

Jun 23rd, 9:00 AM - Jun 28th, 5:00 PM

## Designing for Sustainability with Sound

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### Citation

Pauletto, S., Delle Monache, S., Ozcan Vieira, E., Misdariis, N., and Voegelin, S. (2024) Designing for Sustainability with Sound, in Gray, C., Hekkert, P., Forlano, L., Ciuccarelli, P. (eds.), *DRS2024: Boston*, 23–28 June, Boston, USA. <https://doi.org/10.21606/drs.2024.1490>

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## Conversation: Designing for sustainability with sound

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[doi.org/10.21606/drs.2024.1490](https://doi.org/10.21606/drs.2024.1490)

**Abstract:** Addressing climate change and related societal challenges requires the acknowledgement that our resources are limited, that a sustainable future depends on how we act now, and that responsibilities are shared. In this context, the choices we make when designing the world around us are of great significance and consequence. In this conversation, we reflected on how sound-driven design can contribute to a sustainable future. Sound is a unique design material that can metaphorically, and sometimes practically, embody sustainability concepts and their complexity. Our discussions encompassed whether current sound technology trends support sustainable behaviors; how notions of care, responsibility and agency are expressed through sound and listening by humans as well as the more-than-human world; and how cultivating a sonic sensitivity can afford new critical perspectives. Through this interdisciplinary conversation we were able to unravel several connections between sound and sustainability and map out directions for future work.

**Keywords:** design; sound; sustainability; futures

### 1. Introduction

Sustainable development means meeting “the needs of the present without compromising the ability of future generations to meet their own needs.” (World Commission on Environment and Development, 1987). The effort of addressing climate change and related societal challenges requires an acknowledgement that resources are limited, that many unsustainable processes cannot be undone, that action needs to be taken now, and that we responsibility is shared.

Sound is a unique design material, and it can metaphorically, and sometimes practically, embody sustainability concepts and their complexity. Our experience of sound is dependent on time and space. The sounds we produce make us aware of what we did and where we did



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it, provoking an assessment of our action and perhaps a sense of responsibility. Sound provides us with an embodied understanding of time, and in doing so it makes it “tangible”. Sound is tightly connected to actions and interactions, behaviours and relations (Delle Monache et al., 2018; Özcan et al., 2022), as well as implicit or explicit intentions and emotions (Tonetto et al., 2014). The contingent nature of sound - in that we cannot produce the same identical sound twice – can become its strength. Sound design can connect us with an unfolding action, the “how”, the “process”, its success or failure, rather than a well-defined and stable “what”. Sound is shared. It does not belong to the producer more than it belongs to the receiver as it “enters” both. Often, we must accept it on its own terms as there are no earplugs unless we cover our ears. Overall sound is powerful, it necessitates responsibility and negotiation and it is therefore political (Voegelin, 2018).

In this conversation, held at DRS2024 Boston, we aimed to reflect on the main question:

How can sound-driven design contribute to a sustainable future?

and the three sub-questions:

1. What are the characteristics of sound as design material that make it particularly apt to embody and exemplify concepts related to sustainability such as time, the relations between the future and the past, responsibility, intentions, dynamic processes, etc.?
2. What is the current state-of-the-art in the field, and what should future directions and milestones be?
3. How can sound-driven design collaborate with other relevant fields of inquiry to address the urgent changes needed?

We report on the outcomes and start to delineate the specific contribution that sound can make in this context.

## **2. Background and conversation set-up**

In design and HCI, sustainability issues have been considered for some time. The focus has shifted away from the creation of ‘sustainable products’ to the development of methods and designs that encourage widespread sustainable behavior (Stegall, 2006; Özcelik et al., 2022; Niedderer et al., 2022; Alwazzan et al., 2022). The field of Sustainable Interaction Design was established at a similar time when principles and guidelines started to emerge (Blevis, 2007; Hansson et al., 2021).

Research on how sound can contribute to design for sustainability is relatively recent (Pauletto, 2024; Marentakis & Dal Palù, 2024). The development, in 2012, of the UN Sustainable Goals (UN SDGs), which highlighted how global development is dependent on the interconnections between different areas such as health, environment, equality, etc., contributed to the establishment, in 2014, of the first Conference on the Sonification of Health and Environmental Data (SoniHED). While research on these topics had appeared

before (e.g. Polli, 2005; Flowers et al., 2001; Ballora et al., 2004), this was the first time a conference brought together these themes and focused on their interconnection. Research in this area has been concerned with sound design for energy (e.g. Lockton et al., 2017; Groß-Vogt et al., 2018; Pauletto et al., 2023; Delle Monache et al., 2024a; Pauletto and Sez nec, 2024), air quality (e.g. St Pierre and Droumeva 2016; Selfridge et al., 2022), water consumption (Hammerschmidt et al., 2013; Sez nec and Pauletto, 2022), weather data (e.g. Harman et al., 2016), health (e.g. Walus et al., 2016; Barrass, 2014; Ettehadi et al., 2020) to name a few examples. Furthermore, research on sustainable soundscapes can be found in the areas of mobility (e.g. Misdariis et al., 2012), health (e.g. Özcan et al., 2020), sonic art and communication (e.g. Gilmurray, 2017) and more.

### *2.1 Conversation set-up*

This conversation took the form of a hybrid 1,5-hour discussion chaired by the first author. At the start of the session, five panelists (the authors) put forward one scenario each (Figure 1) with a corresponding sound example. This allowed to kick-start the event with diverse view-points and applications of sound for sustainability, engaging the audience on what might be achieved through interdisciplinarity and collaboration. In addition to this, we used the interactive online platform Mentimeter ([www.menti.com](http://www.menti.com)) to solicit short written answers to questions that were posed at the beginning, middle and end points of the conversation.

The questions were:

- How would you relate the words sustainability and listening/sound making?
- How can we understand needs through listening?
- Sustainability implies negotiation, tolerance, diversity. Can you think of sustainable listening/sound making practices?

About 23 people participated in the conversation, including the five panelists. The session was audio recorded and then transcribed.

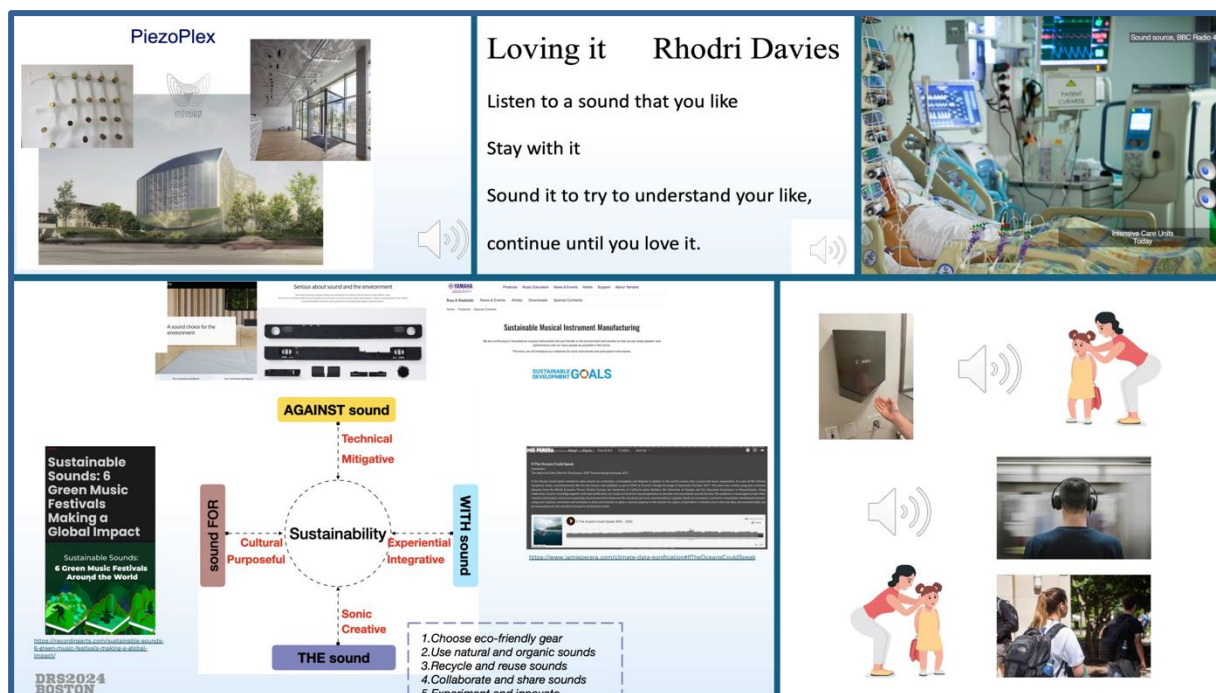


Figure 1: Illustration of five scenarios presented by panelists. Clockwise from top-left scenario by Misdariis, Voegelin, Özcan, Pauletto and Delle Monache.

## 2.2 The Panelists' scenarios

### Promoting ecological responsibility by making invisible processes audible through sound

Nicolas Misdariis presented a collaborative project involving IRCAM, the Arts and Design School of Les Mans (France), and the French artists' collective Ménure. The initial idea was one of the outcomes of a 2-week students' design workshop. Ménure took this idea and made it into an interactive sonic intervention for an energy efficient building used for student accommodation and commissioned by the Région Île de France. Briefly described, the building produces its own energy by warming up water tanks during summer and delivering the stored energy in winter. The project aimed to address three questions:

- How can sound help us understand how the building works in terms of energy?
- How can sound promote a sense of ecological responsibility and behavior in its residents?
- What are the characteristics of sound (as opposed to, for example, visuals) that make it particularly apt to promote ecological behavior and responsibility?

The final intervention, called *PiezoPlex*, is installed in the ceiling of the building's entrance and consists of more than 300 piezo-electric devices delivering sounds composed in a codified manner - a sort of language - to provide information about the levels of the building's batteries and similar data.

### **Promoting sonic sensibility for an ethics of participation**

Salomé Voegelin started by playing the piece *Loving it* by Rhodri Davies. In this piece, a single harp string is plucked every few seconds, until its resonance fades to silence. The piece is part of the album *Paint your lips while singing your favourite pop song*, 2023, (see <https://flamingpines.bandcamp.com/track/loving-it>) which features eight pieces produced in response to eight scores written by Voegelin for the artists. Voegelin's intention with this work was to get people to develop a sonic sensibility that does not look at the world from afar, as the organisation of separate objects and bodies, but that *sees* their relationality. In this way sound is used to provide access, making thinkable, and thus understandable the relationality of the world as an indivisible sphere. The suggestion is that a sensibility to sound, in its relational nature, brings us closer to the concept of reciprocity and thus of responsibility; how we are part of the design of the world. To achieve sustainable design (visual as well as sonic), the invisible relationships that surround us - ecological, political, social - need to be accessed, and sound can afford us a way to do that. In this piece, Davies is getting into a relationship with the harp's sound, and through listening we, the audience, are getting into a relationship with it also. "My *sounding* is part of the listening and provides a clue on how I participate in the world." (Voegelin) Sound implies an ethics of participation and points at how we are all connected rather than how we are separate. To answer design questions for a sustainable future, we need to reflect on this connectedness and sound can help with that.

### **A methodological perspective on sustainability and sound**

Stefano Delle Monache proposed a methodological perspective (inspired by Delle Monache et al., 2022; Delle Monache et al., 2024b) to look at the connection between sustainability and sound. "Through the way we approach sound, we can have an impact on different aspects of the listening experience." (Delle Monache). Designing *against sound* for sustainability is the most obvious and includes any action aimed at mitigating unsustainable environmental noise. By focusing on material qualities and systems, this approach extends to the development of sound technology (e.g. loudspeakers as well as musical instruments) that prioritize the sustainability of the manufacturing process rather than solely the final sound quality. For example, one might decide not to use very rare, expensive wood for building a musical instrument, putting sustainability concerns on the same level as sound quality. Designing *with sound* for sustainability focuses instead on the experiential and meaningful aspects of listening in context. In this respect, sonifications of climate change, or other sustainability-related data such as pollution, offer valuable examples of information design cases. Designing *sound for*, with sustainability in mind, stresses the use of sound as culturally relevant and meaningful *for* a specific audience or community, where examples may include the current efforts to make music festivals, and other cultural events, sustainable. Finally, designing *the sound* for sustainability has an impact on the sound designers' practices and sound production processes, including the use of eco-friendly tools, ecological and organic sounds, as well as favoring practices of sharing and reusing, towards developing new standards for sustainable sound design. These sound-driven approaches

help raise awareness, pinpoint design opportunities and create a new culture around sustainability and sound.

### **The sustainability of acoustic environments of critical care**

Elif Özcan described how some environments, such as Intensive Care Units (ICUs) in hospitals, are extremely noisy due to the many auditory alarms present. These acoustic environments are unsustainable for both patients and nurses. The patient is forced to inhabit an acoustic environment that impedes their recovery - because the alarm sounds constantly remind them that they are sick, as well as make it very difficult to sleep – often making their stay in the hospital longer than necessary. Similarly, nurses struggle with alarm fatigue; they become desensitized and even stop distinguishing between the different alarms. This unfortunately leads every year to several avoidable deaths. Overall, one could say that, in this environment, the machines, which aim to provide safety through monitoring the patient, take over and the patient becomes ‘invisible’. Sustainable design in this case needs to look at questions such as: How can we measure the *listening capacity* of patients, nurses and doctors? How can we design alarms taking this *listening capacity* into account? How can we use this knowledge to ensure that nurses are able to distinguish between false and true alarms? Furthermore, addressing these issues helps tackling the financial costs that the current acoustic environment produces. Understanding what factors should be considered when defining the *listening capacity* of patients and hospital workers is key to develop a more hygienic sound environment and, above all, to achieve sustainable health, sustainable workforce, and sustainable financing.

### **Reflecting on current sound technology trends: do they promote participation or isolation?**

Sandra Pauletto presented her reflections on the usage of two everyday design objects - hand-dryers and wireless earbuds/headphones - that seem to contradict the possibilities of sound as a material for sustainability. She described how she noticed that in the restrooms of many public cultural institutions there are very powerful electrical hand-dryers, sometimes called ‘Airblades’, that make a very loud noise when in use. Research shows that children find them unbearably loud (Keegan, 2020). For example, to reduce her discomfort, Pauletto’s daughter resorts to asking her mum to cover her ears. Marketed as energy efficient, these hand-dryers appear to be sonically unsustainable – ‘ear-blades’ - for children, or those towards whom we should be most responsible. Pauletto asked: “Why don’t we listen to the children? Why such aggressive designs have been allowed in restrooms, spaces that are intimate, personal and shared? Why are we fooled into thinking that they cannot be removed, and instead teach our children that we are powerless and can only try to defend them by covering their ears?”

The second observation regarded the ubiquitous use, particularly by young people, of wireless earbuds or headphones. Sometimes this behavior can be understood as a way to cover one’s ears because the surrounding noise – i.e. reproducing the defensive behaviour described above – and other times it seems to be a way to isolate oneself from unfamiliar

surroundings. Pauletto asked: “Are wireless earbuds or headphones becoming a kind of ‘ear-blinders’? A way for us not to deal, or to (noise)cancel, the world around us?” This sound technology hinders listening, rather than promoting it. It seems to teach young people that they can only defend themselves by sabotaging their most important inquiring and alarm system: their ability to listen to the world.

### 3. Content of the Conversation

In this section, we report on the themes emerging during the conversation, and then, in Section 4, we discuss how these themes relate to the conversation’s driving questions.

#### *3.1 Sound technology: from sharing to isolation*

Sound is inherently a shared material. As it propagates in the air between source and listener, sound forms the material for dialogue, conversation, singing and dancing. The industry of sound technology has historically developed tools for enhancing this sharing quality by developing instruments and spaces that project sound to a distance. Examples are recording technology, that allows us to hear sounds produced elsewhere, amplifiers, powerful speakers, the radio, and so on.

The invention of headphones, particularly the introduction of the Walkman in 1979, defines the moment when sound technology starts focusing on individual listening, rather than on sharing. While headphones can allow a more focused listening experience, they can also turn sound into a material for isolation, for closing one’s ears, or masking exterior sounds and, as suggested by Pauletto, for ignoring, rather than acting upon, unsustainable environments.

At the start of the conversation, participants made several observations regarding these technologies, discussing the implications of their current use for social interactions and sustainability. One person stated: “(Earbuds and wireless headphones) have been kind of forced into society for us to isolate ourselves” (P1). The same person noted that there was an increased pressure for people to find time in their schedule to consume media (podcasts, music, etc.), even when perhaps such need for consumption could be questioned. They continued observing that these gaps in someone’s schedule often end up being during commutes to and from work, when we also use sound to defend ourselves from, and mask the sounds of, an unsustainable modernity (e.g. overpopulated cities, noisy commuter trains, anonymous metropolitan neighborhoods, etc.). Another participant pointed out how these isolating technologies might help young people “maintain a sense of calm” (P2) when they feel overwhelmed by stimuli. Furthermore, participants highlighted how the use of these technologies is culturally related. For example, using sound isolating technology in relatively quiet cities might have different underlying motivations (e.g. maintaining the boundaries of personal space) than when using it in noisy environments (e.g. defending oneself from noise).



### 3.2 Flipping sound technology: from isolation to control and participation

The possibility of masking external sound, or canceling noise, provides a way to *control* the sometimes overwhelming stimuli of society. This can also facilitate the creation of a sense of familiarity - for example, by listening to familiar music or podcasts - when a person is alone in a large city where there is no immediate community.

Another participant, however, highlighted that to develop a sense of belonging and community in a new place it is important to access the surrounding sound. Listening to a transport disruption announcement, even in a city as large as New York, can provide a way to spark a conversation among commuters that one sees every day, for example.

It seems that while, on a personal level, these sound technologies can provide a way to control and modulate our environment making it more sustainable, they also interfere with the potential that shared sound and listening have to create communities, develop shared opinions about the environment, and promote active participation.

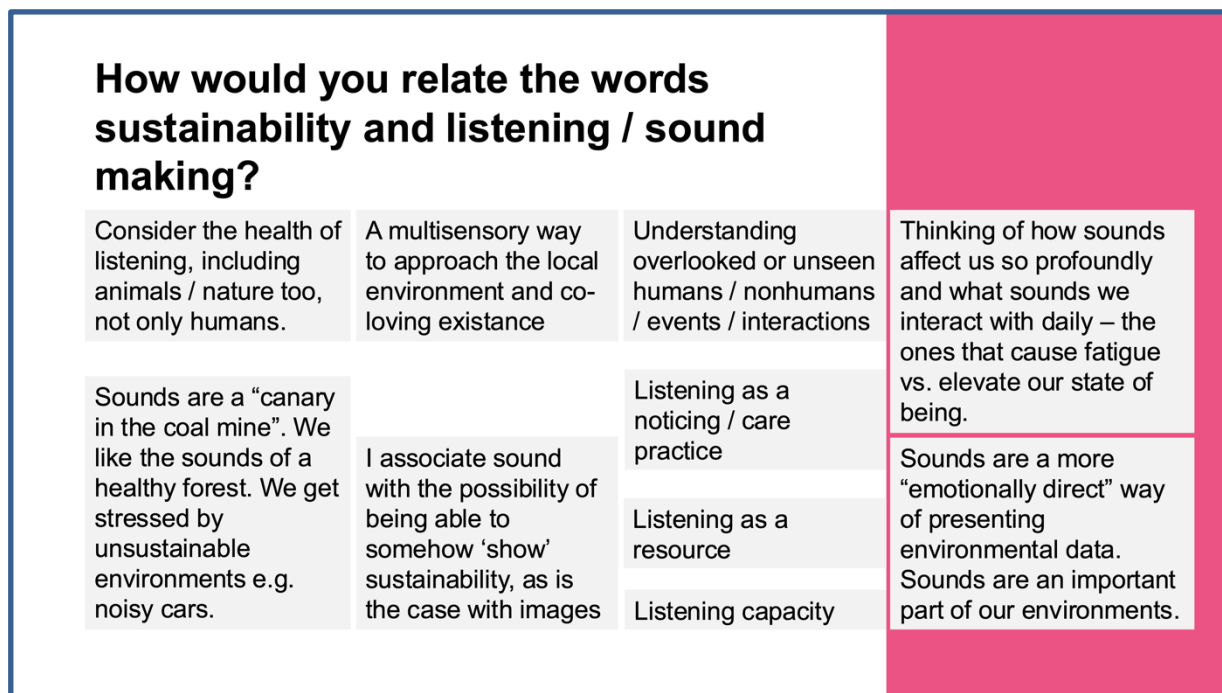


Figure 2. Selected results from the question 1 on Mentimeter.

### 3.3 Detecting through sound: from surviving to living

When looking at the responses to the first question on Mentimeter (Figure 2), one participant (P3) stressed the notion of the ‘*canary in the coal mine*’. This is an allusion to caged canaries that miners would carry down into the mine tunnels with them. If dangerous gasses collected in the mine, they would kill the canary before killing the miners, thus providing a warning to exit the tunnels immediately.

“Sound can let us detect things or understand how things function” (P3), implying that it can help us detect unsustainable processes. A couple of comments pointed at how sound making can be a way to ‘somehow *show* sustainability’. But most comments linked

sustainability and sound through listening as a resource, a capacity, a noticing and care practice, as well as pointing to the importance of auditory hygiene and the potential for listening to the more-than-human world.

Being indeed our primary ‘alarm system’, ears should still exploit this ability in relation to sustainability. A participant concluded: “So it is important not to close our ears, right? Otherwise, we don't know what the needs are” (P4).

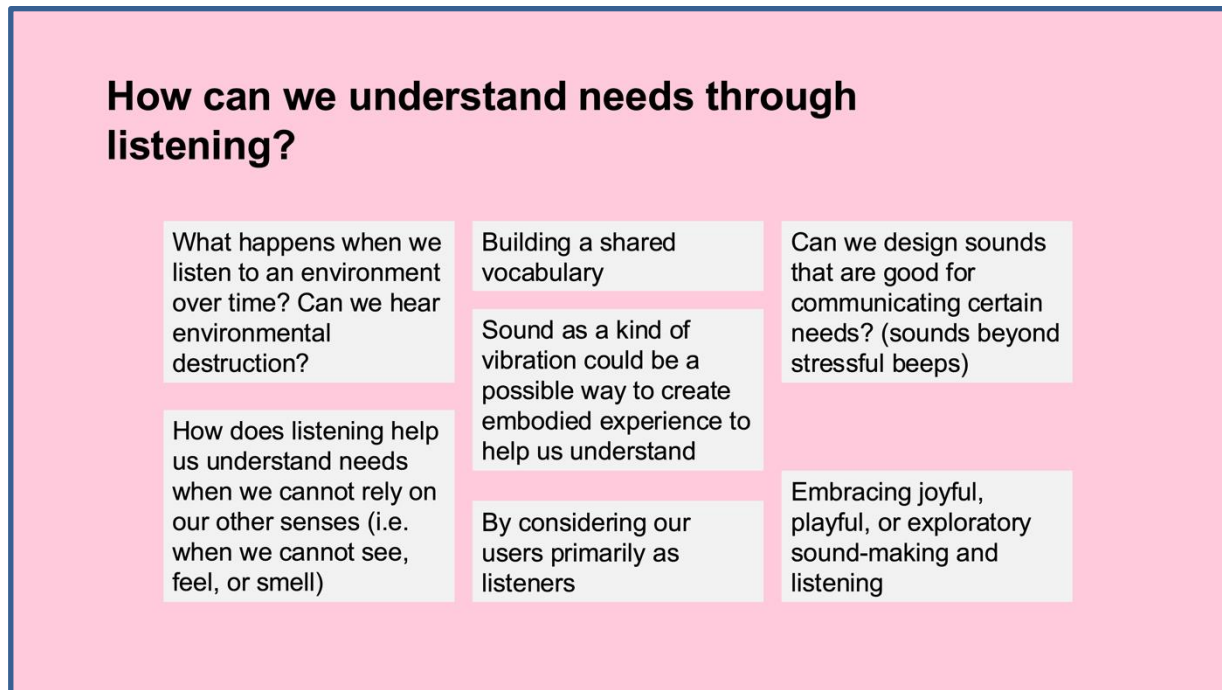


Figure 3. Selected results from question 2 on Mentimeter.

### 3.4 Diversity, subjectivity and cultivating sound

In the next part of the conversation, we discussed how *needs* (Figure 3) might be communicated through sound and understood through listening in context. One participant noted that, in our conversation, “the importance of subjective experience” (P1) had emerged strongly. As an example, they mentioned that a sonic experience can be unbearable for some (e.g. the hand dryer for a child), while not being very problematic for others (e.g. the hand dryer for an adult). They continued:

“Personal experiences come into a lot of importance in defining what is sustainable in terms of using, and also withstanding, sound. [...] We are building environments where we're just dealing with sound, rather than trying to *cultivate* the sound” (P1)

Finding ways to accommodate diverse, subjective experiences come to the fore in critical environments such as ICUs. One participant (P5) recalled an observation made by the authors of (Sen et al., 2022) when presenting their paper: “They said that the hearing sense is the last sense you have before dying” (P5), therefore the tone that monitors the heart rate - a very harsh tone - will most likely be the last thing a person will hear before dying. Özcan, who has expert knowledge of ICU acoustic environments, pointed out that the alarm sound

levels in critical environments are so poorly designed that they nauseate people and impact on lives. She continued noting that, in these environments, safety trumps any other concern therefore silencing alarms at the bedside is very difficult.

A sustainable approach then lies in the balance between the safety priorities and the diverse subjective experiences. This new approach needs to be *cultivated*: it needs to be nuanced and somewhat dynamically modulated. One participant added: “Then we should strategically position the practice of sound design in parallel to other product development processes. It goes together: it shouldn't be an afterthought” (P10).

Another participant (P6) added that sound can be considered an aspect part of “experience design”. For example, they described how they complemented obstetric ultrasounds with designed sounds to help the “patient and physician relationship” (P6), and to provide an experiential and emotional layer to the situation. Someone else noted that such approaches need to be culturally informed: “I think the cultural aspect of sound is very interesting, (something) that we don't really think about, because we think about a sound as a universal kind of thing” (P7).

In this regard, P8 added: “we are very visually literate, all of us, we train from right at the beginning to understand the world visually”, on the other hand there is a lack in education and training in sound. They continued: “(In sound,) there are *likes*, there are also *hates* and *loves*, and they can give us an indication of how we are in the world through sound [...]” (P8).

Another participant mentioned that “we don't have any consensus on what we perceive as listeners” (P3). They continued saying that, in the visual domain, if we say ‘a red triangle’ or ‘green square’ what we mean is clear. In this context, developing and *cultivating* a sound vocabulary could be beneficial. However, ambivalence was expressed by another participant: “I am kind of on the border of making sound as more cognitive process rather than perceptual process” (P1). P3 responded noting that we already use coded sound signals, but that the codes are often not universally shared and therefore can be misinterpreted. As an example, P3 reflected on the American auditory signal for pedestrians’ road crossings, which can sound like a shooting gun (see, for example, <https://tinyurl.com/37pw29wy>) and can be frightening for those who are not familiar with it.

### 3.5 Care, thresholds and negotiation

One participant (P9) suggested that many of the concepts discussed – isolation or not from noise; subjectivity vs. diversity - resonate with notions of *thresholds* and *care*. They brought to the discussion a reflection on *thresholds* that was presented at the *Tender Loving Care* exhibition of the Museum of Fine Arts in Boston (see <https://www.mfa.org/exhibition/tender-loving-care>).

The reflection on thresholds stated:

“Thresholds.

We experience thresholds every day. Sometimes they mark being inside or outside a place, like standing in a doorway, sitting on a window ledge or passing through a gate.

A threshold can also be a feeling, like when we hold back tears, burst into laughter or reach our breaking point. These spatial and emotional experiences help us discern the presence or absence of care. The artworks gathered here help us explore the sensations they provoke. Do thresholds protect us or form unforgiving boundaries?"

P10 mentioned that maybe this perception - that sound is mainly about thresholds - is the reason we often talk about presence or absence of noise rather than in a more nuanced way about balancing diverse experiences, needs and subjectivities. And they asked: "What is the experience in between? How can it be articulated?" (P10)

One participant (P8) suggested that the concept of *negotiation* is key and sound can promote it:

"When we talk about language, or visual language, semantic language, we have this idea that we don't have to negotiate: it's all there, it's kind of transparent, it's neutral, we understand each other. I would like to suggest that we don't. We don't exactly because we are diverse, because we are contingent, because we have different backgrounds, orientations and different thinking. But, somehow, we've managed to convince ourselves that we do." (P8)

For example, in the scenario of the building presented by Misdariis, we understand the visual elements (walls, windows, etc.) in a way that we believe to be universal, however when sound is introduced (via *PiezoPlex*), it tells us about the building infrastructure, its dynamics, indicating how this building is different from others. As sound is contingent, subjectively perceived and understood, it brings certainty into doubt: we find ourselves "questioning our norms, having to renegotiate, having to be tolerant, having to understand our diversity and others'. [...] That is for me one of the most powerful aspects of what sound asks designers to do." (P8)

It provokes the question:

"Who is afforded resonance? Who is made audible in certain architectures, conceptually as well as actually? These are the questions where design can really meet the political, the ideological and ecological. And it's so important, because it makes everything else a bit less sure." (P8)

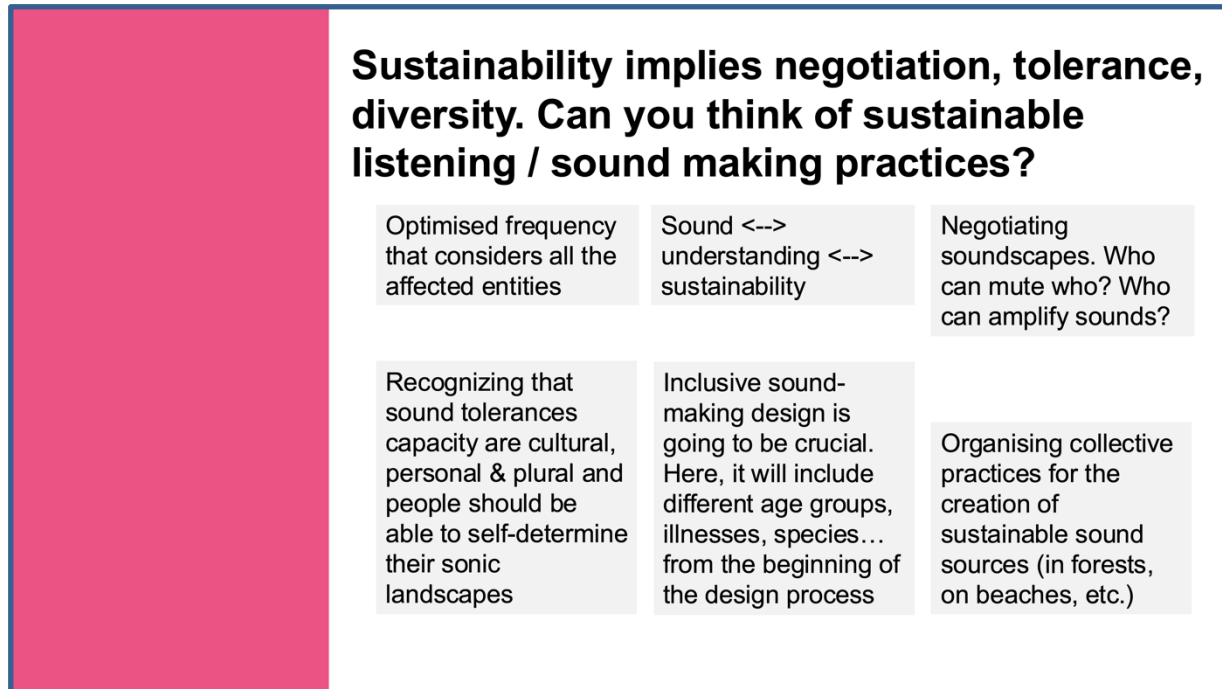


Figure 4: Selected results from question 3 on Mentimeter.

### 3.6 Agency and More-Than-Human

The final part of the conversation was concerned with who has agency in relation to the sonic and sustainability (Figure 4). P4 asked: “Does sound and listening promote agency? We seem to be mainly covering our ears or masking noise with other sounds”. One participant continued: “We are kind of conditioned to *react* to (sound) rather than *respond* to it” (P1). In this regard, P4 recalled a recent workshop they conducted in which non-expert participants could not imagine how to modify unwanted sounds and would only conceive to cancel or mask them. The importance of training and education in sound was once again brought forward by participants who noted that without it, people cannot have equal agency in relation to sound: “I think that's the politics of sound; the environment determining how we perceive the sound and how we treat the sound. And we are shouting back” (P1).

This discussion concluded with a reflection on whether the more-than-human world should also have agency. One participant stated:

“As humans we have language to communicate with each other, but animals, plants, whatever, don't have language, but they make sounds (note: also inaudible sounds that we can amplify with technology) which are a way of communicating, and I think that is a very kind of untapped resource that we can be much better at listening to the sounds of the more-than-human world to understand that they are communicating with us like all the time we're not just listening.” (P12)

This sensitivity to the more-than-human world can make marginalized points of view emerge allowing us to respond to them.

## 4. Reflection

The aim of this conversation was to discuss how a sound-driven approach to design can contribute to a sustainable future by leveraging on what is unique about sound as a design material. We reflect here on how the themes that emerged from the conversation address our initial questions.

### 4.1 What are the characteristics of sound as design material that make it particularly apt to embody and exemplify concepts related to sustainability such as time, the relations between the future and the past, responsibility, intentions, dynamic processes, etc.?

Both sound and sustainability are about addressing what connects us, rather than what keeps us apart. Starting from this observation, several links can be drawn between the concepts of sound and sustainability (Figure 5). The definition of sustainable development - addressing the needs of the present without compromising the future - emerges from a scientific prediction: if we continue consuming our limited resources, we will not be able to have a future. Addressing this requires us to understand what our existing and future needs are, and to find ways of sharing our resources. Sharing requires negotiation, as well as understanding and taking care of others' needs. For this negotiation to be just, people need to feel that they can participate, take responsibility and have agency. Sound is fundamentally relational or, as Voegelin (2018) writes, it can be seen as "the agitation of the between of things", and it deals with similar concerns. In everyday life, sound helps us monitor the dynamic processes happening around us. It is a tool for investigation and prediction. In short, it is our primary alarm system: when familiar patterns change, we may be able to predict what is happening next. Sound is shared and is the primary way through which we can communicate our individual and diverse needs to others. Sound is not a neutral material: it can be very powerful and violent, as well as disappear into silence. And because sound is shared and powerful, it requires negotiation, care and responsibility. Finally, sound can bring to the fore the issue of who has agency. In our conversation, this emerged through questions such as: 'who has the power to change an unsustainable sonic environment? Are current sound technologies, such as wireless earbuds, promoting better listening and agency, or are they some kind of 'ear-blinders', i.e. tools for disengagement?'

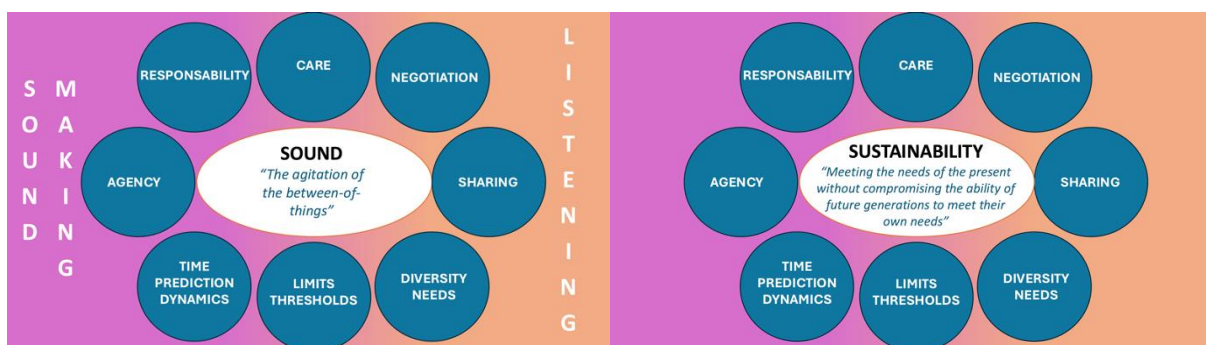


Figure 5 Illustration of the "common ground" between sound and sustainability.

#### ***4.2 What is the current state-of-the-art in the field, and what should future directions and milestones be?***

There is still much that needs to be done to use the full potential of sound as a design material for sustainability.

Four main future directions emerged from this conversation:

- Through interdisciplinary research, events such as this conversation and new conferences such as SoniHED, the common ground between sound and sustainability (Figure 5) is starting to emerge. This new awareness, combined methodological approaches (as proposed by Delle Monache), can form the basis for a new framework of sound-driven design for sustainability
- A reflection must be conducted regarding the kind of sound technology we want to develop in the future. Current trends seem to focus on loudness (how to enhance it and how to constraint it) or on sonic isolation and masking (through wireless headphones/earbuds). New directions could look at defining the concepts of ‘listening capacity’ and ‘auditory hygiene’, and develop adaptive sound technology that is able to account for these
- There is a need to embed a sound-driven approach at the start of most design processes. Treating sound as an afterthought, or simply as the noisy by product of other parts of a design, can often result in unsustainable outcomes
- Finally, there is a need to increase training and education about sound and listening at all levels. This is key to increase sonic sensitivity, sonic awareness and responsibility, and to use design to cultivate and shape environments for a better life.

#### ***4.3 How can sound-driven design collaborate with other relevant fields of inquiry to address the urgent changes needed?***

Interdisciplinary efforts need to delve deep on how we can leverage the connections between sound and sustainability (Figure 5) to design experiences that allow people to ‘feel’ and understand sustainability concepts through sound as well as other modalities. In this regard, one urgent focus could be designing ways in which people can understand and try out, through sound, how they are responsible and can have agency. Additionally, in contexts where sound is meant to be understood unequivocally by all, interdisciplinary efforts are needed to develop standards and codes that work for all and across cultures.

## **5. Conclusion**

The conversation was successful in eliciting a rich dialogue about sustainability and sound. The diverse scenarios presented at the start of the event were helpful in prompting discussions in different directions: some focusing on theoretical aspects and others more applied. By analyzing and reflecting on what was discussed, we were able to identify and map out new exciting directions for future work.

**Acknowledgements:** We acknowledge the support of the Sound for Energy Project <https://soundforenergy.net>, which is funded by the Swedish Energy Agency (project No. 51645-1).

## 6. References

- Alwazzan, A., Mejía, G. M., Xie, Y., & Fischer, D. (2020). Incorporating behavioral theory in design ideation for changing sustainability behaviors, Design Research Society Conference. <https://doi.org/10.21606/drs.2020.178>
- Ballora, M., Pennycook, B., Ivanov, P.C., Glass, L. and Goldberger, A.L., (2004). Heart rate sonification: A new approach to medical diagnosis. *Leonardo*, 37(1), pp.41-46. <https://doi.org/10.1162/002409404772828094>
- Barras, S., (2014) Acoustic sonification of blood pressure in the form of a singing bowl. Conference on Sonification of Health and Environmental Data (SoniHED).
- Blevins, E. (2007) Sustainable interaction design: invention & disposal, renewal & reuse. CHI Conference, ACM. <https://doi.org/10.1145/1240624.1240705>
- Delle Monache, S., Cera, A. and Pauletto, S. (2024a) From data to dialogue: “Earth Electric”, a sonic journey through global energy landscapes. ACM Audio Mostly Conference, Milan, Italy. <https://doi.org/10.1145/3678299.3678301>
- Delle Monache, S., Rocchesso, D., Bevilacqua, F., Lemaitre, G., Baldan, S., and Cera, A. (2018). Embodied sound design. *International Journal of Human-Computer Studies*, 118, 47-59. <https://doi.org/10.1016/j.ijhcs.2018.05.007>
- Delle Monache, S., Misdariis, N., and Özcan, E. (2022). Semantic models of sound-driven design: Designing with listening in mind. *Design Studies*, 83, <https://doi.org/10.1016/j.destud.2022.101134>
- Delle Monache, S., Özcan, E., and Misdariis, N. (2024b). Designing [The, With, Against] Sound [For]: Towards A Semantic-oriented Coding Scheme For Protocol Studies In Sound-driven Design. Design Research Society Conference, Boston, USA. <https://doi.org/10.21606/drs.2024.761>
- Ettehad, O., Jones, L. and Hartman, K. (2020) Heart Waves: A Heart Rate Feedback System Using Water Sounds. International Conference on Tangible, Embedded, and Embodied Interaction (pp. 527-532). <https://doi.org/10.1145/3374920.3374982>
- Flowers, J.H., Whitwer, L.E., Grafel, D.C. and Kotan, C.A. (2001) Sonification of daily weather records: Issues of perception, attention and memory in design choices. International Conference on Auditory Displays.
- Gilmurray J. Ecological Sound Art: Steps towards a new field. *Organised Sound*. 2017;22(1):32-41.
- Groß-Vogt, K., Weger, M., Höldrich, R., Hermann, T., Bovermann, T. and Reichmann, S. (2018). Augmentation of an institute’s kitchen: An ambient auditory display of electric power consumption. International Conference on Auditory Displays, <http://hdl.handle.net/1853/60088>
- Hammerschmidt, J., Tünnermann, R., & Hermann, T. (2013). Infodrops: Sonification for enhanced awareness of resource consumption in the shower. International Conference on Auditory Displays <http://hdl.handle.net/1853/51642>
- Hansson, L. Å. E. J., Cerratto Pargman, T., & Pargman, D. S. (2021). A decade of sustainable HCI: connecting SHCI to the sustainable development goals. CHI Conference, ACM. <https://doi.org/10.1145/3411764.3445069>
- Harman, A. et al. (2016). NotiFall: Ambient Sonification System Using Water. CHI Conference. ACM, New York, NY, USA, 2667–2672. <https://doi.org/10.1145/2851581.2892443>



- Keegan, N. L. (2020). Children who say hand dryers ‘hurt my ears’ are correct: A real-world study examining the loudness of automated hand dryers in public places. *Paediatrics & Child Health*, 25(4), 216-221. <https://doi.org/10.1093/pch/pxz046>
- Lockton, D., Bowden, F. and Matthews, C. (2017) Powerchord: exploring ambient audio feedback on energy use. *Living Labs: Design and Assessment of Sustainable Living*: 297-308.
- Marentakis, G., & Dal Palù, D. (2024). It sounds sustainable: practices in designing sound for sustainability, Design Research Society Conference, Boston, USA. <https://doi.org/10.21606/drs.2024.791>
- Misdariis, N., Cera, A., Levallois, E., and Locqueteau, C. (2012) Do electric cars have to make noise? An emblematic opportunity for designing sounds and soundscapes. *Acoustics 2012*. <https://hal.science/hal-00810920/>
- Niedderer, K., Ludden, G., Desai, S., & Hermsen, S. (2022). Design for Behaviour Change: Taking the Long View Fast, Design Research Society Conference, Bilbao, Spain. <https://doi.org/10.21606/drs.2022.1075>
- Özcan, E., Broekmeulen, C. L., Luck, Z. A., van Velzen, M., Stappers, P. J., & Edworthy, J. R. (2022). Acoustic biotopes, listeners and sound-induced action: a case study of operating rooms. *International Journal of Environmental Research and Public Health*, 19(24), 16674. <https://doi.org/10.3390/ijerph192416674>
- Özcan, E., Rietdijk, W., and Gommers, D. (2020) Shaping critical care through sound-driven innovation: Introduction, outline, and research agenda. *Intensive Care Medicine* 46.3 (2020): 542-543. <https://doi.org/10.1007/s00134-019-05832-6>
- Özcelik, A., Löchtefeld, M., & Tollestrup, C. (2022) Long-lasting smart products: Overview of longevity concepts in sustainable ICT and design for sustainability. Design Research Society Conference, Bilbao, Spain. <https://doi.org/10.21606/drs.2022.638>
- Pauletto, S., Barahona-Ríos, A., Madaghiele, V. and Sez nec, Y. (2023) Sonifying energy consumption using SpecSinGAN, Sound and Music Computing Conference, Sweden. <https://doi.org/10.5281/zenodo.10062986>
- Pauletto, S. (2024) Sonification and Sustainability, in Filimowicz, M. (ed.) *The Routledge Handbook of Sound Design*, Focal Press.
- Pauletto, S. and Sez nec, Y. (2024) Connecting Sound to Data: Sonification Workshop Methods With Expert and Non-Expert Participants,” *Journal of the Audio Engineering Society.*, vol. 72, no. 5, pp. 328–340 <https://doi.org/10.17743/jaes.2022.0143>
- Polli, A. (2005) Atmospherics/weather works: A spatialized meteorological data sonification project. *Leonardo*, 38(1), pp.31-36. <https://doi.org/10.1162/leon.2005.38.1.31>
- Selfridge, R., Barone, C., & Pauletto, S. (2022). Sonifying an Office Gadget to Indicate Air Quality. *Sound and Music Computing Conference, France*. <https://doi.org/10.5281/zenodo.6572709>
- Sen, Avery, Yoko Sen, Matt Barile, Sage Palmedo, Andreas Walden, and Vitor Vicente Antunes (2022) Functional and sensible: Patient monitoring alarm tones designed with those who hear them. Design Research Society Conference, Bilbao, Spain. <https://doi.org/10.21606/drs.2022.684>
- Sez nec, Y., & Pauletto, S. (2022). The singing shower: A melody-sensitive interface for physical interaction and efficient energy consumption. *Sound and Music Computing Conference, France*. <https://doi.org/10.5281/zenodo.6798253>
- SoniHED - Sonification of Health and Environmental Data conference <https://www.kth.se/profile/pauletto/page/sonihed>
- St Pierre, M. and Droumeva, M., (2016) Sonifying for public engagements: a context-based model for sonifying air pollution data. *International Conference on Auditory Displays*. <http://hdl.handle.net/1853/56580>

- Stegall, N. (2006) Designing for sustainability: A philosophy for ecologically intentional design. *Design issues* 22.2: 56-63. <https://www.jstor.org/stable/25224047>
- Tonetto, LM, et al. (2014) Modifying Action Sounds Influences People's Emotional Responses and Bodily Sensations. *i-Perception*, vol. 5, no. 3, May 2014, pp. 153–63. <https://doi.org/10.1068/i0653>
- Voegelin, S. (2018). *The Political Possibility of Sound: Fragments of listening*. Bloomsbury Publishing USA.
- Walus, B. P., Pauletto S., and Mason-Jones, A. (2016) Sonification and music as support to the communication of alcohol-related health risks to young people. Study design and results, *Journal on Multimodal User Interfaces*, vol. 10, no. 3, s. 235-246. <https://doi.org/10.1007/s12193-016-0220-0>
- World Commission on Environment and Development (1987) *Our Common Future: Report of the World Commission on Environment and Development*, A/42/427, 1987, <http://www.un-documents.net/ocf-02.htm#l>

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