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23–28 June 2024

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Colin M. Gray
Estefania Ciliotta Chehade
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Editorial: Welcome to DRS 2024

A very warm welcome to DRS2024, a historic moment as we gather for the first DRS conference in the United States. Design research in the US is rich but distributed and we hope with this conference to not only bring together design researchers across the US, but to provide an opportunity to connect with design researchers across the globe. This milestone is a testament to the expanding reach and inclusivity of the design research community. Our journey to this conference has been one of dedication and collaboration, highlighting the resilience, adaptability, and increased reach of our field.

Boston, a city renowned for its academic traditions and historical significance, is our setting for the conference this year. And Northeastern University's College of Arts, Media, and Design is our host institution, in partnership with the Harvard University Graduate School of Design and the Massachusetts Institute of Technology Morningside Academy for Design. We are also welcomed by the City of Boston Mayor's Office of New Urban Mechanics, the Design Museum Foundation, and the Museum of Fine Arts Boston. This setting provides an inspiring backdrop for a conference that values the impact of design in a multitude of contexts and that reflects the diverse and dynamic nature of design research.

The call for papers for DRS2024 resulted in a huge response, with 1184 abstracts and 869 full paper submissions—over a 47% increase from DRS2022. Of these submissions, 78 were desk rejected and 791 papers underwent rigorous peer review. Based on this review process, we are pleased to include 386 accepted papers in our program, reflecting a 44.4% acceptance rate. This rigorous selection process ensures that we continue to uphold the highest standards of academic excellence in design research.

Our program is rich and varied, featuring 29 conversations and 38 workshops designed to foster deep engagement and lively debate. We are very pleased to welcome over 770 delegates, including more than 180 online participants and 590 participants on-site in Boston. This hybrid blend of in-person and online participation, a key feature of DRS2022 in Bilboa, enriches our conference through making it accessible.

Research papers remain at the center of the conference, and we are proud to present 28 invited theme tracks, comprising 342 of the accepted papers. These tracks cover a wide array of topics, from more-than-human design and sound design to design for policy, ethics, and pluriversal design. Themes that reflect both established and emerging areas of interest within the design research community. While many of these tracks are sponsored by

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DRS Special Interest Groups (SIGs), others represent new and exciting areas of exploration.

The diversity of our theme tracks underscores the expansive nature of design research. Our field continues to progress and evolve, integrating new perspectives from disciplines such as anthropology, politics, economics, law, and healthcare. This cross-disciplinary approach enriches our knowledge creation and pushes the boundaries of design research.

PhD and early-career researchers play a crucial role in this conference, representing the next generation of design scholars. Their fresh perspectives and innovative approaches are helping to shape the future of our field. We welcome those for whom DRS2024 is their first opportunity to participate in a conference, we hope you will have a rewarding and transformative experience.

Supporting and enabling the design research community is the DRS Digital Library, a central hub for disseminating design research with almost 1 million downloads. Since its inception in 2020, the Library has become a vital resource, facilitating connections, promoting collaboration, and communicating the scope and value of design research.

As we gather in Boston, we celebrate not only the achievements of our discipline but also the potential for future contributions. DRS2024 is a platform for new ideas, new connections, and new opportunities. We look forward to the powerful discussions and collaborations that will emerge from this conference, driving design research forward in innovative and impactful ways.

Acknowledgements

We extend our deepest gratitude to everyone who made DRS2024 possible. Special thanks to our local hosts in Boston for their support and hospitality. We also thank the 133 Theme Track Chairs and 1067 Reviewers for their incredible dedication and hard work, ensuring the high quality of this conference.

We are grateful to all the authors who submitted their work for review. Your contributions are the heart of this conference, and we hope that you will continue to engage with and grow within the design research community.

Finally, we acknowledge the invaluable efforts of our support team and volunteers. Your commitment and countless hours of work have made this conference a reality.

DRS2024 Proceedings Editors:

Colin M. Gray, Estefania Ciliotta Chehade,
Paul Hekkert, Laura Forlano, and Paolo Ciuccarelli

26 How Do You Sound Design? Articulating Experiences and Cultures via Listening

Session chairs

Nicolas Misdariis, Stefano Delle Monache, and Elif Özcan

Editorial

Stefano Delle Monache, Nicolas Misdariis, Elif Özcan, Daniel Hug, Sara Lenzi, Sandra Pauletto, Davide Rocchesso, and Simone Spagnol

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Sound-Driven Design: Foundations

Designing [The, With, Against] Sound [For]: Towards A Semantic-oriented Coding Scheme For Protocol Studies In Sound-driven Design

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Sound-driven design is a collaborative and multidisciplinary design activity which uses sound as catalyst of the design approach. We present a semantic-oriented methodology and coding system to capture the diversity of sound-driven concepts that support the design process. We evaluate the methodology in a protocol study of a design team, composed of one sound designer, one acoustic engineer, one designer, and one expert user, engaged in exploring the listening dimension in the caregiving experience. We use linkographic analysis to integrate and evaluate our coding scheme. The methodology proves to be effective in revealing the semantic models of the participants and representing their semantic contribution to the design process. Two protocol studies in the same context are in progress to iterate the methodology and the coding scheme. The results are expected to provide a solid ground to devise methods and boundary tools to facilitate participation and co-creation in sound-driven design.

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Augmenting soundscapes of ICUs: A Collaborative approach

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In this study we investigated characteristics for designing soundscape augmentations within Intensive Care Units (ICUs). We introduced soundscape perception and fundamental needs as the basis of design strategies for augmenting sound-scapes experienced by critically ill patients. We used results of a previous study, where in interviews regarding current ICU soundscapes, patients revealed four concerns and underlying needs. They found that ICU soundscapes were alienating, unvaried, unfamiliar, and disruptive. These insights were used as contextual inputs in a collaborative workshop with ICU nurses, resident doctors, and researchers. In separate groups, they developed three system concepts named Smart Environmental Assistant, Patient Soundscape Dashboard, and Familiar Wake-ups. Based on qualities of these concepts, we found five characteristics for designing effective soundscape augmentation systems for ICUs: personalized, user-friendly, integrated, humanized, and familiar. These characteristics, rooted in perspectives of various ICU experts, are essential for reshaping the ICU soundscape into a more positive listening experience.

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Guiding design students to sound-driven design from the base camp of semiotics

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The lack of knowledge in the field of sound-driven design lags our educational efforts to teach BSc students about the role of sound in current design process methodologies. Teaching programs rarely include subjects dedicated to creating a coherent experience using data-to-sound strategies, sound informativeness, or the interactions that users have with product sounds. Understanding sound at the same level as other sensory cues prepares students to enrich the usability, attractiveness, and communicative qualities of products, services, and systems. This contribution aims to provide an integrative and multidisciplinary perspective of sound-driven design through the adaptation and application of the 'Design Framework for Audible Alarms' as a conceptual design tool in semiotics. The framework is exemplified through several design cases carried out in the sessions of the subject 'Semiotics in design' during two academic years, as part of the BSc in Industrial Design and Product Development Engineering.

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It sounds sustainable: practices in designing sound for sustainability

Georgios Marentakis[1], Doriana Dal Palù[2]
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Design for sustainability has received significant attention in the past years. Start-ing from green design, the focus gradually shifted towards eco-design, the circu-lar economy, and sustainable development. Meanwhile, design for pro-environmental behavior highlighted the importance of designing for a sustaina-ble use phase of products. Sound design encompasses several practices such as in sound for film, radio and podcasting, sound for interaction and games, and prod-uct sound design. Sound is an important element of any

experience and can con-vey several emotional and aesthetic product qualities. The relationship between designing sound and designing for sustainability, however, has not received much attention. Motivated by this, we review here situations in which sound design has been used when designing for sustainability or sustainable behavior. Subse-quently, we relate this to the broader perspectives offered by design for sustain-ability and identify opportunities for cross-fertilization between the two fields.

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Towards a Definition of Autographic Sonifications: Listening as an Act of Knowledge

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In recent years, sonification as a method to analyze, represent and communicate data through sound has grown significantly showing a diversity of purposes, users, and topics. In data journalism, education, art, or data monitoring, sound is used to both support and engage experts, researchers, and the general public with a broad range of scientific and social phenomena. As the field is moving towards shared design and evaluation processes, new practices seem to emerge that put the listener at the center. By analyzing recent cases from the Data Sonification Archive, the paper proposes a definition of autographic sonification as a self-encoding process in which the act of listening becomes central to making sense of complex phenomena.

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Sound-Driven Design in Action

ICU alarm management reimagined: Sound-driven design and the role of acoustic biotope

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Staff well-being and patient safety are undermined by false alarms in the ICU. This study focuses on enhancing the effectiveness of sound-induced actions in the ICU by assessing the distinctness and informativeness of alarm sound events as perceived by nursing staff. We investigated the alarm load in an adult ICU, with an emphasis on alarm durations and their impact on actionability. As a strategy to mitigate false alarms, we simulated the introduction of alarm delays and examined how this affected alarm characteristics across various vital parameters. Results demonstrate that the introduction of alarm delays reduce the number of alarms remarkably, with a 10-second delay eliminating more than half of the alarms. Our results indicate that delays should be tailored to each specific vital parameter and medical context. We further address key considerations for implementing alarm delays in alarm management practice.

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Designing tools for designers: The Data Sonification Canvas

Sara Lenzi[1,2], Paolo Ciuccarelli[3,4]
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Although data sonification i.e., the use of sound to represent data is gaining momentum, its impact is still limited. The lack of shared design methods and tools is seen as an obstacle for the expansion of sonification from a scientific method to a mass-medium for better human-data interaction. The Data Sonification Canvas is a design tool that supports authors during the creative process. Our paper first describes the genesis of the Canvas, grounded in expert interviews and literature from sound design for film, human-computer interaction, and data visualization. We then present an evaluation study with 20 participants that measured the pragmatic and hedonic quality of the Canvas. Results show that users consider it a valuable, self-oriented, and practical tool that meets their needs in a structured, yet straightforward manner. Areas of improvement include uniform the terminology; increase accessibility; include multi-media content and customize the spatial organization of the components.

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Designing Sound for Public Spaces Through a Research-Creation Collaboration Framework

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When designing a sound installation in public spaces, creators consider a wide range of factors related to the site where it will be deployed as part of the artistic statement. However, anticipating the impact of the sound installation on user experience is difficult in the absence of established methods to inform the design and evaluate the outcomes. Based on three case studies involving sound artists and soundscape researchers, we propose a research-creation collaboration framework through four stages: 1) field recordings of pre-existing sound environments; 2) diagnosis of pre-existing sound environments and public space usage; 3) sound installation prototyping in laboratory settings; 4) evaluation after deployment. These stages, alone or in combination, can systematically inform – or eventually drive – the design and evaluation of new sound installations in public spaces.

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Designing through ecological soundscape to foster human-nature interaction

Francesca Valsecchi, Herun Chen, Qingyu Zhang
Tongji University, China, People's Republic of, College of Design and Innovation

Sense of hearing provides an effective, immersive and empathetic way to observe, map and explore places with a more-than-human approach. In our contemporary mediascape inundated by visual stimuli, the rediscovery of sound offers a different understanding of the world. By discussing two research-based sound design projects, this study discusses 1) the potential of using soundscape as an empathetic research tool in multispecies ethnography and 2) how soundscape as a communication media could stimulate more-than-human exploration and empathy. Such design outcomes develop an empathic and conscious understanding of human-nature interaction, even in an urban context. Intersecting science, research and creative practices, the projects use soundscape for ecological exploration and narratives. The projects contribute to how ecological soundscape plays a significant role in the sound-driven design process to re-establish kinship between humans and more-than-humans, thereby nurturing urban-nature re-discovery and coexistence.

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Acoustic patterns for urban attractors

Juan Salamanca
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This study proposes the use of forms of entrainment as an interaction design principle for social computing. Entrainment could be used to design computational artifacts that produce socially beneficial effects, suitable for design projects that promote collaborative action. This study explores acoustic entrainment to gather cyclists into groups to reduce carbon-intensive urban commuting. The system uses visual cues and rhythmic patterns to gather riders with similar routes around mobile GPS signals. Preliminary results from a small empirical study (n=8) show how pattern phasing can encourage riders to accelerate. This method has limitations in communicating negative acceleration and proximity. Adjusting pattern tempo and volume may compensate for this shortcoming. Conclusions are drawn concerning the effects of acoustic entrainment on cyclist's engagement with others and with the environment.

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It sounds sustainable: practices in designing sound for sustainability

Georgios Marentakis
Østfold University College, Norway

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It sounds sustainable: practices in designing sound for sustainability

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Abstract: Design for sustainability has received significant attention in the past years. Starting from green design, the focus gradually shifted towards eco-design, the circular economy, and sustainable development. Meanwhile, design for pro-environmental behavior highlighted the importance of designing for a sustainable use phase of products. Sound design encompasses several practices such as in sound for film, radio and podcasting, sound for interaction and games, and product sound design. Sound is an important element of any experience and can convey several emotional and aesthetic product qualities. The relationship between designing sound and designing for sustainability, however, has not received much attention. Motivated by this, we review here situations in which sound design has been used when designing for sustainability or sustainable behavior. Subsequently, we relate this to the broader perspectives offered by design for sustainability and identify opportunities for cross-fertilization between the two fields.

Keywords: sound design; sustainable behavior; design for sustainability; eco-feedback

1. Introduction

Since the beginning of the century, several researchers have investigated how design research can contribute to solving the great sustainability challenges faced by humanity. The results of these investigations formed a notable trend within design research: *designing for sustainability*, which underwent through several refinements over the last years as did the very concept of sustainability.

Designing for sustainability has reached into several fields not necessarily strictly related to product design such as architecture and the built environment, transport, resource use and management, computing and interaction design, health but also music, art, and culture

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which only testifies to the fact that design is an area of major importance in the journey towards more responsible and sustainable production and consumption model (Bhamra & Hernandez, 2021).

Design for sustainability is concerned with all phases of the product lifecycle including the use phase. Sound is an essential part of the experience and use of products and can be shaped by design in accordance with predefined requirements. Methods for sound design become relevant in this context. Sound design existed for several years as a practice in film, animation, and contemporary music but is nowadays receiving significant attention by design researchers involved in sonic interaction design, auditory display, warnings and alarms, computer games, and sonic interactions with products.

Researchers in sound and music interacted relatively early with the sustainability discourse, which led to research in soundscape, acoustic communication, and acoustic ecology (Schafer, 1993; Truax, 2012; Westerkamp, 2002a). Initial attention was in understanding the soundscape and how it is perceived by listeners (Schafer, 1993), how information flows and creates relationships between listeners and their environments, and to the system of relationships between organisms and their sonic environments. This research also influenced music and composition (Truax, 1996; Westerkamp, 2002a). Subsequent investigations can be found in the related fields of ecoacoustics (Farina & Gage, 2017) and bioacoustics. Acoustic ecology helped sensitize to our changing soundscape but also to the adverse effects of noise (WHO, 2018).

Design has been an issue within acoustic ecology in particular in relationship to designing soundscape interventions for urban spaces. In such cases, users are asked to adjust the relative balance between ambient recordings, foreground sources, and the sound of possible interventions e.g., (Botteldooren et al., 2020; Davies et al., 2014; Stevens et al., 2018; Sudarsono et al., 2017). However, the approach taken when designing and evaluating soundscape is not entirely compatible with the *designing for sustainability* discourse, which often is directed to topics such as the circular economy, green product design, and sustainable behavior. More recently, however, researchers were involved in understanding how sound can be used in contexts closer to the ones targeted when *designing for sustainability*. However, there has been little effort to understand how the two fields interact and provide possibilities for cross-fertilization.

We attempt here to provide this perspective by analyzing the results of a literature review aiming to identify existing connections between the two fields (Figure 1). We proceed by presenting key concepts in designing for sustainability and in sound design. Then we present the results of the literature review and our interpretation on the main categories that emerge as a result of an inductive analysis of the publications we have identified. We then close with a discussion of perspectives we consider worth investigating further in relation to sound design for sustainability. We find that there is significant potential for innovation through *designing sound for sustainability*.

Figure 1 A visualization of the process followed.

2. Design for sustainability

Design for sustainability has been an area of research that has developed significantly over the last 30 years. Following the first definitions of sustainable development in the late 1980s, initial efforts such as *Green design* primarily focused on lowering environmental impact through redesigning (Burall, 1991). *Eco design* emerged as a design approach soon thereafter that aimed to reduce the environmental impact of each stage of the product life cycle – material acquisition, manufacturing, use, and disposal - in accordance to the life cycle approach (Han, 1997). More recent approaches highlighted the social and human-related aspects emphasizing user behavior during the use phase. The Product-Service Systems (PSS) approach (Roy, 2000) aims to reduce the amount of physical products circulating by leveraging shared use, social design, and related services. Emotionally durable design has similar aims but focuses on forming stronger emotional bonds between products and users (J. A. Chapman, 2008). Design for Sustainable Behavior (Bhamra & Hernandez, 2021; Lilley, 2009) also focuses on the use phase emphasizing and the resources required for product operation. Design for sustainable behavior draws on environmental psychology and theories of pro-environmental behavior (Klöckner, 2015) but also behavior change (Daae & Boks, 2014). The use of eco-feedback (Froehlich et al., 2010) is quite prominent to inform users on resource use, enable comparisons but also to help keep track with consumption goals.

3. Sound design

Sound design originated as a practice in film and product sound design but nowadays finds applications in video games, auditory display and sonification, sonic interaction design, aural architecture, etc. Sound design aims to make these (listening) intentions audible (Susini et al., 2014) and designers target sound form (i.e., sound quality) and sound function (i.e., purpose in the context of use). Cera et al. (Cera et al., 2016) emphasizes composing sound using a lexicon of *physically-grounded phenomena*, thus keeping a direct link to sound imagination.

Most sound design processes evolve in a linear manner. A well-cited approach consists of analysis, creating, and testing steps (Misdariis & Cera, 2017; Misdariis & Hug, 2020; Susini et al., 2014). A similar three-step approach called briefing, debriefing, and validation is presented by Carron (Carron et al., 2014). Özcan & van Egmond (Özcan & van Egmond, 2006)

also propose a linear sound design process that involves problem analysis, conceptual design, embodiment and detailing steps and included small feedback cycles.

Similarly, Nykänen et al. (Nykänen, 2008; Nykänen et al., 2015) also propose a linear process which involves identifying customer needs, establishing target specifications, generating, selecting, and testing product concepts, setting final specifications, planning development and obtaining feedback in focus groups.

Sound design often includes a sketching step which aims to support the thinking process but also to store and communicate ideas (Marentakis, 2023). Several approaches to sketching have been proposed which include the use of low-fi sound (Nykänen et al., 2015), sketching using similar sounds (Buxton, 2010; Kemper & Hug, 2014; Pirhonen et al., 2007), performative sketching (Kemper & Hug, 2014; Pauletto, 2014), embodied sketching (Delle Monache et al., 2018; Jansen et al., 2011), and verbal sketching (Carron et al., 2017). Cera et al. (Cera et al., 2016) suggested designing sound by transforming sound sketches into sound designs.

The aforementioned processes combine design and evaluation steps and emphasize function similar to designing for auditory displays and sonification (Barrass, 1998; Brazil & Fernström, 2009; Frauenberger & Stockman, 2009). Hug & Misdariis (Hug & Misdariis, 2011), however, identified tensions between sound design methods and sound design practice. Practitioners tend to weigh form and sonic considerably more than when designing functional sounds (icons, earcons, and sonifications) and emphasized emotional and expressive qualities and context. Activities are hard to identify as parts of a process (Hug, 2020). In reaction to this (Kemper & Hug, 2014) propose a sound-driven performance-led design approach.

4. Sound design and sustainability in the literature

In this section, we present the result of the literature search we carried out. The goal of the literature search was to identify existing connections between sound design and sustainability. The literature search was performed in Google Scholar in two steps. The first was a title search using the keywords: sustainability AND sound, sustainability AND music, and sustainability AND sound design. The second step was a full search for again for sound and sustainability, music and sustainability, and sound design and sustainability but this time in ACM, IEEE, Audio Engineering Society, and Acoustical Society of America and in a number of related conferences such as New Interfaces for Musical Expression, Sound and Music Computing, Audio Mostly, International Conference on Auditory Display. Google scholar was also used for the latter search. Even if soundscape, acoustic communication, and acoustic ecology research have documented links with sustainability, these were not investigated using keywords due to space limitations but also because these research areas are well established but have a limited focus on design (for sustainability). However, we included articles that relate to these areas which were provided but the keyword search we did perform. Finally, we followed up the citation lists in the found articles for references we might have missed. The results were screened for relevance and finally we came up with 105 publications which were considered. The first article in the collection was published in 2002 and the

most recent was from 2024. By observing Figure 3, we see that there is an increasing interest in the intersection between sound design and sustainability research. There were 52 journal articles, 43 conference papers, 6 books, and 4 theses in our sample.

Subsequently the publications were reviewed and categorized according to their research domain as this emerged by considering the publication venue and the disciplinary area we believed was most appropriate to describe the work presented. These are presented in Figure 2. Then an inductive process based on thematic analysis took place in order to identify the research themes according to which the articles could be grouped as deemed appropriate by the two authors. These are presented in the next section. The whole process was summarized in Figure 1.

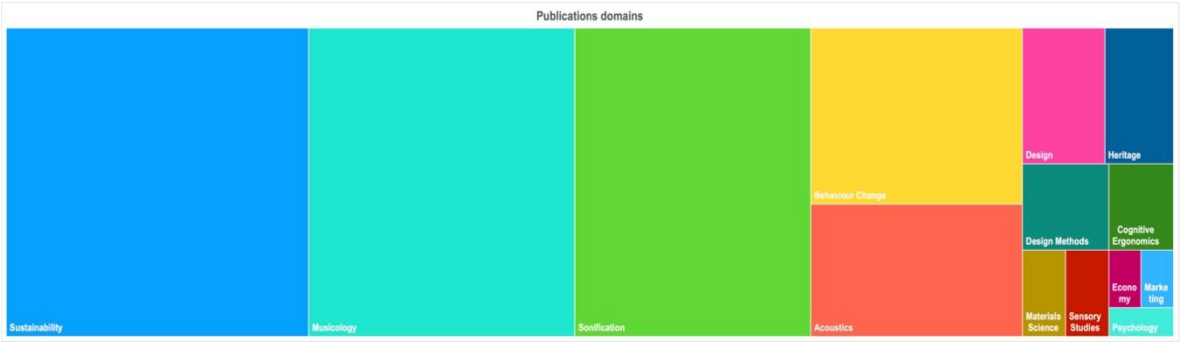

Figure 2 The distribution of the publication domains (i.e. the disciplinary areas).

5. Themes in sound design and design for sustainability

We present here the results of an inductive analysis of our sample which aimed to identify themes around which the intersections between designing sound and designing for sustainability have formed. The themes and the frequency with which they appeared are presented in Figure 4.

5.1.Sound, music, and the environment

Despite not targeting soundscape research, a number of entries we identified related to the themes of sound, music, and the environment as these appear in the soundscape and acoustic ecology discourse. These include contributions reexamining the notion of soundscape (Droumeva, 2021), studies and devices on noise, ambient and even ultra-sound sound, and perceptual studies on the effect of noise-masking sounds on brain activities (Gerlsbeck & van Orden, 2009; Grimshaw-Aagaard & Bemman, 2022; Li et al., 2022; Lucherelli et al., 2014). We also have studies on ecological sound art (Gilmurray, 2017) and music (Keller & Lazzarini, 2017; Spence & Ballora, 2021) that follow up on established themes in this line of research (Truax, 1996; Westerkamp, 2002b).

5.2. Eco-musicology

Eco-musicology often pops up when looking for articles looking at the relationship between sustainability, sound and music. Eco-musicology sprang out of eco-criticism, a field of literature that studies cultural products which imagine and portray human-environment relationships. In this sense, eco-musicology is eco-critical musicology and not necessarily related to sustainability or the environment (Allen, 2011).

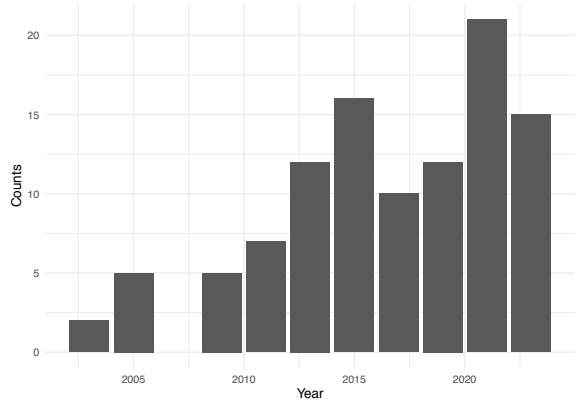

Figure 3 The number of articles by publication year

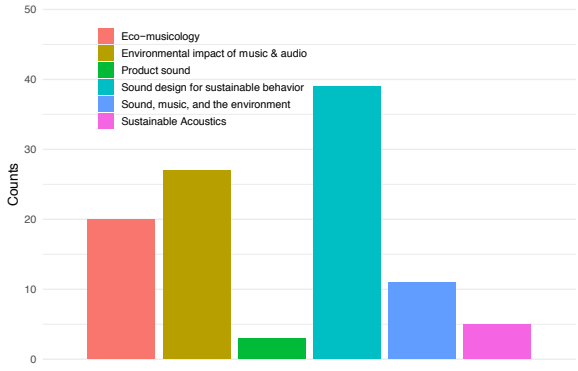

Figure 4 The frequency of the identified research themes

Still, eco-musicology relates aesthetics to sustainability, advocates sustaining a world that 'looks good, feels good, sounds good, and is good' (Allen et al., 2014; Allen & Dawe, 2015) and reached out into music education (Soliman, 2012). Within this category, we also have a line of research that is looking into the sustainability of music ecosystems, musical heritage, and music in general (Abels, 2015; Castelo-Branco, 2022; Harrison, 2020; Kagan & Kirchberg, 2016; Schippers & Bendrups, 2015; Schippers & Grant, 2016, 2016). (Kagan & Kirchberg, 2016) provide a review of cultural sustainability but also of cultures of sustainability in relation to music including the DIY artist (Oliver, 2010). In total 20 publications were assigned to this category.

5.3. Environmental impact of the music industry

Another line of research looks at the environmental impact of the music industry (Harkins, 2022). We identified 27 publications in this category. Live music and music tourism encourage travel but also energy consumption in live performances and several studies look into the impact on the environment (Brennan et al., 2019, 2020; Chamoff, 2023; Gohoungodji & Amara, 2024; Schmid, 2024). Sustainability has also been considered among music therapists (Bolger & McFerran, 2013). Streaming music has resulted in that 'the price that consumers are willing to pay for listening to recorded music has never been lower than today, yet the hidden environmental impact of that experience is enormous' (Brennan, 2020; Brennan & Devine, 2019, 2020; Della Wirasti et al., 2023). The environmental impact of music also includes music production but also the manufacturing of loudspeakers and musical instruments both acoustic and electronic ones (Isenegger et al., 2024; Kahl-Placek, 2022). Quite

striking is the observation that while the amount of non-recyclable materials in acoustic instruments in small, this is not the case with electronic instruments which are primarily made of plastic and electronic components (Brennan, 2020). Furthermore, much of the commodities produced e.g., vinyl plates often originate in non-renewable oil-based plastics.

Another line of research looks closer on the environmental impact of the internet of sounds or the internet of audio things and considers how this can become sustainable (Cannam et al., 2012; Gabrielli & Turchet, 2022; Lostanlen et al., 2021; Turchet et al., 2020, 2023).

5.4.Sound design for sustainable behavior

A significant body of work exists in auditory and sonification for sustainable behavior in particular with the provision of sonic eco-feedback using non-speech sound, while more recently conversational agents also come into play.

Fickert et al. (Fickert et al., 2006) developed SonEnvir an environment for working with data (including electrical) in scientific and artistic ways using sonification. Lockton et al. (Lockton et al., 2014b, 2014a, 2017, 2019) has investigated the use of sonification and ambient auditory feedback for electricity consumption. Lockton et al. (Lockton et al., 2019) further developed ideas in an installation. (Ford et al., 2014) looked intro designing audio feedback to current electricity consumption level. Groß-Vogt et al. (Groß-Vogt et al., 2018, 2020) also look into sonifying the energy consumption of a research institute kitchen using an artificial reverberation system. (Madaghiele & Pauletto, 2022) created a sonic carpet which sonified that amount of energy, emissions, as well as the grid power source. Pauletto et al. (Pauletto et al., 2023) also investigate sonification of energy consumption using the sound of fire consisting of a fire base mixed with the sound of crackles. Giudice et al. (Giudice et al., 2019) develop a framework for the development of conversational agents for supporting domestic sustainability. Cowden & Dosiek (Cowden & Dosiek, 2018) looked at sonifying the voltage in the power grid in order to provide a window to this complex phenomenon.

Concerning water, Waterbot (Arroyo et al., 2005) monitors faucet water flow, and provides auditory feedback when tap is closed, visual feedback about consumption (light & sound). Fernström & Taylor (Fernström & Taylor, 2010) looked into sonifying water toxicity using pitch and duration of sounds to represent the number of Daphnia magna crustaceans in a Petri dish. Hammerschmidt et al. (Hammerschmidt et al., 2013) focus on enhancing the showering experience and present a system that uses auditory feedback and blended sonification. Stewart and Willis (Stewart et al., 2013; Willis et al., 2010) experimented with the WaiTEK Shower Monitor which (together with a visual display) sounds an alarm (beeps) for excessive water consumption. Groß-Vogt (Groß-Vogt, 2020) developed a smart jar which would remind people to keep up with the regular water intake using a sound whole amplitude varied in inverse proportion to the distance to the drinking goal. Bird sounds were used. Sohn & Nam (Sohn & Nam, 2015) developed several feedback designs for sinks. Golan & Fenko (Golan & Fenko, 2015) demonstrate that amplifying the sound of water in faucets can change the judgment of the amount of running water which can be used to motivate people to close the tap faster. Seznec & Pauletto (Seznec & Pauletto, 2022b) investigate a

workshop methodology for getting input towards the design of sonic interactions related to energy in the home setting. Seznec & Pauletto (Seznec & Pauletto, 2022a) develop the signing shower in which singing is used to activate water flow and help reduce water use towards to this of a naval shower.

Sound has also been used to help reduce fuel consumption. Hammerschmidt & Hermann (Hammerschmidt & Hermann, 2017) used a continuous sonification of fuel consumption. Compared to a visual display the sonifications helped reduce consumption and optimize engine RPM. Jamson et al. (Jamson et al., 2015) point out that for visual displays, the inclusion of complementary auditory feedback not only improved eco-driving performance, but also lowered visual distraction. Ketonen (Ketonen, 2021) perform parameter mapping sonification of air quality data.

Another application of sound design for sustainable behavior can be found in influencing consumer choices in retail environments. Nature sounds have been used by retailers to enhance in-store ambiance, but also contributed to customers make more sustainable food choices. In fact, 'nature sounds might therefore be an effective, yet subtle in-store tool to use on groups of consumers who might otherwise respond negatively to more overt forms of sustainable food information' (Spendrup et al., 2016). On the other side, hedonic attributes such as luxury (Lageat et al., 2003) or premiumness (Almiron et al., 2021) associated to materials and product sounds are more investigated.

5.5. Product sound

The relationship between product sound and the perception of sustainable product properties, what could provide a basis for the aesthetics of sustainability, has been little investigated. A very recent investigation was carried out on the sensoaesthetic sustainable properties of biomaterials, in terms of "sensory enhancement" and the construction of a "memory identity," with a focus on those offered by new biomaterials applied here to create drumsticks (Inglese et al., 2023). In the same category, we find studies looking at designing sound for electric vehicles (Kato & Yokote, 2022; Lee et al., 2023).

5.6. Sustainable Acoustics

Such investigations have already taken place for novel but also existing materials for sound treatment which have been investigated from an acoustical but also a sustainability point of view (Desarnaulds et al., 2005; Pelletier et al., 2019). Furthermore, considerations are being made concerning the impact of such materials on the acoustics of new spaces (Rogers, 2006; Salter et al., 2006; Wilson, 2017) but also into designing sustainable 3D printed instruments (Jackson, 2017).

6. Designing sound for sustainability

Motivated by the desire to explore links between the designing for sustainability and sound design literature, we carried out a literature review which we then analyzed in order to identify the major trends in addressing sustainability within sound design. Our intention was to

scope the areas of convergence between the two domains in order to move closer to what we imagine can become *designing sound for sustainability*: a niche that is concerned with the the design of sustainable practices on the basis of an enhanced aural perception of what is sustainable. In the literature, we identified the following research themes: (1) sound, music, and the environment, (2) eco-musicology, (3) designing sound for sustainable behavior, (4) product sound design, and (5) sustainable acoustics.

The articles in the first category essentially follow up already established directions within soundscape and acoustic ecology research. Links to *designing sound for sustainability* originate in understanding, documenting, and preserving acoustic cultures and extend to the design of contemporary soundscapes for urban areas. The preservation and documentation of soundscape cultures is a significant resource for sound designers, vital for recreating soundscapes for productions. In addition, the very act of observation and documentation is an important sound design task. Further links may be found in understanding the restorative function of sound and the potential for contribution in sound design for health and well-being. King (King, 2022) reflects on how noise can represent a very real barrier to achieving many of the SDGs, and argues that good sound management, alongside noise control, can assist in the realization of some of the SDGs. However, design is not always central in these investigations and the focus is on the science of soundscape and on how it affects us.

A related category is eco-musicology which focuses on cultural links between music and sustainability. Publications in this category investigate the relationship between music and nature in composition but also the sustainability of musical ecosystems and musical heritage which are endangered by changes in lifestyle and climate. The cultural and social topics addressed here are often absent from the *designing for sustainability* discourse.

The theme of assessing the environmental impact of the music and sound industry is also receiving significant attention. Early results indicate that both live and streamed music have a considerable environmental impact. Several of the concerns regarding the environmental impact of the music industry are likely shared by sound design practitioners who also rely on streaming services and plastic and electronic components for equipment. On the other hand, some sound design practices, for example, foley or sound design using found objects, rely less on such technology, and may thus have a smaller environmental impact. Circular economy (MacArthur & others, 2013) and circular systems suggested that sustainability is a system property and a holistic process-based, multi-scale and systemic approach guided by a vision instead of traditional goal-based optimization approaches (Ceschin & Gaziulusoy, 2016) is necessary. This perspective is not always considered by the music, audio, and sound design industries.

The category in which sound design and design for sustainability intersect the most is probably what we named *sound design for designing for sustainable behavior*. This category includes interventions aiming at reducing electricity, water, and fuel consumption were identified using techniques found in auditory display and sonification. However, in contrast to sev-

eral examples in the *designing for sustainable behavior* literature, comparisons to other modalities are not done and the potential of the proposed designs to encourage behavior change is not evaluated. This is important as sustainable lifestyle, is achieved when the person makes a change in their habits, whether conscious or unconscious, in the direction of new practices (Chick & Micklethwaite, 2011). Departing from the sonification approach often adopted, sound design for sustainable behavior could be directed to the study of the activation of new, more sustainable practices, even at the subliminal level, given the ability of sound to communicate to the final consumer in an immediate and direct, yet subliminal way (Beckerman & Gray, 2014). Why couldn't for example *eco* programs not only be (sometimes) quieter, but also emphasized thanks to sounds characterized by a sustainable identity, and therefore pleasant, convincing, encouraging? The right sound to convey sustainability values will have to be defined for each project, product, and probably culture under consideration in order to truly link it to a shared sustainable meaning (Horlings, 2015).

The next two categories we identified relate to sustainable acoustic materials and their perception and product sound design. The first category is very much aligned with designing for sustainability in particular in relation to building and room acoustics. Product sound design, however, is likely the area in which the least work has been done and significant achievements may be expected in the future. Design for sustainability is tightly related to the materials with which products are produced and the sound of their operation. Subsequently, this context truly enables one to focus on "how a specific product/service/material/interface/system/etc. should sound to communicate its sustainability”? The sonic perception of sustainable qualities, i.e., understanding what is more (or perhaps even truly) sustainable, is a fundamental issue here. Links to product sound memory, visual context, but also affective qualities have been investigated (Nykänen, 2008; Özcan et al., 2014, 2017; Özcan & van Egmond, 2007, 2009, 2012). However, the role of sound in forming “green aesthetics” remains obscure and could have an important role to play in shaping “green aesthetics” and their adoption by customers (J. Chapman, 2014; Rognoli & Karana, 2014; Walker, 2009). Building on training a culture of listening (Purdy, 2000), people can be empowered to distinguish, understand and orient themselves in sustainable ways based on auditory perceptions as, when we could still recognize a bird by its song, or judge the ripeness of a fruit by its full or hollow sound, or identify a celebration by the tolling of a bell (Schafer, 1993).

Such investigations could enable the design of sound that could help differentiate between different types of packaging (plastic, or bioplastic, or paper) and guide purchasing or even recycling decisions. Exciting opportunities emerge also while developing new materials with reduced environmental impact as for example biopolymers and other circular materials. Materials could even be designed so as to sound in ways that communicate values related to sustainability. In this context, the role of material libraries - intended as research centers dedicated to innovative and traditional materials - is crucial, and several organizations invest heavily in this topic (Del Curto et al., 2022; Lerma & Dal Palù, 2016; Miodownik, 2007; Rognoli, 2010). For some material families, and in particular for biopolymers, perceptual qualities related to sustainability have been investigated more thoroughly (Martyn, 2021;

Rognoli et al., 2011). Similarly, explorations on the aesthetics of *revived* (i.e. circular) materials have also been recently published (Du Bois et al., 2021; Sauerwein et al., 2017). In most of these studies, however, the visual aspect is shown to be preponderant (Zafarmand et al., 2003), likely due to lack of familiarity with the material itself.

It is apparent that s*ound design for sustainability* can have a positive impact on different aspects of sustainable development which can be related to the 2030 Agenda and the Sustainable Development Goals (SDGs). Designing sound for sustainability can increase resource use efficiency and lead to a greater adoption of clean technologies and a more conscious use of resources, materials, and inform consumption choices. There are clear links to SDG11 (Sustainable Cities and Communities), SDG12 (Responsible Consumption and Production), SDG9 (Industry, Innovation, and Infrastructure), SDG6 (Clean water and Sanitation), and SDG7 (Affordable and Clean Energy). Designing sound for sustainability can increase interest in acoustic ecologies and help shape the soundscape of public environments to support psychological and physical well-being. It can also help shape indoor environments and increase the quality of work or learning, and thus contribute to SDG3 (Good Health and Well-Being). Lastly, the listening education mentioned above, and in particular with a reference to the relationship between sound and sustainability (environmental, economic, social), crosses SDG4 (Quality Education), the cradle of greater attention towards these issues also by the new generations of designers, and ordinary people, key figures for achieving progress in sustainable development.

7. Conclusion

Motivated by significant developments in designing for sustainability and sustainable behavior and in sound design we carried out a literature review to understand better ways to sound sustainable as these have been developed by researchers in the intersections of the two fields. We identified possible intersections in music, sound and sustainability, soundscape, and acoustic ecology, but also sound design for sustainable behavior, and in product sound design, sustainability, and sustainable materials. The results highlight the potential of a sound design for sustainability as a practice directed towards the Sustainable Development Goals aiming to enhance our understanding of what sounds sustainable and how to design for it.

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