experiencing more-than-human futures

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Abstract: The paper explores the learning possible from including the public in explorations of more-than-human future visions. We presented an installation at a design festival of a speculative scenario that emerged from ethnographic research with urban permaculture farmers, using sounds to represent concentrations of nutrients in soil. We studied how visitors wearing a sensor ring experienced the playing of these sounds upon insertion of a finger in the installation’s soil. Responses underscore the importance of cultivating the skill of noticing through deep listening, alongside the profound connection thus established between humans and the more-than-human world. In a further contribution to more-than-human design, the paper examines implications for practices of noticing and presents four principles for problematising and reimagining how data pertaining to the more-than-human world may be sensed and represented.

Keywords: more-than-human design; sensing; sonification; soil care

1. Introduction

The transition to more sustainable societies requires not only novel technologies but also novel ways of thinking. Therefore, many design scholars have turned to posthumanism. The posthuman turn marks a radical shift in what is considered possible in research and design. Here, the idea of more-than-human design signifies attention to interconnections, ecologies, flora, fauna, technologies, and elements while bringing in questions regarding who and what matters, has agency, and carries knowledge (Alaimo, 2016; Barad, 2003; Braidotti, 2019; Haraway, 2016; Ulmer, 2017; Wolfe, 2010). There are many conceptualisations of what it might mean to design for and with this vibrant more-than-human world (Clarke et al., 2018; Forlano, 2017; Giaccardi, 2020; Giaccardi & Redström, 2020; Søndergaard & Campo Woytuk, 2023; Tarcan et al., 2022; Wakkary, 2021; Yurman, 2022) and of methods suited to studying others than humans as stakeholders in design processes (Edwards et al., 2022; Kirksey & Helmreich, 2010; S.-Y. (Cyn) Liu et al., 2019; Poikolainen Rosén et al., 2022a; Reddy et al., 2021; Roudavski, 2020; Veselova et al., 2022). However, design research offers far fewer examples that showcase projects framed as more-than-human designs throughout the design process. Hence, a need exists for describing how more-than-human design processes unfold in practice and how people are experiencing the outcome of such processes. For this, it is important to produce practical designs for the present and simultaneously render visions of more-than-human futures concretely experienceable. Therefore, we analysed a design case of reimagining soil sensing as a more-than-human practice and of actualising this scenario as an interactive experience for public participation and feedback.

The case is grounded in previous studies, in which ethnographic work with urban permaculture farmers resulted in several speculative design suggestions (Poikolainen Rosén et al., 2022b). With this paper, we report on our experience and results from selecting one of these speculations and making it into a tangible experience. In this interactive material experience, people wearing sensor-equipped rings poke their finger into soil to generate sounds that represent the soil's nutrient concentrations. The design is intended to support people in caring for the environment through the data it makes available but also, in line with more-than-human thinking (J. Liu et al., 2018; Puig de la Bellacasa, 2011; Søndergaard & Campo Woytuk, 2023), to encourage the careful actions and relations it elicits, such as physically engaging with soil. Practitioners could use such a design to optimise soils for specific plants and prevent overuse of fertilisers, an imposition on the planet's boundaries that urgently demands attention (Steffen et al., 2015).

The implementation was showcased at a sustainability festival alongside other exhibits of interactive designs and artworks on the theme of living with urban nature. We used design fiction and the idea of 'experiential futures' for staging an experience with prototypes to investigate this potential future and enrol people in revealing their attitudes (Baumer et al., 2020). Experiential futures (Kelliher & Byrne, 2015) enable people to engage with scenarios for the future, reflect on them, and apply the emerging knowledge in the present. Through these scenarios, technologies create interactions that feel real within a controlled study setting.

In summary, the paper explores how future sensing devices could shape experiences and understanding of the more-than-human world. Referring to interviews, questionnaires, and observations, we discuss how participants experienced the set-up at the festival and what such experiences imply for more-than-human design. The focus is on approaching living soil as a more-than-human entity while recognising also that the sensing technologies and data too express the more-than-human world and are inherently entangled with the main phenomenon examined. We contribute to more-than-human design further by articulating four principles that problematise and reimagine ways of sensing and representing data connected with a more-than-human world.

2. Engaging with soil in more-than-human design

More-than-human design is often informed by posthumanism, which takes a relational perspective to making sense of the world and seeks to transcend traditional boundaries and such dichotomies as nature–culture, mind–body, and human–technology (Abram, 1997; Barad, 2003; Bennett, 2010; Haraway, 2016). Drawing on posthuman philosophy (actornetwork theory, agential realism, and post-phenomenology in particular), Christopher Frauenberger (2019) has advocated applying notions of entanglement as instrumental in shaping design. Under this view, designers reconfigure networks of associations wherein humans, other organisms, and technologies are mutually constituted. As Ron Wakkary (2021) has pointed out, this shift implies that the designer operates as a single human no longer. Rather, designers, integrated into an assembly of humans and non-humans, carefully design **with** assemblages of this nature or, as Donna Haraway (2016) phrased it, "stay with the trouble" by seeing design as a process of constant critical engagement rather than problemsolving (Søndergaard, 2020). In this generous framing of design, stakeholders such as urban permaculture farmers and other environmentally engaged citizens act as designers when they work with the systemic relationships of their gardens and local environments.

Soil, a complex assemblage of matter and living ecologies, provides an excellent context for exploring these ideas of 'designing with'. In this regard, maria Puig de la Bellacasa (2017) underscored the imperative of re-evaluating our connection with the soil and all aspects of the environment such that we recognise soil's agency, its value, and recasting of it from a resource into a living entity with distinct needs and rights.

In endeavours of designing with soil, practices such as noticing (J. Liu et al., 2018; Livio et al., 2019; Tsing, 2015) and deep listening (Oliveros, 2005) spotlight the capacity for individuals to enhance their environmental attentiveness. Noticing involves refining sensitivities to perceive nuances, complexity, and entanglement in phenomena over time. With deep listening, in turn, we distinguish between involuntary hearing and conscious listening through striving to foster heightened awareness of the acoustic environment by encouraging experimentation and playfulness. Design research inspired by these approaches has highlighted the need for a multimodal representation of environment-related data, designs that afford direct interaction with the phenomena of interest and expand the scope of our sensing (J. Liu et al., 2018; S.-Y. (Cyn) Liu, 2021; Poikolainen Rosén, 2022).

Design examples in this vein have entailed recording and amplifying soil soundscape produced by the movement of insects and microbes to make biodiversity – or lack thereof – more perceptible (Maeder et al., 2019). Others have translated digital readings of temperature, humidity, and biometrics-detected movement in soil into musical notes to "explore a more embodied and aesthetic form of human–nature interaction that attunes human senses to the rhythms of the natural environment" (S.-Y. (Cyn) Liu, 2021). Similar research has focused on 'sonification' of solar energy in aims of creating a more embodied presence of that energy as a vibrant phenomenon (Mackey et al., 2023). There are also examples of wearing moisture sensors on one's hand to sense soil data via more direct engagement with the environment (J. Liu et al., 2018).

3. The case

The design work behind this paper stems from ethnographic studies with urban permaculture farmers wishing to grow plants 'in harmony with' the more-than-human world (Normark et al., 2021; Poikolainen Rosén et al., 2022b). Many urban farmers want to obtain detail-level information about the soil while maintaining direct interaction with their gardens. Drawing these studies' insight together to inform a speculative design project, the first author proposed the idea of 'Dirty Nails' soil-sensing rings to an urban farming community as one speculation within a set of several, illustrating multiple aspects of the rich ethnographic data. This speculation assumes future miniaturisation and wider availability of light-spectrum analyses for specific soil compounds. When the associated design ideas were presented in poster form and discussed by the urban farmers, project participants highlighted the Dirty Nails idea as particularly promising. This called for further exploration: *What could sonic representation of the data sound like? How would it feel to touch the soil?* Therefore, we embarked on studying and exploring the experience of what it might be like to use these rings in a possible future where engineering advancements allow their existence. The following sections detail our efforts to make this speculative idea tangible.

3.1 The design idea and set-up: Dirty Nails soil-sensing rings

We begin by breaking the implementation into its constituent elements.

The concept: When the Dirty Nails rings are submerged in soil, they measure phosphorus, nitrogen, and potassium, nutrients that play vital roles in the health of plants and soil microbes. The rings connect to a smartphone over Bluetooth to retrieve precise measurements. If the 'play with soil' mode is activated, the smartphone presents the data acquired, in sonic form.

The set-up: Figure 1 shows the set-up of the prototype. Participants saw three terracotta pots, with visibly different soils (marked 'A', 'B,' and 'C'); three smaller, plastic containers, containing samples of the macronutrients in a chemical state that ensured that they are safe to touch; and signs displaying the names 'Phosphorus', 'Nitrogen', and 'Potassium' on an image alongside a spectral analysis of the respective compounds (see the left-hand pane in Figure 2). Hidden from view were capacitance sensors stuck to the bottom of each container, wired under the cloth to a microcontroller that triggers pre-recorded sounds when that container's contents are touched.

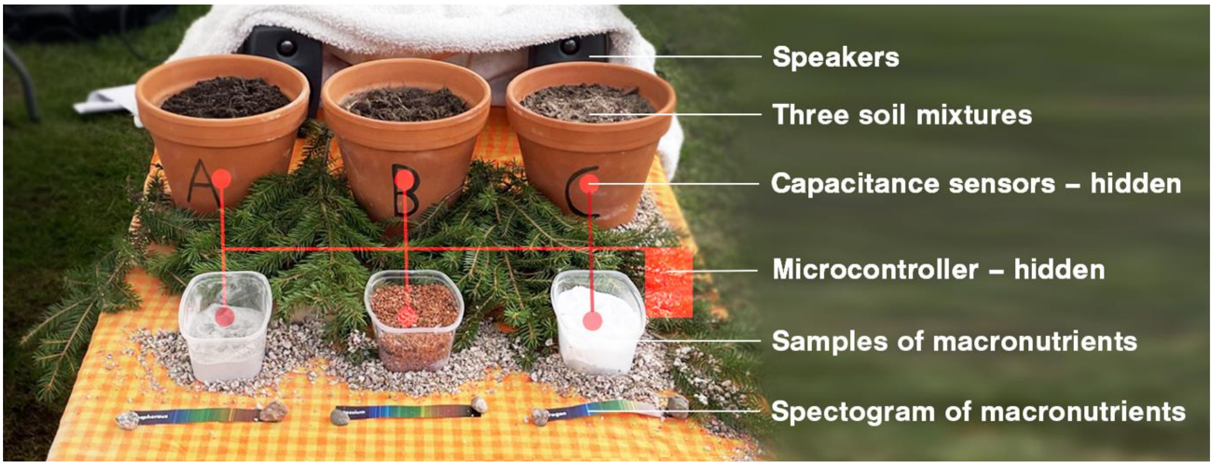

Figure 1 The prototype installation, with the microcontroller, wiring, and capacitance sensors hidden beneath the tablecloth.

Interaction: We handed participants a 'smart ring' with visible electronics, telling them that it conducts spectral analysis of soil and that it uses the finger as an extended sensor when touching a material. Also, we described the rationale for how the spectral analysis of the compounds is presented as sound (see subsection 3.2). The participants then were instructed to put on the ring and engage freely with the samples and soil. All festival participants were eager to stick a finger in the soil, although our previous work had identified the possibility of some perceiving this action as uncomfortable or provoking (Poikolainen Rosén et al., 2022b). As the participants familiarised themselves with the functionality, we introduced the task of estimating the nutrient balance of the three, different soil mixtures on the basis of the individual compounds' distinctive auditory signatures. The sounds of the pots were designed to represent a) non-fertile soil, low in all three nutrients; b) fertile soil, rich in all three sets of compounds; and c) soil with high levels of nitrogen but low levels of phosphorus. Participants then could try to judge the concentration levels by listening to the 'pure' samples of macronutrients, which served as a baseline for comparison.

3.2 Sonification of soil compounds.

Designing the sounds in accordance with the physical properties of soil macronutrients was central to our work since the time we spent making choices based on the qualities of soil compounds became a way of **being with** soil in a manner that increased our knowledge of it. We explored properties such as standard atomic weight, density, and light-spectrum representation. Through this process, we came to imagine a possible future wherein the physical properties of compounds can be identified through such spectral analysis in real time by a small device fitting inside a ring.

Sonification, the communication of data through sound for human comprehension (Kramer, 1994) is an exploratory field with its aesthetics and approaches still evolving (Barras & Vickers, 2011). We opted to align our approach with analogous parameter mapping (Grond & Berger, 2011; Kramer, 1994; Walker, 2011) to create auditory representations that distinctly characterise each compound. This led us to define two principles for creating a characteristic sound for each chemical compound.

Mapping compounds' light spectrum via sound density: Our first principle, the central one for our sonification, was to interpret the full spectral patterns of nitrogen, phosphorus, and potassium as sound waves (see Figure 2). For this analogue of the light-spectrum analysis of the compounds, the sound density aurally represents the spectrum's density through the number of frequencies occupied in the human-audible sound range. We made some additional aesthetic choices to ensure that each nutrient's characteristics were acoustically discernible, by representing them with a particular timbre (the sound spectrum's intensity and its evolution over time is captured well via timbre; see Plomp, 2001). For example, we accentuated the prominence of lower frequencies in potassium's light-spectrum analysis by making the sound rich in the lower frequencies and slow oscillations, whereas filters and reverberation applied for the nitrogen sound rendered it ethereal, reflecting more intense high-frequency components.

Mapping compounds' density with sound oscillation: Secondly, we assigned compounds present in higher density (phosphorus compounds) a more rapid sound oscillation, creating a continuous feel, while less prominent ones (potassium compounds) manifested slower oscillations. This enhanced clarity (Warren, 1982).

After we had created a unique sound for each compound, we developed a principle for communicating the concentration of a compound. A lower concentration was indicated by decreasing the overall frequency spread and volume of the sound pattern, while a high concentration was indicated by raising the volume and broadening the frequency spectrum of the sonic pattern.

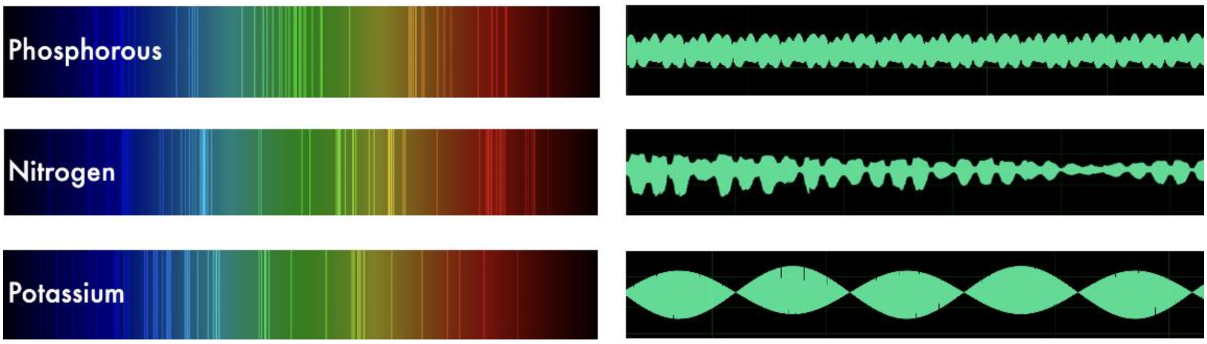

Figure 2 Left: The spectral lines of phosphorus, nitrogen, and potassium as shown to participants. Right: These patterns interpreted through sonification.

3.3 Demonstration in a festival setting

The design was demonstrated at the one-day festival Living with Feral Ecologies (Lauterbach & Dolejšová, 2023), held in Helsinki. An international group of art and design researchers together presented 20 works exploring open-ended, multisensory spontaneous engagement in the context of everyday practices, rituals, and relationships emerging around encounters with the more-than-human world. Through the demonstration, we followed our interest in investigating how novel sensing devices could shape experiences and understanding of the more-than-human world. We turned our attention additionally to two practice-oriented questions: *How well does the set-up simulate the future functionality imagined? How do people experience representation of environmental data as sound?*

Over the course of the festival, 58 people, among them 10 children (aged 4–10), tried the design. The first author focused on instructing them in using the system designed, while the second author conducted interviews. Both researchers took field notes, including direct quotes.

Questionnaire forms: Of the individuals who tried out the design, 32 took part in an optional survey wherein adults were asked to estimate the concentration of nutrients in the pots and answer questions on the overall experience that probed matters such as what was easy or hard. Ten respondents were men, 20 were women, and two identified with another gender. Their age distribution featured eight individuals aged 18–25, 10 aged 26–35, nine of ages 36–45, and five who were 46–55.

Other background variables probed were related to associated interests and experience. Regarding sustainability, 13 participants reported strong interest and 19 expressed very strong interest. Gardening experience varied, with six reporting very low, seven low, seven extensive, and 12 neutral levels. Interest in technology varied likewise but was generally high, with two respondents each reporting no such interest or very little and one little, while 12 were neutral, 12 indicated a strong interest, and three expressed very high interest. In the analysis presented below, comments made during the survey are denoted with an 'S' followed by a serial number for the response (e.g., S12).

Interviews: Participants were invited to take part in an optional interview. Six accepted the invitation, engaging in three interviews each: a one-on-one interview and two group interviews. All interviews lasted 16–19 minutes, with a total time of 51 minutes. We transcribed the recordings by means of an automatic transcription tool.

Data analysis: We employed open thematic analysis (Rosala, 2019) to analyse the interview transcripts, field notes, and free-form survey responses. This process assigned codes to words, sentences, or paragraphs that illustrated recurrent themes. In our presentation of findings, boldface highlights ideas that were central to this analysis. We continued the process by conducting concept-driven analysis (Miles & Huberman, 1994) to frame the findings with posthuman theory sensitised through the concepts of the more-than-human, noticing, and deep listening.

Table 1 Interviewees' background details

ID	Age	Gender	Interest in technology	Experience in gardening	Interest in sustainability
P1	28	female	neutral	extensive	very high
P2	28	female	neutral	extensive	very high
P3	24	female	high	very little	very high
P4	26	female	high	very little	very high
P5	30	female	high	very little	very high
P6	35	male	high	little	very high

4. Findings

Below, we consider how the participants experienced the soil-sensing rings in general terms, then discuss two aspects of the experience that were particularly salient in the data: noticing the more-than-human world and the skill of deep listening.

4.1 The overall experience

A child exclaimed "It's magic!" when sticking his fingers in a soil sample and hearing the direct sound response. This joyous engagement, accepting the design as fully functional, was salient also for adult participants: "It was really nice because the whole act sort of made it so accessible, like we really felt like we were interacting with the soil" (P1). In the survey, 19 people (66%) agreed or strongly agreed that it felt as if the rings were sensing soil data, while nine (40%) were neutral in this regard or did not know. Only one person disagreed with the statement (4%). This suggests that the set-up was generally successful in creating an experience that conveys a sense of real-time hearing of soil data. One participant described how she "felt empowered, in a sense – oh my gosh, if I wear this ring I can hear and I can make these connections" (P5). Her friend expanded on this:

> "Yeah, it's **like a superpower**. Like you wear a suit and you can suddenly fly. It was very interesting **but also overwhelming**, **in a good sense**, that I was trying to connect different things together and make sense of it. But I couldn't, because it is not my field [...], like my mental space was just a bit overthinking." (P4)

As these comments illustrate, the possibilities of the rings were perceived as "interesting" (P3, P5, P6), "empowering" (P4), and "involving" (S1), while the challenges of accessing these possibilities in practice were highlighted in terms of both a lack of skills on the participant's part (e.g., "I'm not a trained musician", observed in the field notes) and the characteristics of the sound design (e.g., "some of the sounds were so close that it was confusing" according to P3). Still, many participants found the soil rings meaningful overall. For example, 42.9% (12 out of 28) agreed or strongly agreed that they would use the sensor rings if they had access to them, while only three (of the 28) disagreed.

Figure 3 Participants engaging with soil and nutrient samples.

4.2 Noticing the more-than-human world

One particularly salient theme was how the design shaped experiences of the more-than-human world and how participants explicitly reflected on this relationship. One participant pointed out that the design was particularly intriguing and thoughtful in comparison to other designs for interaction with nature that he had tried:

> “I see a lot of this, **bringing technology and nature togethe**r, but sometimes it feels [artificial and made up]. But I feel like this is interesting […]; this creates this feeling of wanting to **explore and discover** these issues more, **like a little appetiser**.” (P6)

Our findings indicate that the set-up was able to spur such curiosity by establishing a **direct physical connection** with the soil (see Figure 3) and offering an experience of what we refer to as the voice of soil.

The voice of soil: The participants appreciated how the installation provided environmental information that would otherwise remain inaccessible to humans:

> “I think I see it, if [the data are] accurate, like **honest communication between the soil and us humans**. So that's a way of talking to each other: ‘Okay, maybe you need more [nutrition]. I can help you.’ Like storytelling.” (P2)

This idea of mutual interdependence in communication manifested itself also when one participant speculated that experienced gardeners who instinctively know the soil might be annoyed by the sounds: “I wonder if this would become like a problem [for experienced gardeners]. They're like **‘no, you're talking too much’**” (P3). The way in which this participant anthropomorphised soil as an entity that could even be excessively vocal indicates perceiving the soil to have agency.

As the extracts above demonstrate, many participants interpreted the design as an installation that gave voice to soil and, by doing so, posed questions about our relationship with the more-than-human world:

> “I'm always wondering about **how we assign [a] voice to nature**. So whenever there are projects where, for example, trees are given a voice, my question is always whether that's the voice of the tree. And it would be the same here. […] [A]nd you explained [that the sound waves map with the light waves], like high frequency, low frequency. So I guess that makes sense. But that's always the question that I ask: **does phosphor[us] want to sound like that?**” (P1)

Direct physical connection: Many participants found the design meaningful since it prompted direct physical interaction with the soil. For example, one visitor pointed out that someone engaged with it is literally grounded with the soil and that the gestalt of the sound emphasised this connection:

> "I think that that's part of what makes it grounding, to have the actual physical elements [of the soil] there; then it starts to make you think because **you are connected, you are grounded** […]. Maybe the sounds themselves also have this grounding, resonance." (P6)

One participant, reflecting further on the coupling of the tactile and sonic experience, found that her sense of touch and hearing merged into a synaesthetic whole:

> "**It was bending my senses a little bit** because I was 'how do you hear soil?' So that was interesting also at an elemental level, because it was not just based on the texture of the soil […]. It was **a clash of the senses of my touch and my hearing** sort of overlapping with each other." (P2)

The emerging sense of cohesive wholeness was picked up on by another participant, who mused about the physical interconnectedness of the world and tied this in with spiritual practices:

> "This idea that **everything is resonating, everything is vibrating**, my atoms and everything is vibrating. And then you can go into the whole science of string theory, whatever […]. It is fascinating how there can be maybe some characteristic sounds and characteristic vibrations of different materials […], how **sound and light are kind of both waves**. Yeah, I think I felt it, actually – a little bit […] ceremonial and ritualistic." (P6)

In sum, the participants experienced a design that impressed them as directly usable to support gardening, farming, and similar practices that necessitate caring for the more-than-human world. Many participants additionally emphasised more reflexive, emotional, or even spiritual aspects of the experience, posing questions about "how we assign [a] voice to nature" (P1).

4.3 The skill of deep listening

We now turn to findings about the sonification. While participants found it relatively easy to distinguish between the sounds of the pure nutrient samples, they faced greater difficulty when sounds from all three components were played in concert upon touching of soil. When asked to estimate the compound concentrations represented by the sounds from each pot, 44% of the answers fell within 'Correct' range. This is only 11 percentage points higher than one would expect from random guessing. Significantly higher rates are necessary for sonic soil data to be of use in practice.

Additionally, remembering the sounds proved challenging – "you need to learn the specifics of each sound really deeply; it's hard" (S1). One participant identified a need to keep going back to compare a soil's sound with the pure samples':

> "You need **a lot of memory practice** as well. You need to remember because we were constantly touching all the things, to make that connection." (P2, W2)

Some participants highlighted that the skills of a musician would be beneficial:

> "Maybe someone who is **musically trained** can maybe hear different aspects more, but I could hear some aspects." (P3)

At a general level, many participants stressed a need to hone the skill of listening, as "it would probably get easier with time" (S5). One participant articulated this conclusion thus:

> "It's **a skill like any other that could be practised**. And the more you do it, the quicker you could identify [what the sounds signify], just like a musician learns to play the piano." (P6)

One person who was an experienced gardener but not what that participant termed a "sound expert" imagined a new job, that of gardener-musician, and elaborated that its skills could be taught in schools. In related thinking, several participants suggested that the device could be used in schools:

> "I mean this will be like **a dream in school for kids**, right? […] [Instead of doing something] boring in the classroom to learn this chemistry stuff [you could] introduce all these interesting different elements so we can understand how this stuff works […]. It's very interdisciplinary because it's bringing together technology, soil biology, and chemistry." (P3)

The challenges of listening to data prompted some participants to state that they "might prefer visual data representation" (S2), and to express a desire to "really quickly take a glimpse at some kind of interface" of that sort (S1). Moreover, one participant opined that it is impractical to have to touch pure soil samples to learn what a compound sounds like and recommended the development of an app with "a sound database, where you can refer to any sound without actually having to touch phosphorus" (P3). This implies that multimodal presentation of environmental data is a preferable way forward, to accommodate diverse needs. In conclusion, interpreting environmental data in the sound form we created is challenging and requires skill, notwithstanding its potential to carry rich information.

5. Discussion: Designing for noticing

We have discussed how the experience led people to reflect on their relationship with the more-than-human world as they highlighted both practical and more philosophical dilemmas of listening to soil. Their experiences enriched our reflections too, creating fertile ground for discussing several implications for more-than-human design. Many participants stated that listening to soil data requires skill and sensibility that can be trained over time. This resonates with the ideas of noticing (J. Liu et al., 2018; Livio et al., 2019; Tsing, 2015) through deep listening (Oliveros, 2005), introduced in Section 2. Making soil compounds noticeable through sound elevates their significance in people's life, thus highlighting the agency that resides in a human–soil relationship. However, we must bear in mind also that making the compounds perceptible is a normative process involving many design decisions that interpret, shape, and dictate how the more-than-human world gets noticed.

Participants' reactions underscore the dilemma of presenting complex environmental data clearly. On one hand, it is important to preserve the authenticity of the raw data, yet clear representation is required at the same time. For instance, participants appreciated the intricate sounds generated from the components' full spectral lines, which sparked acknowledgement of the relationship between "sound and light as [both] waves" (P6). However, they still found these complex sounds less understandable when played together. Some participants wished for simpler representations such as individual notes or bare numbers, while others emphasised the importance of representing natural phenomena correctly, asking such questions as "Does phosphorus want to sound like that?" (P1). While designers might not resolve this tension, we propose four guiding principles for staying with this trouble.

Moving from extracting to listening: Maria Puig de la Bellacasa (2015) pinpointed that more-than-human thinking calls for a fundamental shift in our perception of soil. Framing soil as living urges us to move beyond merely extracting soil data, to listening actively to the soil. Here, acknowledging the 'voice' of the soil prompts us to seek understanding and meaning even if we cannot fully grasp a comprehensive message. Our design artefact reflected this shift from extracting to listening by not providing ready-made frameworks or guidance for interpreting, using, or acting on the data. Perhaps partly in response, visitors identified deep listening as a skill that one can cultivate and strengthen over time. Through this approach, the simple act of slowing down by poking a finger into the soil marks a starting point for listening to it in a multifaceted – and hence ambiguous – manner. Simultaneously, we recognise that presenting data in real time and in a one-point-in-time scenario may encourage people to act quickly instead, in response to the 'need' of the soil, instead of waiting for slow ecological processes to unfold. While quick responses might be preferred in several forms of agriculture, there are many potential benefits in studying the temporal relations that a device such as the sound-sensing rings could produce if used over time in a real-world setting. For example, would people learn to perceive nuances in their soils' changes over extended periods?

Moving from representation to imagination: In the discourse on more-than-human design, questions about the limitations of human language in conveying natural phenomena and the perspectives of other entities recurrently raise their head (Abram, 1997; Akama et al., 2020; Rolighed et al., 2022). We advocate accepting our human position in the world while acknowledging our capacity to imagine worlds that are other, thus adopting a position of critical anthropomorphism (Burghardt, 1990). The imagination we suggest here does not imply fabricating data. On the contrary, real and reliable data should always serve as a foundation for imagining otherwise. Our design work reflected this awareness through attending to such scientific factors as light-spectrum analysis and atomic weight, then imagining how they could be represented as sound in a way that makes sense to people. The goal in this was to hint or gesture toward the presence of a phenomenon while not claiming to represent it fully. Thereby, the implementation left room for the participants to create their own (necessarily partial) image of the phenomena.

Moving from single measurements to plurality of methods: When sensing the three macronutrients – phosphorus, nitrogen, and potassium – we focus on them as central for soil health, but by doing so we render other aspects of soil health less visible, such as the complex entanglements of microbes, carbon-capture capacity, and aridity/moisture. We make an agential cut (Barad, 2014; Sanches et al., 2022) through which some aspects of the phenomena matter and have agency while others do not. Through this, the soil becomes what we sense it to be. If we want soils to be rich, dynamic, nutritious, and fertile, our methods for knowing soil must mirror that goal. The case presented here developed accordingly. However, it represents merely one of many engagements with soil in our design research. We could also cite examples that involve temperature measurements highlighting microbial activity, moisture sensors that spotlight watering patterns, and chemical tests that draw attention to specific aspects of chemical composition (Poikolainen Rosén, 2022).

Moving from knowledge to wonder: The design inspired a sense of wonder in many participants. To wonder means both to be surprised and to entertain questions. Isabelle Stengers (2011) is among the proponents of wonder-based science that acknowledges how the diversity and dynamism of matter consistently exceed the confines of scientific conceptual frameworks – we cannot know the world completely. Proceeding from this framing, designing for wonder means accepting being affected and troubled but also being forced to think and question apparent knowledge in terms of the restricted set of practical situations in which that knowledge is relevant: *What practices are supported by knowing the concentration of phosphorus in soil? In what practices does it not matter? How are you affected by soil qualities you are not aware of?* The design explored in this paper represents a device designed for wonder. It was intended not to create comprehensive knowledge of soil but, rather, to gets us to wonder about it as a multifaceted phenomenon. From this standpoint, we will never know what phosphorus wants; it most likely does not want anything. Nevertheless, the creation of a design that causes people to wonder about such questions offers opportunities to be more aware of the agency throughout our environment. Becoming aware of this agency can make us – designers, gardeners, farmers, and researchers alike – into better designers through collaboration with more-than-human assemblages. Efforts in this direction dovetail with related work focused on the productive capacity for wonder that resides in and radiates from data – or, rather, the entanglements between data and data-producers (MacLure, 2013).

6. Conclusion

We can identify multiple contributions afforded by the findings from our study of the speculative scenario showcased at the design festival, in which macronutrient concentrations were presented in sound form by means of sensor rings. Firstly, the reactions of festival visitors revealed a pressing need to cultivate noticing through deep listening, a skill that interactive technologies can facilitate. In related reflections, participants in our study identified a fundamental dilemma: the desire to preserve the authenticity of the data stands in opposition to a desire for simplification for ease of representing the data, in at least some respects. Rather than strive in vain to resolve this tension, more-than-human design needs to stay with it.

We suggest several routes to this end. We can support this outcome through listening (e.g., to the soil) rather than focusing on extraction of data, pushing the limits of data's representation by challenging our capacities of imagining, applying multiple methods to study the environment, and designing for wonder. These principles underscore the vital role of direct sensory experiences, such as touch and listening, in motivating care for the environment – a matter of utmost urgency in the face of ongoing destruction of ecosystems.

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