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Designing with listening in mind

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Semantic models of sound-driven design: Designing with listening in mind

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Sound-driven design is a design practice informed by technology and listening in the multisensory dimension of interaction. An automated content analysis of 20 semi-structured interviews with sound designers, design researchers, engineers and expert users stressed the inherently embodied and situated conceptualisation of sound, and how it relates to their professional activity. The four categories of professionals bring in different designerly orientations towards sound. Listening, as a way of knowing by using sound in interaction, proves to be the red thread between the participants' semantic models. Overall, the findings contribute to characterise the concept of sound in current design practices, and position the role of nonverbal, yet auditory representations in the design process.

Keywords: design research, design knowledge, interdisciplinarity, sound-driven design

Design research represents the natural playground to investigate the pragmatic nature of human and non-human sound manifestations inhabiting our contemporary lived environment. Either intentionally designed or as by-products of mechanisms and processes, sounds are essential presences in our everyday life, from notifications and alarms, to machinery of various kinds and voice-based virtual assistants.

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Sound design is a broad label that encompasses a variety of practices and domains, from cinema and video games (Grimshaw, 2010), sonic branding

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(Jackson, 2003), sound scenography for exhibits (Bubaris, 2014), to product sound quality (Lyon, 2000) and aural architecture (Blesser & Salter, 2009). In this respect, designing sound at large can be defined as the reverse process of listening, that is making design intentions audible (Susini et al., 2014; Zattra et al., 2021).

In the scope of this article, we narrow the sound design label to the design and craft of auditory displays that convey functions and information with aesthetic requirements, essentially in computation-enhanced products, services and systems (Filimowicz, 2019). Whether for applications in the automotive, transportation, healthcare and well-being, and the lived environment in general, sounds typically take the shape of notifications and alerts or continuous sonifications for peripheral to focal monitoring (Hildebrandt et al., 2016; Misdariis et al., 2019; Rönnberg & Löwgren, 2021; Sousa et al., 2017).

In this context, we are witnessing an ongoing transition from designing the interaction (Franinović & Serafin, 2013) and the information (Barrass, 2018) mediated by sound either as a display or as an input medium (i.e., sonic), to embryonic, socio-technological approaches to sound issues to drive innovative design solutions (i.e., sound-driven): that is a methodological shift from a *design-oriented research* towards a *research-oriented design* (Fallman, 2007).

The first aims at producing a corpus of cumulative knowledge and consensus around sonic interaction phenomena. Here, sonic interactive artefacts are sketched and developed as means to understand how sound and action intertwine to shape dynamic relationships between humans and objects (Rocchesso et al., 2019).

In the second, the perspective is flipped, the focus is about designing *with knowledge*, and its main outcome and goals are realising evidence-based designs and interventions with a higher degree of completeness (Edworthy et al., 2018; Özcan et al., 2018). In this respect, a sound-driven approach to design utilises sound as catalyst of the design space, and outlines a practice that aims at seamlessly being societal in its performance, and yet grounded within a larger network of research disciplines. Whether aimed at designing the driving experience of an electric vehicle, improving the performance of an hydraulic pump or of an electric shaver, or devising priority-based alarms for patient monitoring systems, the design practice involves multidisciplinary areas of expertise and knowledge, including psychoacoustics, engineering, computer science, psychology, interaction design, and sound production (Özcan, 2008, Chapter 8).

A sound-driven design process must inevitably make sense of how audio technology (e.g., from acoustic and digital musical instruments, the ring-bell and the buzzer, to sound recognition, streaming, and active noise control algorithms) and descriptions (e.g., from visual representations and narratives, to gestures) mediate the engagement, the experience and the meaning of the encoded physical energy of sound (Leman, 2007; Verbeek, 2005). Therefore, addressing the semantic gap problem by design research relates to how people talk about sound, how they communicate and externalise the sonic experience, and implies to tackle sound as flip side of the perceptual problem of listening, including its own apparent idiosyncrasies and ambiguities (Ingold, 2000, Chapter 14).

From the design research perspective, this is relevant not only to probe the extent of the sound-driven design inquiry, but also to develop appropriate representational competencies and tools, from sound sketching to prototyping, and boundary objects that are instrumental to the understanding of the users' sonic experience, making discoveries and creating sound-driven concepts. Design communication about sound can be difficult even between sound experts. In this respect, it has been shown how an embodied approach to designing sound can fill the semantic gap between sensory-related (i.e., proximal, auditory images) and source-related (i.e., distal, physical properties) representations of sound (Delle Monache et al., 2018). This is even more relevant when designing for complex systems and environments, which require the partnership, collaboration and participation of multiple stakeholders (Arias et al., 2000; Bratteteig & Wagner, 2012; Özcan et al., 2018).

Therefore, our research question in this work is: How is sound used, internalised and communicated as a design concept and phenomenon? To address the semantic gap problem in sound-driven design, we investigate the conceptualisation of sound, as resulting from an automated content analysis (Nunez-Mir et al., 2016) of 20 semi-structured interviews with different categories of professionals involved in the multidisciplinary field of sound and design. By framing our study in the ecological approach to (auditory) perception (Gaver, 1993; Gibson, 1979), and embodied (sound) cognition (Roddy & Bridges, 2021; Shapiro & Spaulding, 2021), we seek for evidence of embodied sound conceptualisations as attributed by design researchers, sound designers, engineers, and expert users, that is framing their semantic models and understanding how sound relates to their professional activities.

This study represents the first step of a wider research project, aimed at developing representational methods and tools to empower designers and stakeholders to collaboratively conceptualise, express, and communicate designs in which the sonic dimension acts as the main driver of iterative evaluation and implementation processes, beyond the creation or optimisation of auditory displays. In this respect, we use the interview as a scoping tool designed to evaluate and ground the initial understandings, assumptions and concepts regarding the actual use of sound in the design domain. Consequently, the rationale of the semantic analysis is to shed light on the common and idiosyncratic meanings of sound, by stimulating the participants into problematising their personal experience of sound in their own daily work routines.

The present study contributes to characterise the concept of sound in the current design practice, and to understand how an approach informed by listening can propagate in design projects, which is relevant to designers that want to incorporate sound in their design in a more holistic way.

The paper is organised as follows: in Section 1 we provide the theoretical framework and present a compressed run-through on studies tackling the role of sound in the design process; we introduce our study, the interview rationale, and the semantic mapping approach in Section 2; the resulting semantic map is presented in Section 3, and the interpretive findings with implications for future research directions in sound-driven design are discussed in Section 4. Finally, we draw our conclusions.

1 *Sound affords action, listening reveals it*

In this section we provide the theoretical framing of our study, and stress the need to mobilise the relevant corpus of knowledge in auditory perception (Neuhoff, 2004), embodied music cognition and mediation technology (Lesaffre et al., 2017) in design research.

As pointed out by Ingold (2000, p. 268), sound does not exist *per se*, but emerges as "experiential quality of an ongoing engagement and participation of the perceiver (i.e., the listener) in their environment". Sound is nothing more than the flip side of listening, that is a way of knowing through sound, which implies active, bodily explorations with all the senses (Gibson, 1966). Sound is not for the ears only. To listen, that is experiencing sound, may require e.g., walking, sitting, turning the head, stirring, grasping and so forth. In this respect, the *leitmotif* is that sound affords action: In most everyday situations, simply listening to a sound, for instance a slamming door or water dripping, would not only recall the action or the event that produced it, but also create opportunities for acting (Gaver, 1993). Action-sound associations are inherently egocentric, plastic and short lived, can be learnt and hence created and shaped by design (Navolio et al., 2016). This is relevant not only for artificially created associations (e.g., beeps, alarm tones), but also regarding the inherent ambiguity and the socio-cultural implications of the schizophonic[1] everyday artefacts we live with (Hug, 2008).

Therefore, to talk about sound is about unfolding a phenomenology of listening (Ihde, 2007; Schaeffer, 1966), that is understanding and acknowledging a distinction between listening intentions and perceived experiences (i.e., causes, meanings, qualities of the perceived sound itself). Building on the seminal works by Chion (1994) and Truax (2001), Tuuri and Eerola

(2012) have the merit of having formulated a consistent taxonomy of meaning-creation modes in the process of listening. Listening materialises as action-oriented intentional activity that informs interpretations and create mental images of the sonic experience at hand: i) listening is inherently *experiential*, and simply hearing a sound can trigger the action that produced it or the action taken in response; ii) listening is *denotative* and facilitates a contextual orientation of the sonic experience, whether focused on the source (i.e., *causal listening*), on the affective quality and emotions (i.e., *empathetic listening*), on the purpose (i.e., *functional listening*), or on the socio-culturally situated meaning (i.e., *semantic listening*); iii) listening is *reflective* and critical when it is oriented on the listening experience itself, or in other words on the qualities of the perceived sound (e.g., as in attending the performance of a string quartet). The listening modes are not exclusive, they can co-exist, shift and intertwine. Hence, they can be used as conceptual lens to disentangle the complexity of a sound-driven experience.

Within this theoretical framework, we look for evidence of sound embodiments in the verbal accounts of professionals dealing with the multidisciplinary field of sound and design in order to add to a better understanding of the potential of incorporating listening in design activities. Thus, creating and producing the sound becomes only one aspect of a sound-driven design.

1.1 Listening as design material

Overall, the problem of designing sound, in contexts which are inherently interactive and multisensory, is to reach a consensus on the meaning of the listening experience (Barney & Voegelin, 2018). More recently, sound as design material has been probed as main driver for explorations in design fiction and speculative design (Chung & Liang, 2021), and as landscape data-driven approach to participatory, co-creation design and fabrication of textiles and patterns (Jaramillo & Mennie, 2019). Olo Radio, a music player that supports and sparks reflective and memory-oriented experiences, allows to explore one's own archive of personal listening history data (Odom et al., 2020). Heart Waves is a heart rate monitoring device, composed of a pulse sensing wristband and a variable speed water system, to reduce anxiety by means of the sound masking effect of the increasing water stream (Ettehadi et al., 2020). Vita is a pillow-like sound player that exploits everyday sounds to promote conversation, playfulness and connection between people with advanced dementia and their caregivers (Houben et al., 2020). CareTunes explores the role of musical sonification of patient's vital sign in the Intensive Care Unit (ICU), as update tool for the nurses or as messaging tool for the families (Özcan et al., 2020). On the same line, a design framework informed by principles of multisensory integration has been proposed in order to reduce noise fatigue, deliver more meaningful clinical information, and improve the patient outcomes (Burdick et al., 2019).

1.2 "Sound designerly" ways of knowing: a compressed run-through

The growing interest in sound as a design dimension brings about several open questions. For example, which are the role and position of the sound designer in the overall process? Does the sound-driven design process unfold as any other established design framework used in the practice? Which tools, methods and representations are more suitable in the various stages of a project development? How do peers and stakeholders negotiate and communicate about a sound-driven concept to achieve a shared agreement? Are there conventions in sound-driven representations, what can be considered a sketch, a blueprint, or a prototype? Which are the appropriate research tools and ontologies to capture the complexity of sound-driven design thinking (Delle Monache & Rocchesso, 2018)?

These questions challenge the established visual paradigm in design thinking and call for an epistemological re-articulation in design research (Heylighen & Nijs, 2014). There are tentative and sparse signs in this direction, aimed at studying the creative processes and representations involved in designing auditorily, and at probing methodologies and analytical means to evaluate sound-driven design cognition, thus complementing the visuo-spatial dynamics account of the design activity (Hay et al., 2020).

Nykänen et al. (2015) studied sonic sketching in the automotive field and observed how the sound design process unfolds in conversations with the sounding materials, in analogy with the *seeing-moving-seeing* process described by Schön and Wiggins (1992). Falkenberg et al. (2020) explored the use of the vocal apparatus as complementary means to draft quick and economical representations in participatory and co-design activities with children. Delle Monache and Rocchesso (2016) applied the Function-Behaviour-Structure (FBS) ontology of design (Kan & Gero, 2017) to the auditory domain, stressing the complexity of capturing and coding non-verbal representations of sound, including gestures. Protocol analyses of vocal sketching sessions investigated the use of voice as embodied tool, in the tension between generating sound and externalising sound-driven ideas and concepts held in the mind: It has been shown how the use of utterances, in combination with verbalisations and gestures, fosters communication and collaboration in multidisciplinary sound design teams (Delle Monache & Rocchesso, 2021).

Hug (2020) analysed the project types, occurring activities, phases, overall structure, dynamics, and social exchanges, based on visualisations of sound design processes, as experienced by advanced sound design students with a professional background: Overall, designing sound results as a rather engineering-oriented, individual activity, kept separate and asynchronous from the global design process. Creativity unfolds linearly to fulfil the expectations or the vision of clients and stakeholders, whereas iterations and evaluation take the shape of general approval or judgement on how well a sound work is received. Zattra et al. (2021) provided a grounded picture on the profession's identity, including the background knowledge and education, the *modus operandi* and the average projects timeframe, by means of a survey research with crowdsourced questionnaire, sent to more than 100 sound designers in Europe.

Embodied sound design tools aimed at covering the semantic gap problem are being explored, especially to empower non-experts to access internal representations of sound and to span vast sound design spaces (Houix et al., 2016). Their design rationale, informed by embodied cognition (Leman, 2007), collaboration and creativity (Goel et al., 2012), emphasises the role of listening as action-oriented intentional activity of making sense of the sonic experience. Speak Lexicon[2] is a validated list of verbal descriptors of the salient characteristics of sound (i.e., general qualities related to intensity, timbre, and morphology associated with temporal variations) that facilitate the communication between sound designers and non-experts, available as pack of cards as well as a software interface[3] (Carron et al., 2017). Co-Explorer is a software tool that exploits reinforcement learning algorithms to enable creative human(s)-machine partnerships in the exploration of high-dimensional, parametric sound spaces (Scurto et al., 2021).

These works provide evidence of a fertile and active ground of inquiry, yet they mostly embrace the perspective of the sound designer only, and are scattered on the periphery of research in design cognition and creativity.

Consequently, we take a step back and equally take in account four categories of professionals involved in the sound and design domain, and namely design researchers, sound designers, engineers and expert users.

2 This study - Interviews

2.1 Method

We use the interview as scoping means to solicit data about how design researchers, sound designers, engineers, expert users conceptualise and use sound in design. First, we derive a model of the topics discussed during the conversations with the four categories of professionals, by making use of Leximancer,[4] software tool for automated content analysis. Then, we interpret the resulting concept map in order to find answer to our research questions, and namely tracing sound embodiments in the verbal accounts of the four categories of interviewees, and stressing their shared and distinctive meaning attribution to sound in relation to their professional activity. We briefly discuss the rationale of our methodological approach, before reporting the study and discussing our findings.

2.2 Automated content analysis

Computer-aided Qualitative Data Analysis Software (CAQDAS) have become increasingly popular in social sciences and design (Woods et al., 2016). They are used to support the researcher in the understanding of complex phenomena, typically by providing semi-automated coding of video, transcripts, and document data, and by assisting their interpretation by means of interactive visual analytics. Whereas the discussion of existing CAQDAS environments is beyond the scope of this paper, we point out that the choice of the tool implies ontological and epistemological considerations (Wilk et al., 2019).

Computer-assisted environments for qualitative data analysis can be broadly split in two main categories, that is tools that emphasise and require the researcher's initialisation of the data analytics process (e.g., NVivo,[5] Atlas.ti[6]), and tools that produce a first data modelling based on textual statistical properties, from simple word-frequency count to more complex probabilistic models based on text-mining and machine learning algorithms (Nunez-Mir et al., 2016), like Leximancer does (Smith & Humphreys, 2006). Compared to the first class of tools, Leximancer's data-driven approach allows a rather exploratory style of the semantic workspace, while decreasing the preconceptions of manual content analysis, especially when an *a priori* model is not available (Sotiriadou et al., 2014).

By using a data-driven approach, we first generate a transparent model of the sound-driven concepts elicited from the participants' verbalisations: Leximancer seeds candidate concepts as list of lexical terms that are ranked according to their frequency of occurrence, then a thesaurus is built and lexical concepts are defined as groups of weighted terms that travel together within the text. Terms are weighted so that the presence of each word in a sentence provides an appropriate contribution to the accumulated evidence for the presence of a concept. Finally, highly connected concepts are clustered in higher-level groups (Smith & Humphreys, 2006). The automated analysis does not replace in any way the role of the researcher, instead the aim is to uncover networks and patterns that may have not been visible otherwise. In this respect, we use the theoretical framework discussed in Section 1 as conceptual lens to make sense of the semantic map generated in Leximancer.

Similar approaches based on natural language processing have been recently used to characterise ambiguous and vague verbal expressions in design conversations, as linguistic markers of the design space (Ungureanu & Hartmann, 2021), and conversely to study design talk by using machine learning to generate text in the style of a design conversation (Lloyd et al., 2021).

As a disambiguation to the reader, we use the term **category** to refer to the groups of professionals, the term **cluster** to refer to the higher-level groups of concepts resulting from the Leximancer's analysis, and the term **theme** to refer to our interpretations of the clusters.

2.3 Participants

We recruited professionals that could represent the multidisciplinary of sound design, as narrowed in the introduction: In our study, the sound designers are practitioners with multidisciplinary background primarily involved in the actual composition and production of sounds (Zattra et al., 2021); the design researchers are academic designers primarily involved in research through design practice (Koskinen et al., 2012), and with experience in the aural dimension of design; the engineers have a shared background in acoustics and sound quality, applied in different domains (Lyon, 2000).

We also included a fourth category of expert users, that is non-sound professionals that make use of sound in their everyday work routine. We limited this category to the field of healthcare, and in particular the Intensive Care Unit (ICU) environment, in which sound, typically alarms, plays a major role in the quality of the care from both the patient and the medical staff perspectives (Özcan & Gommers, 2020). The assumption is that any user is an expert in their own context (Ostroff, 1997), and we seek for evidence of the listening expertness of non-sound experts (e.g., the caregivers in the ICU in this study). We acknowledge that there are many other categories of expert users, yet we narrowed the context to have more coherent verbal accounts.

We interviewed 20 professionals (mean age = 44 years; *SD* = 8.8; mean experience = 17 years; *SD* = 7.1), 5 sound designers (SndDes), 5 design researchers (DesRes), 5 engineers (Eng), and 5 expert users (ExpUs), whose main fields of expertise are reported in Table 1.

Figure 1 shows the distribution of the competencies per category, reported as free verbalisations by participants during their presentation in the interview. The research and management abilities across the categories reflect the seniority of the participants. The healthcare represents a shared applied field, clearly longitudinal to the ExpUs category. DesRes shows the widest coverage of knowledge and competencies.

The candidates were invited via email, and provided in advance with the information sheet and the informed consent form. The interviews took place remotely on Zoom,[7] to take advantage of the automatic audio transcript functionality. Each interview, preceded by a short introduction by the interviewer and a presentation of the interviewee, had a duration of 40 minutes on average. The interviews were held in English, yet only two participants were native speakers. The average English speaking confidence and skills were of good level, nonetheless we observed a reduced vocabulary richness in non-native

Table 1 Fields of expertise per category of interviewees

Category	*Fields of expertise*
Sound designers	Audio branding, automotive HMI, alarms, digital services
Design researchers	Sonic interaction design, research policy, experience and cognition, media technology, VR for the critical care
Engineers	Alarms management software, automotive/transportation, noise/vibrations, patient monitoring and ventilation
Expert users	Critical and intensive care, nursing, anaesthesiology

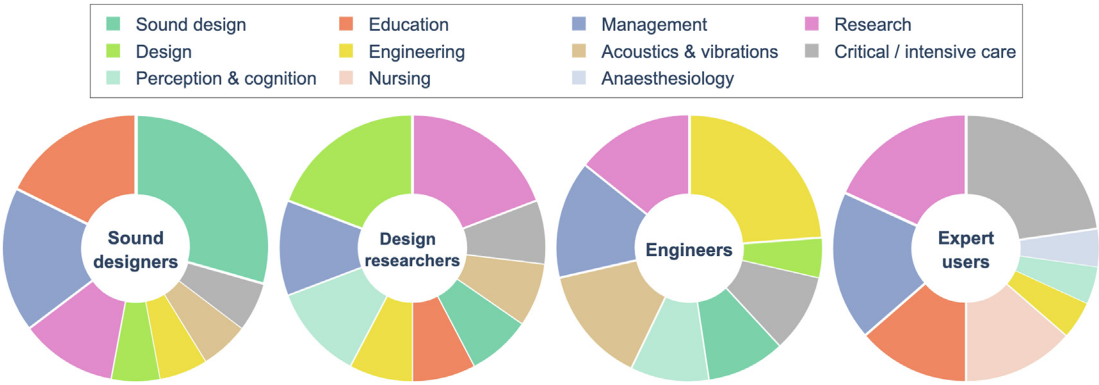

Figure 1 Distribution of competencies across the four categories of professionals

speakers, which may have hindered their ability to fully express their opinions. In the ambiguous cases, the interviewees were further asked to add to and elaborate on their opinions. The transcripts data underwent a clean up, including full anonymisation, the editing of transcription errors, basic text processing (e.g., stopwords removal). The data relative to the interviewer's dialogue were removed as well.

2.4 Interview rationale

The interview drives the participant into discussing the experience of sound in their daily work routines, and is arranged in three open questions detailed in Table 2. The rationale of asking the same questions is to approach the four categories without any preconceived differentiation, by stimulating the participants to freely reflect on *Q*1) the long-term experience of sound, *Q*2) the ability to externalise and share the perceptual experience to others, *Q*3) the creative possibilities triggered by sound.

As seen from a design process perspective, *Q*1 and *Q*2 set the discourse in the problem space, and *Q*3 triggers a synthesis in the solution space.

Eventually, understanding the shared and peculiar semantic attributions to the concept of sound by the four categories of participants represents the first step

Table 2 Interview script: *Q*1 and *Q*2 stimulate analytical reasoning on the sonic matter and its communication respectively, whereas *Q*3 represents the synthesis phase

Q1:	- Which role does sound play in your working routine?
	- How does sound affect your daily tasks?
Q2:	- Have you ever been involved in designing with others? How?
	- How did you manage to express and share your ideas on sound?
Q3:	- If you had a magic wand that could fix two things in your experience, which would you choose?

to facilitate the introduction and communication of sound-driven representations in the design process.

3 Results

The software coded 1124 text blocks and found 40 concepts across the four categories.

Figure 2 shows the concept map generated by Leximancer. The circles represent the clusters, and the concepts are arranged as nodes in a network. The clusters are colour-coded, that is the hot-coloured circles (i.e., red, brown) are more relevant than circles in cold colours (i.e., green, blue, purple), reflecting the number of text blocks (i.e., hits) in the data, associated with the cluster, and reported in the synopsis in Table 3. The clusters size instead, that is the circles boundaries, can be adjusted by the analyst to fit a meaningful granularity in the exploration of the data (i.e., a 100% size would produce one single cluster). We set the initial cluster size to 33%, which allowed us to uncover a good number of topics (i.e., the clusters) to analyse. The clusters are named after the most prominent concept in the cluster. Concepts and categories (tagged in red) are positioned on the map according to their connectedness (e.g., *patient* is highly interlinked with *alarm*, but not with *knowledge*).

In the remaining, we analyse the raw concept map produced by the software, and then propose our interpreted version in the discussion, in Section 4.

From the visual inspection of the map topology, we can outline 3 main layers of information: 1) the central position of the Sound and Work clusters and their overlap outlines a group of elements that are conceptually related at the intersection of the four categories; 2) the outer clusters, linked to the categories, group concepts representing the specific category; 3) the Feel cluster does not have any direct connection with the categories, and emphasises peculiar aspects or issues relative to the *sound* concept.

Table 4 reports the mean prominence of the clusters per category, that is the correlation between the clusters and each category. Prominence in Leximancer

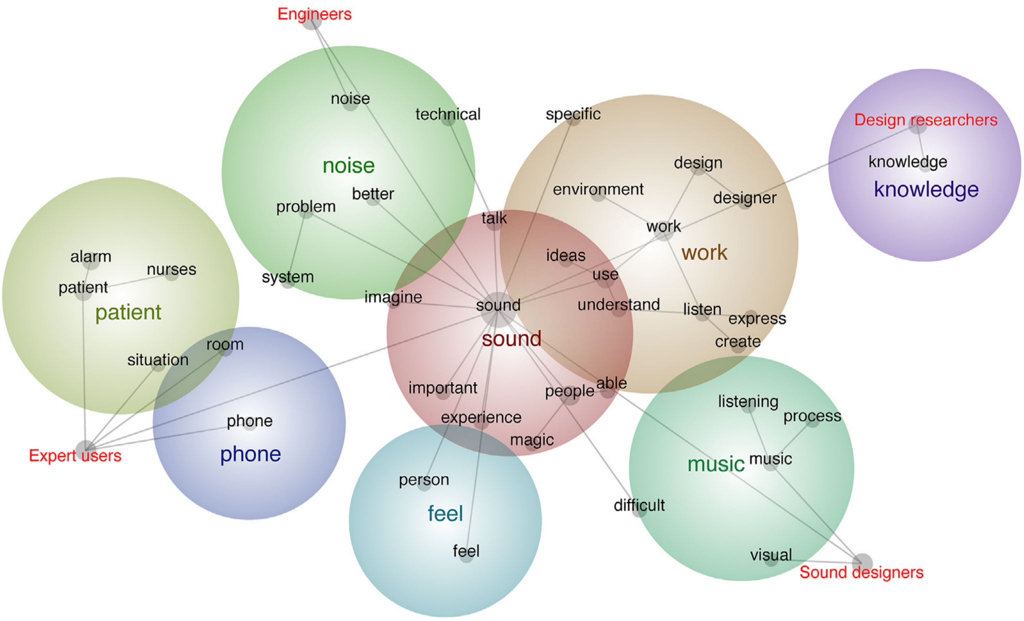

Figure 2 Concept map generated by Leximancer, with a cluster granularity set to 33%. The clusters' relevance is colour-coded, from hot (red, brown) to cold (green, blue, purple) colours. The clusters are named after the name of the most prominent concept in the cluster (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Table 3 Clusters are ranked based on the number of text blocks associated to each cluster

Clusters	Hits	Concepts clustered
Sound	604	sound, people, talk, experience, able, important, imagine, magic
Work	343	work, use, design, understand, environment, listen, specific, ideas, designer, express
Patient	222	patient, alarm, room, situation, nurses
Noise	140	noise, problem, better, technical, system
Music	136	music, create, listening, process, express
Feel	43	feel, person
Phone	25	phone
Knowledge	15	knowledge

is a statistical measure that takes in account the conditional probability of the concept, given the category (i.e., the relative frequency), and the conditional probability of the category, given the concept (i.e., the strength).

Table 4 **Mean values of absolute prominence of the most relevant clusters per category. The Patient, Noise, Music and Knowledge show a stronger correlation with a reference category. A prominence score > 1.0 indicates that the cluster and the category are not independent**

Cat.|Clusters	Sound	Work	Patient	Noise	Music	Feel	Phone	Knowledge
SndDes	1.12	1.77	0.12	0.60	3.00	2.19	0.86	1.43
DesRes	1.61	1.66	0.42	0.77	1.32	0.97	0.24	2.43
Eng	1.28	1.41	1.46	2.43	0.86	0.59	1.24	1.38
ExpUs	1.38	0.64	3.25	1.51	0.29	1.65	2.90	0.35

mean prominence

The Sound and Work clusters group concepts that are discussed by all the participants, but that are apparently more saturated or that imply slightly different, yet coherent meanings. In other words, these clusters represent the "greatest common divisor" between SndDes, DesRes, Eng and ExpUs, as emerging in the answers to $Q1$, $Q2$, and $Q3$ (see Section 2.4). The Sound and Work clusters contain the commonalities, whereby the outer ones unfold the idiosyncrasies of the four categories of professionals.

3.1 Disentangling the Sound and Work clusters

The inspection of the data associated to the Work cluster revealed strongly contextualised reflections triggered by $Q1$, about the impact of sound in the participants' working routine and daily tasks. Two main lines of thought were stressed, on a) sound as socio-technological space (Dourish, 2006), and on b) sound as working means:

	a) Sound as spatial practice	*b) Sound as working tool & process*
SndDes	in the studio	for creation/production of audible experiences
DesRes	in the workshop	for design strategy/conceptualisation
Eng	in the lab	for systems development/evaluation
ExpUs	in the ward (ICU)	for diagnostics/monitoring/caring

This two-sided connotation is a recurrent refrain in the professionals' narratives. In this respect, the *work* concept acts as bridge between the Sound and Work clusters. Therefore, to make sense of these two clusters, we looked at the co-occurrence of the *sound* concept with the other most ranked concepts in the two groups (i.e., *sound-people*, *sound-use*, etc.), and inspected the corresponding, associated blocks of textual data.

Figures 3a and 3b show the co-occurrence of the *sound* concept with the other most ranked concepts in the Sound and Work clusters, respectively. These are the concepts that mostly travel together when *sound* is discussed in the data (co-occurrence), and that at the same time are very likely to include *sound* when they are individually considered (likelihood of the co-occurrence).

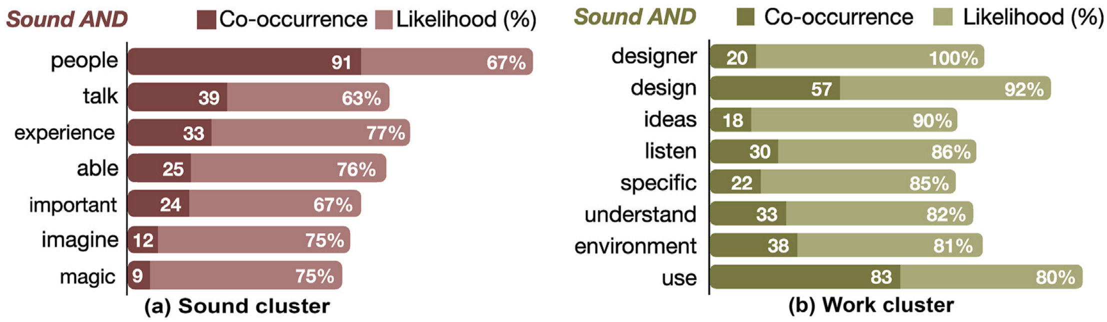

Figure 3 Co-occurrence and likelihood of co-occurrence of the sound *concept with the most ranked concepts in the two clusters (see Table 3)*

3.1.1 *Summary of the clusters' narrative*

Sound, as embodied experience grounded in action and perception (Tuuri & Eerola, 2012), is framed by participants from a designerly perspective. That is, the sensory, aesthetic, interactive and social *experience* materialising between *sound* and *people* represents both the focus and the means of the design action. *Listening* is the active, intentional behaviour that channels *understanding* and consequently the ability to *talk* about *sound*, *express*, *imagine* and *create ideas*. However, making this process explicit, shareable, and especially actionable from the *design* perspective, is *difficult*:

"This difficulty to explain sound is a key issue in engaging the audience and stakeholders, and prevents sound-related disciplines to broaden their impact" (SndDes). "The lexicon is not rich and easy, and even designers struggle with using good sound examples that can be understood by everyone" (SndDes).

"Presenting a sound always create expectations in the client, that are then very difficult to remove" (SndDes). "In visual design, sketches and prototypes are universally understood as provisional representations, with sound instead it is very difficult to go through this intermediate step" (DesRes).

"What I find most difficult, as a designer, is being able to get from my audience an informed reaction, rather than general comments on the sound itself" (DesRes). "People are not educated to criticise it, they only feel the bad effect that sound has, typically that sound is annoying, but they cannot really specify what it is"(DesRes).

"It is hard to make stakeholders to dare, play with the sound, especially when cultural differences inhibit the expression" (Eng). "What is really difficult and requires an expertise is, once you know the concepts or the values or the images that you want to convey, that you have to transform them into musical ingredients" (DesRes).

The major bottleneck is to conceive plausible design representations that exploit listening as shared ground of discussion, in a domain which is essentially visual-centered.

3.1.2 Sound as conceptual placeholder

Participants use the word *sound* in a holistic acceptation to mean the product itself, the function, the information and its quality, the sound-producing system or device, but also “the presence of things and beings”, “the surrounding aspects of how it influences my work”, the subjective responses, positive and negative, that sound elicits:

> “It is like I’m a fish trying to talk about the water around me, sound is my primary way of being aware of the environment around me”. “It is a subtle presence that influences our mood and emotions, but I’m concerned with the negative impact that can be alleviated in the sound that’s not carefully thought about.” (SndDes).
>
> “As a consumer of sound, I try to optimise the level of notification”. “There is this thing of sound and agency, be it by humans or machines acting. This is something which affects me a lot”. (DesRes).
>
> “The sound should convey the urgency of the situation and the local liability”. “I appreciate the right sound for an engine, but basically, I appreciate silence”. “There are many devices, and you can hear the amount of effort it takes to ventilate, the frequency especially” (Eng).
>
> “You can hear the machine going on and off, when it is functioning, is the sound necessary? Family members are often afraid and come to us”. “My familiarisation with sound is just by being surrounded by it, and training is something I’m fascinated with”. (ExpUs).

The concept of *people* serves as counterpoint and identifies the listener, as stakeholder potentially active in the design process, or end-user. We suggest the reader to replace the word “people” with the word “listeners” in all the following quotes in the remaining of the text:

> “In the automotive industry, we have three categories of people. For the first category, sound is primarily an annoyance. For the second one, sound can be synonym of comfort. And then there’s a third category which looks at new branding experiences” (Eng). “We are really looking into intelligence in decision support to provide advice to the user. But in the meantime, people are getting used to voice assistants” (ExpUs).

3.1.3 *The situatedness of listening: sound as spatial practice*

Sound and listening do not exist in isolation, but are always situated and channel the connectedness with the given context and space:

> "Providing the specific use context of sound is important for measuring its impact on people" (DesRes). "We have environments with five, six, or seven equipments nearby the patient, and they all emit their own sound" (ExpUs), "when I am in the hospital, my brain switches, and I feel that these sounds are useful, they are there to watch the patient" (ExpUs).
>
> "I can operate with a much clearer auditory vision, when I'm surrounded by a more peaceful and lower volume environment" (SndDes), "I try to be very mindful of which apps are giving me which sound notifications, […] but also to have the right level of notification" (DesRes).

In this respect, the *specific* concept represents the methodological counterpoint, a recurring refrain by which DesRes, SndDes and Eng acknowledge that designing sound is to design for specific use context. Yet they are faced with the dilemma of how to move from the general to the ultimate particular, especially of how to present their design argumentations auditorily in an effective and rigorous way (Stolterman, 2008):

> "I would like to have a simultaneous understanding of how people interpret and listen to sounds for real. There are some things in the visual world that are universally accepted, whether true or not, we have a language, we have an understanding of what is yellow, what is purple, what is black, etc. I feel that it does really not exist with sound and this drives me nuts." (SndDes).
>
> "For some people abstraction is easy, for others is not." "I always come back with the experience prototyping idea that you should, as soon as possible let people hear and interact with it, in order to interpret their reaction and statements." (DesRes).
>
> "We express a specific problem based on an existing sound recording, we isolate the problem, and then augment or reduce it to communicate the what if scenario on sound, and then we qualify it objectively with psychoacoustic indicators, when this is possible." (Eng).

Overall, *sound* is conceptualised as an inherently social, experiential and embodied phenomenon, where the emphasis is on listening as sense-making activity.

3.1.4 "I use sound to": sound as acoustic action

The data associated with the co-occurrence of *use* ↔ *sound* and *listen* ↔ *sound* concepts further qualify *sound* as a holistic manifestation of something to use (see Figures 2 and 3b). ExpUs provide the most compelling examples of using sound, to assess the patient's condition, and this expert listening–doing activity is called diagnostics and caring:

> [They] "listen to blood vessels and lungs, and use percussion to use the resonance of the abdominal cavity". [When coupled with alarms,] "the intention of the sound is to say – I have a problem, please come and fix the problem – And it could be both the device asking for assistance or the patient asking for help, and these sounds are part of the reassurance that the patient is watched" (ExpUs).
>
> [As a design intention,] "we use listening to build languages, systems of sounds that help to build narratives or can guide the users" (DesRes). [Process-wise, listening is used] "to probe the people who will be using and hearing those sounds", [with the intention of] "reducing misunderstandings and enforce directions during a project" (SndDes). "We use sound measurements, psychoacoustic descriptors and visual means, including spectrograms, to objectively qualify a given problem at a system level" (Eng).

This compound of concepts, often manifested in the frequent colloquial expression "I use sound to", provides the most compelling evidence of the sound-driven experience as embodied phenomenon and stresses the behavioural connotation of sound and listening as working tools and process.

3.1.5 Trust in design methods and awareness of listening

The difficulty of conceiving plausible and effective design representations to channel active listening is reflected in a mistrust towards sound design. *Q*2 triggered the participants' critiques on the current tools, methods and approaches to tackle the semantic gap problem in the design practice. From a methodological perspective, the actual effort and object of using sound in design are to gain trust and promote sonic awareness:

"People are aware of music, but not of the power of sound, we are still very much used to mix sound with categories that come from our personal music experience" (SndDes). "A large part of our work is more about helping people to be more aware of sound, rather than actually being able to improve it, [...] and I wish there is a way that we can create an establish a sense of trust with the public" (SndDes). "The issue is partly legislation, partly trust, so that doctors and nurses need to trust that what the machinery is doing is correct" (Eng).

"Working with engineers and designers whose expertise is not making sounds, they already have certain vision about their product because that's like their baby for many years", and "they struggle, but they have a vision and want to make sure that it is made with methodology" (SndDes).

"So my role is to convince stakeholders of our creativity and methodology in managing sound design projects", and "make them understand and be aware of the design process that is required" (Eng).

[If I had a magic wand,]" I would create a universal language for us to describe the experience with sound", "I wish there is a way to create a sense of trust with the public" (SndDes).

"I would block the really loud sounds in an environment for a second to empower people, sometimes sounds can be so badly designed that they don't just realise it" (DesRes).

"I would have my own audiobox with all the technological resources, CPU and algorithms, all the clearance and authorisations to place it in the car systems of top executives and some clients to sketch in context and scale prototypes efficiently" (Eng).

The "*magic* wand" concept, primed by *Q*3 and appearing in the Sound cluster, is a container of remedies and wishes about participatory and communication means, including pedagogical approaches, to provide stakeholders with abilities to express themselves and gain their trust. These include advancing knowledge on the semantics of listening, promoting basic education on sound and listening at school level, and ultimately developing technological solutions and tools to quickly provide veridical sonic impressions of the design concept at hand.

Summary: the Sound and Work clusters highlight the semantic gap problem of sound from the design methodology viewpoint. All the professionals are apparently expert listeners in their specific domain. Sound as acoustic action in context results as commonality of the four categories of stakeholders, and their verbal accounts stress its complexity and multifaceted nature. Listening–doing is the active and intentional behaviour by which the professionals access action-sound couplings, form the experience, perceive, sense and associate events, create purposes and attribute socio-culturally situated meanings.

The process of sound-driven design is concerned with making these intentions audible, that is providing a shared ground for the cognitive and reflective listening skills of all the participating actors (i.e., the SndDes, DesRes, Eng and ExpUs categories). In this respect, using sound in design entails designing with and for the listener(s), beyond producing *the* sound.

3.2 The outer clusters

The outer clusters describe the idiosyncrasies across the categories of professionals. In Table 4, we showed the correlation between categories and clusters, that is DesRes ↔ Knowledge, SndDes ↔ Music, Eng ↔ Noise, ExpUs ↔ Patients. The concepts in these clusters unfold how sound as acoustic action relates to the specific activities and interests of the four categories of professionals. In other words, we can find the professionals' listening cultures and position them in the sound-driven design discourse. Therefore, to make sense of the professionals' focus towards listening and design, we turned our attention to the five most ranked concepts associated to each single category, and in particular to those that name the outer clusters (i.e., the most prominent).

Table 5 provides evidence of the professionals' dissimilarities, by reporting the first five most ranked concepts per category, with their co-occurrence value

Table 5 The likelihood percentage in the brackets follows the co-count of the associated text blocks. The words in red represent the concept which names the corresponding cluster in the concept map of Figure 2. Albeit it is the second ranked concept associated to the DesRes category, *knowledge* represents a strong attribute of design researchers, with 6 out of 15 associated text blocks in the Knowledge cluster (see Table 3)

Fist five most ranked concepts per professionals' category					
SndDes	process 16 (64%)	express 5 (63%)	listening 15 (60%)	visual 12 (55%)	music 27 (54%)
DesRes	designer 9 (45%)	knowledge 6 (40%)	create 9 (36%)	specific 8 (31%)	design 19 (31%)
Eng	noise 38 (69%)	specific 12 (46%)	problem 15 (44%)	technical 10 (42%)	better 14 (40%)
ExpUs	room 25 (76%)	nurses 15 (71%)	patient 59 (57%)	phone 14 (56%)	alarm 62 (55%)

and likelihood percentage (in the brackets). In other words, these concepts are attributes of the categories.

SndDes design *the* sound (Music): The sound designers are the actual producers of audible experiences. Their tacit knowledge spans wide expertise on sound processing, from perception to articulation and production, and back. They use listening as a form of interaction and measurement by ear to facilitate and empower stakeholders—listeners in the process of sound creation. For this purpose however, SndDes constantly resort to visual analogies and metaphors. Music is generally intended as a formal language of sonic form, but also as a problematic terrain.

> "I do my best to immerse in the ideas and visions that stakeholders can't articulate and to translate them into sounds by means of different processes". "The artistic and magic things happen in the mixing and mastering process".
>
> "During the presentation then, I explain how I translated descriptors into sounds, although this works only when stakeholders participate in the descriptors selection". I exploit my technical abilities, that's why I don't consider myself the author of a particular sound, because it's always a collaboration with many people".
>
> "Music is one of those fields that I come across, where everybody feels they're an expert in music, even if they have no experience".
>
> It would be really great to kind of know the musical universe of your listeners when you produce something. With such a musical palette, you could extract how evolves their harmonic feeling, because depending on their listening experience, they may have different preferences and reactions"

Sound designers perform the translation of design concepts into acoustic actions that enhance the expression of products, services, and systems. Within the sound-driven paradigm, their design by listening commitment is straightforward and focuses on *designing the sound*.

DesRes design *with* sound (Knowledge): The design researchers position themselves as sound experts, but not as producers. Their focus is on conceptualising the experience driven by sound, and conversely on using sound as a design tool to create descriptions and experiences.

"I focus on the listening and the description and the critique of a given sound design project, an as a designer [researcher] I need to be able to quickly sketch an idea draft, in a way that illustrates and channel a strategy without suggesting that this is the final sound. What relevance and what possibilities does sound offer as a modality?"

"What's the role of sound in design? Or what does sound mean in the everyday life of people? What is the position of sound in design ethics, what does that mean for sound design?"

At least in the scope of the answers elicited from the interview, DesRes orient their listening culture to accumulating project-based evidence, distill it in methods, tools, and knowledge, and perform a research through design practice that can be rephrased as *designing with sound*.

Eng design *against* sound (Noise): This cluster is quite explicit and stresses a design culture focused on the "aesthetic and functional aspects of noise". The engineers qualify sound as noise, but not necessarily to imply an inherent annoyance of sound. The noise word reflects as well the participants' jargon and background, being involved in managing acoustics and vibrations in various application fields, as discussed in Section 2.3.

"Our job is to show, simplify, digest and present as efficiently as possible the acoustic and vibratory phenomenon to our peers. We show measurements and simulation results compared to a target level so that everyone can understand that we have a problem".

"If you're dealing with the NVH [Noise Vibration Harshness] of an engine, you have to understand combustion, the operation of the engine and all the trade offs. It is a wide spectrum of knowledge". "And there's a strategy level that our customers should implement to fulfil regulations to reduce the negative feedback by end-users. We discuss about mechanical and electronic criteria, rather than pure sound design".

"We have standards and ISO to comply with, and yet to improve. Thus, we work on more efficient algorithms to reduce the number of false alarms in the ICU, as well as optimising their perceived sound quality".

"We have quite a lot of alarms that basically trigger the nurses to look at the patient, but not really take action. Delegation is a major issue, but in the future the whole chain could be completely silent, my personal focus is to reduce the noise to the patient".

In general, the engineers connote the systemic character of noise as acoustic action, both at a mechanical, structural and at a management level. They use sound as probe to improve the quality of systems. Their approach may look conservative, and their listening orientation is towards *designing against sound.*

ExpUs design sound *for* (Patients): The ward and the patient's room are where acoustic actions take place (e.g., infusion pumps, ventilators, monitoring systems, air conditioning, alarms, and conversations). The peculiar listening culture of the participating ExpUs is caring, that is, more in general, providing a service. Their foci of interest is improving the caring experience, that is both the patients' hospitalisation and the working conditions of the medical staff. In this specific context, noise fatigue and alarms compliance represent major threats.

"Alarm sounds are very useful and necessary, yet if the technology is working correctly and the patient is still, but nowadays we try to wake up and stimulate the patients very early in the ICU. The bodily movements displace catheters and sensors, thus producing false alarms and that's the challenge in designing alarms or software to cope with these issues".

"The danger is that you are constantly warned that a situation can be really true. But you'll never know until you check the monitor".

"We are trained to recognise alarms, react to them, and place them in the right context. I would like systems tailored to the patient's movement, smart enough to recognise first whether the problems concern the sensors, the movements, the occlusion, etc. and then to produce the alarm".

"As a nurse, I have to take care of two or maybe three patients at the same time, but I'm exposed to all the alarm sounds in the ward. The patient, especially, does not need to hear them all".

The *phone* concept problematises alarms compliance from a technology viewpoint. Alternative delegation solutions are discussed, based on the use of mobile devices and motion tracking systems in the ward, to improve the alarms localisation. Novel acoustic actions are imagined, whereby monitoring systems and devices could also give advices as conversational agents, rather than only calling for action as current alarms do.

The Patient cluster stresses the pragmatic nature of a design approach driven by sound and informed by listening. When asked to reflect, describe and reimagine the experience of sound in the daily working routine, ExpUs engage in discussions about situations, events, systems, feelings, and people (i.e., patients-listeners). Explicit reflections on the morphological and aesthetic qualities of sound are only touched upon, nonetheless the ExpUs' verbal accounts provide evidence of how sounds are listened for. They are not formally educated as designers, and yet they manifest a designerly thinking.

Therefore, by extending the [*with*, *the*, *against*] characterisation of designing sound as acoustic action, we position *designing sound for* as peculiar orientation of expert users in the sound-driven design discourse.

4 *Discussion*

We used the interview as data collection method to frame the semantic gap problem of sound-driven design, that is addressing how professionals involved in this multidisciplinary field talk about sound, communicate and represent it. The interviews generated rich data regarding the shared and distinct meaning attributions to the concept of sound by professionals with expertise in sound and design (i.e., design researchers, sound designers and engineers), as well as by professionals with expertise in the use of sound in a specific context (e.g., nurses and clinicians as expert users in the intensive care unit).

In Figure 4 we provide the annotated version of the Leximancer's generated concept map, as result of our interpretive process based on the analysis supported by the text statistics, and grounded in the ecological and embodied approach to meaning-making (Johnson, 2007; Kiefer & Harpaintner, 2020; Leman, 2007). Compared to the raw map in Figure 2, the clusters size has been slightly increased from 33% to 40% to best accommodate the Phone and Sound clusters according to results presented in Section 3.

The reader will notice that clusters and concepts are named differently from the raw concept map. As a reminder, a concept in Leximancer is a collection of words that travel together throughout the text, represented by the most frequent word, the concept seed. For example, the concept seed *alarm*, which is a frequently occurring word, is associated to a weighted list of other words such as “false”, “dangerous”, “sensors”, “frustrating”, “functions”, “oxygen”, “loudspeaker”, “reassures”, “doorbell”, “patient”, “operators”, “screaming” and many others. Based on the meaning-making process of the associated text blocks in their context, this concept talks about *noise fatigue and alarm compliance*. Its higher co-occurrence with ExpUs' verbalisations accumulates evidence of the semantic model of this category. As further example, the more abstract concept *better*, renamed as *improve algorithms*, included terms like “innovative”, “inventing”, “clearer”, “augment”, “simulation”, “automate”, among the others. This reasoning applies to all the concepts in the map and their grouping, which have been renamed to best reflect their interpreted meaning.

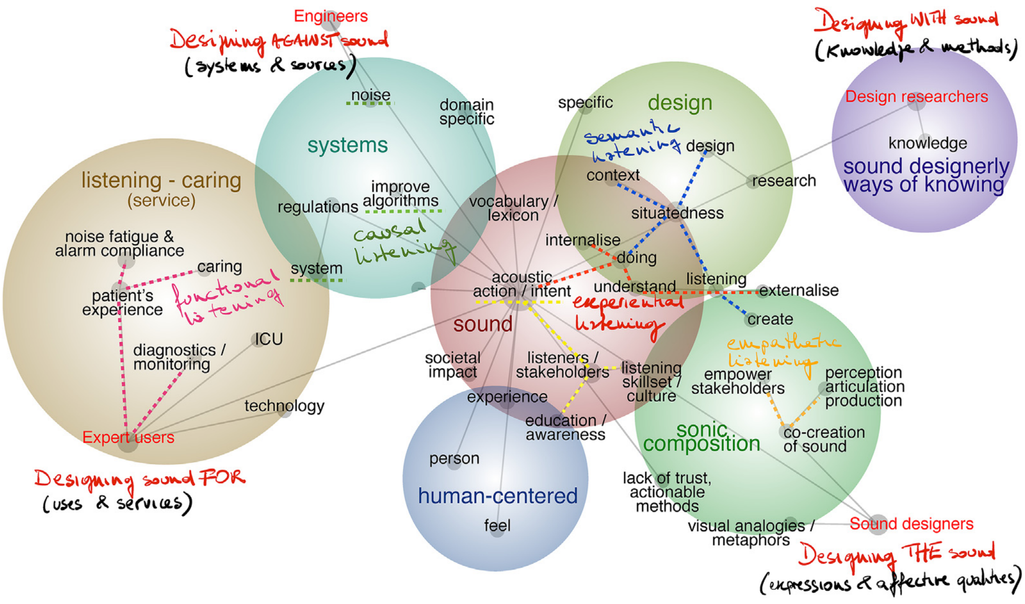

Figure 4 Annotated thematic map, with a cluster granularity of 40%. Concepts and clusters have been renamed according to the topics resulted in the interpretive analysis. The four orientations of designing [the, with, against, for] sound reflect the semantic models of the categories. The colour dashed patterns represents examples of possible denotative listening intentions occurring in the sonic experience (For interpretation of the references to colour in this figure legend, the reader is referred to the Web version of this article.)

Taken together, the themes in the annotated semantic map in Figure 4 highlight the complexity and the richness of a design approach driven by sound and grounded in listening: Incorporating any **sound** in a **service** inevitably hits the **sonic composition**, the **design** of the design process and **systems**, as well as its effects on people's life. For example, alarms are meant to represent given situations in an environment-system. An audible alarm is essentially a call for a specific action, however a vague expression of the system-source may elicit contradictory or conflicting interpretations and hamper the effectiveness and meaningfulness of the call. In this respect, the Human-centered theme resonates much with the leit-motif "function resides in the expression of things" by Hallnäs and Redström (2006, p. 166).

We positioned the design by knowing-through-sound foci as **designing [*the*, *with*, *against*] sound [*for*]**: that is whether the design action is oriented towards 1) the expression and aesthetics of *the* audible experience; 2) the description and creation of experiences, *with* sound as epistemic design means; 3) improving the quality of systems by conceiving solutions *against* unwanted sound (noise); and 4) providing sound-based services *for* the user(s)—listener(s). These sound-driven design orientations reflect the semantic models of the categories of professionals in the interviews.

At the center, the Sound theme reflects the underlying conceptualisation of sound as embodied phenomenon, shared in the participants' verbalisations: Talking about sound elicits reflections on its experience, situated in the socio-cultural environment of the participants; the speakers conceptualise sound as the experience of listening in action, embodied in the object and the practices of their profession; the professionals' focus on the experience of knowing through sound is mediated by their listening cultures and intentionality. Listening is what a listener does. In this respect, all the participants represented themselves as expert listeners in their own reference context.

Further, the taxonomy of listening modes by Tuuri and Eerola (2012) (see Section 1) acknowledges the multifunctionality of listening, that is any given situation may accommodate a concurrent multitude of meaning-creation intentions towards the sound-driven experience. The taxonomy of listening modes provides as well a magnifying lens on the attributes of a listening experience, including the multidisciplinary design activity itself. As looked from above, Figure 4 may well describe a potential situation in a multidisciplinary sound-driven design project with different design orientations at stake.

In the figure, we isolated a few patterns of concepts (colour dashed lines) that represent the diversity of denotative meanings that can occur in the sound-driven design inquiry, whether.

- human/context-oriented - focused on the actual purpose (functional·mode·of·listening) and the emerging situated meaning (semantic· mode· of·listening);
- source/sound-oriented - focused on systems and their configuration (causal·mode·of·listening) and the expression and affective qualities of the auditory display (empathetic· mode·of·listening).

The experiential· mode·of· listening unfolds the perception-action loop in the conceptual pattern "internalise → doing [acoustic action] → understand → externalise", and connotes the activation of auditory-motor associations that can be learned, stored, recalled, manipulated, and hence designed as perception-action ensembles. The dashed pattern stresses the link between sound as acoustic action and the listeners/stakeholders with their own cultural background and abilities.

However, these intention-sound couplings are not attributes of the categories of professionals in any way, instead they reflect ways of sound-driven knowing about the world in general, and about the design space in particular.

To summarise, the designer that wants to integrate sound in a design project should carefully consider not only the opportunities given by the four sound-driven design orientations, but also to invest on the design of the design process (Buxton, 2007), since different types of conceptual representations of sound may elicit different responses by the stakeholders (Özcan et al., 2014), which in turn may affect the understanding of the design space (Smulders et al., 2008), the communication and the overall effectiveness of the design process.

4.1 Limitations and directions for future research

The expert users participating in the interview were all involved in healthcare. This may represent a limitation of this study, yet the assumption is that any user is an expert of their own experience, and that this expertise is situated (Sanders & Stappers, 2008). In this respect, the higher homogeneity of this category provided stronger contextual insights on the situated nature of the sound-driven inquiry, as well as on how users-listeners use and interact with sounds in this field. Any field, system, product and service have their own listeners, and we may speculate that other homogeneous categories of expert users would bring in other context-based reflections regarding their designing sound [*for*] orientation.

A further limitation is that the four designing [*the*, *with*, *against*] sound [*for*] orientations are proposed as characterisations of the semantic models of the four categories of professional, as resulted from the analysis of the single interviews with the participants. For an ecological account of these design orientations however, we intend to study the actual dynamics of a multidisciplinary design team, composed of a design researcher, a sound designer, an engineer, and an expert user, and involved in sound-driven designing. Design cognition is a wide area of research focused on the mental processes and representations involved in designing, and the methodologies and analytical means to evaluate cognition (Hay et al., 2020). Protocol analyses of transcripts and non-verbal representations at large will be aimed at pinpointing the four design orientations proposed and tracing how they interact and intertwine in the design process. Similarly, it would be relevant to capture the listening intentions (i.e., the meaning-creation modes) of the participants and investigate how they relate, contribute to or affect the conceptual coherence of the teamwork (Vande Moere et al., 2008). These results are expected to provide a solid ground to devise and assess methods and boundary tools to facilitate participation and co-creation in this multidisciplinary design field (Sanders & Stappers, 2014).

Taken together, the interviews highlight two main research narratives to tackle the semantic gap problem of sound-driven design:

Understanding, representing, communicating the listening experience – The research activity focuses on establishing and sharing a design knowledge on auditory perception, cognition and creativity to inform strategic uses of sound-driven design representations for mediation purposes;

Sensitising, participating, empowering – The existing methods to cope with and facilitate to a certain extent the active participation in the design process rather represent tactics based on the experience of the diverse actors. The research focuses on the understanding how to design the sound-driven design process. In this respect, it is timely to devise a collection of sound-driven design protocols in shareable datasets, such as in the Design Thinking Research Symposium Series (Cross, 2018).

5 Conclusions

We have presented a semantic analysis of a set of interviews with design researchers, sound designers, engineers, and expert users. The interview was used as scoping tool to frame the semantic gap problem of integrating sound in design projects, by investigating how the four categories of participants conceptualise sound in relation to their professional activities. The analysis generated rich data regarding the semantic models of the professionals, their shared and distinct meaning attributions to the concept of sound. In line with the ecological and embodied approach to meaning-making, we found in the verbal accounts of the professional, that sound is conceptualised as an embodied, situated, experiential phenomenon. We positioned the professionals' idiosyncratic orientations as 1) designing *the* sound (sound designers); 2) designing *with* sound (design researchers); 3) designing *against* sound (engineers); 4) designing sound *for* (expert users). We see the four design orientations (i.e., *the*, *with*, *against* sound *for*) as active forces modulating the sound-driven design process.

We found that listening, rather than sound, is the actual red thread between their semantic models, and an approach grounded in listening can widen the scope of the current sound design practices. Consequently, a sound-driven design approach is concerned with the interactive experience of listening, as a situated form of knowing through sound.

Finally, designing with listening in mind adds to the debate about the embodied and multisensory nature of design, and contributes to the foundation of a "soundscape" of design research.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Notes

1. Schizophonia is a term coined by Schafer (1977) to describe the separation of sound from its source by means of electroacoustic reproduction. In this respect, we do not listen to the sound source, i.e., the loudspeaker, but we represent the event, e.g., the empty trash sound on the computer desktop.
2. https://support.ircam.fr/docs/speak/.
3. https://forum.ircam.fr/projects/detail/speak-web/.
4. https://info.leximancer.com/.
5. https://www.qsrinternational.com/.
6. https://atlasti.com/.
7. https://zoom.us/.

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