DRS Biennial Conference Series

DRS2026: Edinburgh

Jun 8th, 9:00 AM - Jun 12th, 5:00 PM

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Citation

Delle Monache, S., Murray-Rust, D., Özcan, E., and Misdariis, N. (2026) Beyond ephemerality: Boundary objects and the plasticity of listening in collaborative design, in Simeone, L., Gray, C. M., Verhoeven, A., de Götzen, A., Bakırlıoğlu, Y., Zohar, H., Stead, M., and Buwert, P. (eds.), *DRS2026: Edinburgh*, 8–12 June, Edinburgh, United Kingdom. https://doi.org/10.21606/drs.2026.1850

Beyond ephemerality: Boundary objects and the plasticity of listening in collaborative design

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doi.org/10.21606/drs.2026.1850

Abstract: Sound-driven design requires shared objects to bridge disciplinary divides and support collaboration between diverse expertise. Boundary Objects and Intermediary Objects typically fulfil this need, yet the ephemerality of sound is in apparent conflict with the stability needed for this boundary work. However, we argue for extending the object beyond the ephemeral sound wave to encompass tools, user interfaces, methods, and lexicons that provide material persistence. To support this we develop an analytical framework combining BO and IO properties and apply it to a selection of sound design tools in the literature. We argue that the required interpretive flexibility and perceived stability arises through the inherent plasticity of listening: different stakeholders actively construct stable, relevant meaning through situated interpretation. We propose the term "Soundary Objects" for artefacts and processes where listening's plasticity is the key mechanism enabling boundary work in sound-driven design, suggesting directions for designing effective socio-technical mediation tools.

Keywords: Boundary / Intermediary Objects; Sound-driven Design; Sound design tools; Methodology

1. Introduction

Research efforts in sound design have been producing and systematising a rich knowledge, methods and tools to support the design of products, services, systems, and environments for better "sonic lives" (Susini, 2014; Franinović & Serafin, 2013; Collins, 2020; Filimowicz, 2024; Kang & Schulte-Fortkamp, 2016; Özcan, 2008; Lyon, 2000). Sound design has been evolving from the view of a specialised activity for "lone wolves" (Hug, 2020) to the one of an interdisciplinary profession more and more embedded in multidisciplinary, complex team dynamics (Özcan & Van Egmond, 2008; Zattra, 2024; Delle Monache, Misdariis & Özcan, 2024). In several cases, the underlying rationale for advancing knowledge in sound design is to test it against the knowledge in the established Design domain (Misdariis, 2024), a field which largely relies on vision as a predominant experiential means that metaphorically and methodologically guides learning, collaboration and decision-making, and that consequently has been thoroughly studied mainly in visuo-spatial terms (Hay, Cash & McKilligan, 2020; Purcell & Gero, 1998; Pei, Campbell & Evans, 2011). For example, Bauhaus-inspired Basic

Design approaches have been applied to investigate sonic form-giving and auditory perception in interactive contexts (Delle Monache & Rocchesso, 2014), bodystorming techniques and video-prototyping have been expanded to vocal sketching methods (Ekman & Rinott, 2010; Delle Monache & Rocchesso, 2019); autographic design approaches have been explored to leverage the act of listening to data sonification phenomena (Lenzi, Ciuccarelli & Offenhuber, 2024); the role of auditory representations has been studied as a means to conceptualise service design (Kuštrak-Korper & Rodrigues, 2023); several design models and workflows have been analysed and adapted to the sound domain (Nykanen, 2008; Nykanen et al., 2015; Susini, 2014; Moesgaar, Hulgaardd & Bødker, 2020; Delle Monache & Rocchesso, 2021; Verstegen, Özcan & Delle Monache, 2022).

These works highlight the specificity of listening in design, as a way of knowing through sound, which implies active, bodily engagement with all the senses, and prioritises the in-depth understanding of the listeners' context and their culture. Consequently, calling for human- listener-centered approaches to sound design requires appropriate means, methods and tools that truly facilitate the collaboration and involvement of all the stakeholders in the design process (Louwers et al., 2025; Koushik et al., 2025; Fraisse et al., 2024).

Along this line of inquiry, in this paper we are interested in the theories of Boundary (BO) and Intermediary (IO) Objects (Leigh Star, 1989, 2010; Boujut & Blanco, 2003; Vinck, Jeantet, & Laureillard, 1996) as a lens to provide a novel perspective on the understanding of mediating capacities of sound design tools in supporting collaboration in design projects that incorporate sound. Although having different focus, scope, and intellectual background, both BOs and IOs share the same purpose, to enable and foster cooperation across heterogeneous groups of stakeholders. However BO/IOs for sound design, or sonic boundary/intermediary objects (SB/IO), are not simply objects that happen to be sonic, instead these are artefacts that leverage the plasticity of listening in creating a shared space for cooperation (Grond & Devos, 2016). In this respect, understanding and characterising how "sound" works as a BO/IO is useful to design better mediation tools and design processes.

To characterise sound as a BO/IO, we selected a set of established studies on BO/IOs, extracted the core definitions and characteristics, and analysed their conceptual origins, teleologies and relations to the design practice. We distilled this information into an analytical framework that takes in account four key functions: 1) the *Representational* (the material form of the object); 2) the *Processual* (the object's role in the design process); 3) the *Bridging* (its sociological function of connecting different groups); and 4) the *Enactment* (its social agency and activeness within the design process). Overall we found 12 precise features that the objects are active in. To give an indication of how this framework captures information about Sonic Boundary Objects (SBO), we carried out an exploratory study on a curated selection of 22 projects of sound design tools in the domains of *auditory information*, *soundscape, product sound*, and *sonic interaction* design. We show that the four families of projects differ across BO/IO dimensions in a meaningful way and that the sound design tools are distinct within the framework on certain axes.

The paper is organised as follows: in Section 2 we cover the literature on Boundary and Intermediary Objects and reflect on the objecthood and plasticity of listening; we present the analytical framework in Section 3; we report and discuss the exploratory study in Section 4, and finally draw the conclusions in Section 5.

2. Boundary AND/OR Intermediary Objects?

We provide a critical review of BOs and IOs with the aim of disambiguating the two concepts and eventually stressing that BOs and IOs are not in opposition, despite their different origin, scope and focus. We disclose instead that BO provides the general sociological theory (Star, 1989, 2010), whereas IO can be seen as the specific application of this theory to design practice (Vinck, Jeantet, & Laureillard, 1996; Vinck, 2011). Our critical review is based on a selection of most relevant literature on BO and IO (Table 1). For each article, we summarise and highlight the most relevant conceptual contribution to BO / IO that we use in the analytical framework. We conclude the section by disambiguating BO and IO and proposing a rationale to combine them in a unifying perspective.

Table 1 Relevant BO and IO literature for the analytical framework.

BO source	**Key concepts**
Star, 1989	Interpretive flexibility; BOs types (form/medium)
Star, 2010	Tacking back-and-forth; Scale and scope (organisational level / cooperative)
Lee, 2007	Negotiation (pushes boundaries; Critique of *standardisation* of BOs
Fleischmann, 2006	BO as *active agent* and constitutive relation between technology and society
Subrahmanian et al, 2003	BO mediating understanding as cognitive structure; problem of BO maintenance
Bergman et al, 2007	Mobilise for action; Legitimise design knowledge; Bridge technical / *political* gaps
Gerling et al, 2020	Affordances of BO; Abstractness / Concreteness; Plasticity / Robustness
Balint & Pangaro, 2017	1-order BO (static); 2-order BO (dynamic, active)
Spee & Jarzabkowski, 2009	Syntactic, semantic, pragmatic boundaries; Designated vs In-use BOs
Thaarchen et al, 2020	Diversity of views / incompleteness / reflexive interaction in design as a resource
IO source	Key concepts
Vinck, 1996	Commissioning vs mediating; Open vs closed objects
Boujut & Blanco, 2003	Support knowledge creation; Malleability and Openness
Vinck, 2011	Equipping work (authority); Ontological transformation (rough / final)
Vinck, 2012	IO as Representation; IO as Translation

2.1 Boundary objects

The concept of the Boundary Object (BO), originally established by Star (1989) drawing on the Chicago school of sociology and Symbolic Interactionism (Blumer, 1986), characterises the means through which actors from heterogeneous 'social worlds' manage to coordinate and cooperate in the absence of consensus. Star defines BOs as having an inherent materiality, interpretive flexibility and plasticity, allowing different groups to maintain distinct, local viewpoints while sharing and using the same object. This crucial property permits the transfer, transformation, and translation of knowledge across different communities of practice. BOs manifest in diverse forms and media, such as repositories, ideal types (e.g., abstract models), maps, and standardised forms (e.g., logbooks), which maintain continuity and identity across the boundaries. They function as an infrastructure that enables cooperation by satisfying the institutional requirements of each involved social world.

In a subsequent reflection, Star (2010) addressed common misunderstandings, asserting that interpretive flexibility alone is insufficient. BOs are equally constituted by their material/organisational structure and the core practice of "tacking back-and-forth". This dynamic involves cooperating groups taking the ill-structured shared object, making it locally specific and tailored, and then cycling between these general and specific forms. BOs, therefore, act as a stable point of reference, enabling cooperation without forcing a unified perspective. Since this foundational work, the theory has evolved, with contributions positioning *BOs as active agents* in conflict resolution (Fleischmann, 2006), examining their underlying cognitive structure (classifications, language, rules) with the support of prototypes (Subrahmanian et al., 2003), and defining features like affordances and the dimensions of *abstractness/concreteness* and *plasticity/robustness* (Gerling et al., 2020). Other developments include framing them as *Boundary Negotiating Artefacts* that actively push boundaries (Lee, 2007) promoting openness and negotiation with coordinating and bridging functions; distinguishing between *first- and second-order BOs* following static and dynamic/coevolutionary aspects (Balint & Pangaro, 2017), and contrasting *designated* versus *in-use objects* that bridge *syntactic, semantic, and pragmatic boundaries* (Spee & Jarzabkowski, 2009). Recently, BO is applied to the Design domain itself proposing interactive BOs based on inherent ambiguities in diverse views and incomplete communication styles (Thaarchen et al, 2020).

2.2 Intermediary Objects

Originating from the French school of Sociology of Technology, Innovation, and Design, Vinck and colleagues (Vinck & Jeantet, 1995; Vinck, Jeantet & Laureillard; 1996) established the concept of the Intermediary Object specifically addressing the role of artefacts in the design and engineering field. Unlike BOs, which coordinate in the absence of consensus in different social worlds, IO theory focuses on the mediation aspects of artefacts to foster deep cooperation and the achievement of a common understanding within a multidisciplinary design team. An IO is fundamentally a processual object, representing an intermediate state of the final, absent product, service, or system. Information, knowledge, and the medium of representation are deeply intertwined within the IO revealing actors, processes and practices locally and globally (Vinck & Pérez-Martelo, 2023). The foundational work of Vinck, Jeantet & Laureillard (1996) introduced a key classification matrix based on two dimensions: *commissioning vs. mediating* and *open vs. closed*. This framework distinguishes objects like *Closed Commissioners* (e.g., passive blueprints) from *Open Mediators* (e.g., sketches) which exhibit high interpretive flexibility and active participation.

The IO's role is to be a mediator that is actively transformed or translated by the working group (Vinck, 2012). This collective transformation is a key dynamic, facilitated by the object's malleability, openness and versatility (Boujut & Blanco, 2003). Furthermore, IOs are central to the practice of "equipping work" (Vinck, 2011), by which cooperative additions of features (e.g., technical references, codes) transform the IO's ontological status from *rough* and unfinished to an *enabled trace*, providing the object with authority and legitimation. The IO thus becomes a tool for creating a shared basis for cooperation, focusing on design artefacts like mock-ups and sketches, and the sociotechnical process of translating abstract intentions into concrete reality, that is a functioning product, service or system, through their continuous equipping work and in doing so, building a common understanding.

2.3 Key differences between Boundary and Intermediary Objects

Table 2 summarises the key differences between BO and IO. BO and IO are no rivals, instead their relation has been described as a "counterpoint" (Trompette & Vinck, 2009). Whereas the BO is the general social theory, the IO represents the specific application to the design practice. It zooms in on the artefacts and describes the process by which designers, engineers, and all the stakeholders achieve cooperation through e.g. transformation, malleability and active mediation. BO may explain why a shared (sketching) tool is necessary to bridge social worlds, IO may explain how that tool works in practice. In this respect, the BO concepts can be used to identify the problem the object is solving (problem space - why?), the IO concepts instead can be used to identify the specific characteristics of the object to solve that problem (solution space - how?).

Table 2 Boundary and Intermediary Objects at a glance: Key differences.

	Boundary Object	**Intermediary Object**
Primary problem	Cooperation without consensus between pre-existing, heterogeneous social worlds.	Cooperation through common understanding in a multidisciplinary team.
Object's Role	To sit in the middle and allow different groups to maintain their different perspectives. It's a stable point of reference.	To be a mediator that is actively transformed or translated by the group. It is a processual object representing an intermediate state.
Key Dynamic	Tacking back-and-forth. Groups take the ill-structured shared object and make it more specific or tailored for their local use. The object itself may remain relatively stable.	Collective transformation. The object is open and malleable (like a sketch), allowing the group to collectively modify it, externalize ideas, set conventions and rules.
Relationship to Consensus	Explicitly avoids the need for consensus. Interpretive flexibility is the solution to this lack of consensus.	Aims to build a common understanding or local convention. It is a tool for creating a shared basis for cooperation.
Object definition	Almost anything: a theory, a map, a repository, or a standard method.	Focus on design artefacts: mock-ups, CAD models, sketches, and the equipping work that gives them status.

2.4 On the objecthood and plasticity of listening

The transposition of the notion of Object to the sonic dimension is historically rooted in the concept of the Sonic Object ("objet sonore") formalized by P. Schaeffer (1966) as a “sound unit perceived in its material, its own texture, its own qualities and its own perceptual dimensions.” This original phenomenological view links to the mode of Hearing, which is an analytical approach associated with the cognitive theory of information processing. Conversely, the objecthood of sound is also framed by the Ecological Theory of perception (inspired by Gibson, 1978 in the visual domain) which posits a direct perception without cognitive intermediary (Gaver, 1993). This can be associated with Schaeffer’s causal mode of listening that actively searches for clues in the sound as to its possible origin and the event that produced it (Chion, 1990). These two con-joint perceptual processes establish sound objects as phenomena we experience (sense, hear, and listen with intent), with extensions to sound-motion (Godøy, 2019) facilitating sound-induced actions completing an entire perception-action trajectory (Lemaitre & Heller, 2013; Ozcan, et al. 2022).

The legitimacy of the sonic object is inherently dependent on the plasticity of listening, which enables a listener to acquire knowledge by focusing not only on the acoustical properties (Hearing) or the discovery of an environmental cause (Listening), but also on the social meaning of a sound—a mode Schaeffer (1966) termed Understand. This third mode operates at a more cognitive level, treating sound as a sign of language and value.

This plasticity is crucial for establishing *objecthood* beyond pure acoustics. Sound associations are inherently plastic (Lemaitre & Heller, 2013), can be learned, and therefore can be designed (Özcan, 2014). This plasticity can be influenced by external factors like identifiability and the expertise of the listener (Lemaitre et al., 2010), as well as the modes of representation adopted to make this intangible phenomenon tangible. Sonic objects are experienced through subjective modes of listening facilitated by both bottom-up and top-down processing (Chion, 1990; Tuuri & Eerola, 2012) further demonstrating the alternating ways of experiencing and interpreting auditory perception. Sonic objects are inherently entangled to visual objects (Kubovy & Valkenburg, 2001), benefitting from conceptual associations evoked by both modalities. Consequently, the evocative power of sounds can either reduce the role of linguistic mediation (Schon et al., 2010) or evoke affects and emotions (Korsmit et al., 2023). In a broader sense, a sonic object can be any artefact, event, action, or space that evokes the physical, perceptual, or psychological dimension of sound, stimulates the auditory and semantic systems and facilitates interactions with the outer world, verbally, bodily, or materially.

Sound-driven design (SDD) is grounded in the ecological approach to perception, embodied cognition, and technology mediation, conceptualising sound as listening-in-action, where the focus of its research is on listening-in-designing (Delle Monache et al., 2022, 2024): In the TWAF framework, Designing [The, With, Against] sound [For] are listener-centric modes of designing that represent how decisions are collaboratively negotiated in a design context (across communities of practice, social worlds). The formation of the framework, which bridges the semantic gap between inter-disciplinary design inputs, further evidenced that while practitioners contain core sound-relevant professional knowledge, they are also able to connect on common concepts of sound.

Finally, sonic objects include by extension tools, instruments, methods, systems, spectrograms, sound archives, etc. capable of evoking sonic representations. Due to the inherent plasticity of listening and the resulting ability of these artefacts to be interpreted from acoustical, causal, and meaningful perspectives, they inherently provide interpretive flexibility. SBOs are thus expected to expose similar qualities of objecthood in use—malleable, plastic, mediating, and transformative capacities—grounded in the act of listening. The critical question remains: what is their organisational scale and scope, so that they effectively transform into boundary objects for cooperative work?

3. An analytical framework for Sonic Boundary Objects

By combining BO and IO theories, the framework is built as a stack, moving from the general sociological problem (the Why) to the specific design-oriented mechanisms (the How). The framework is organised in four key dimensions (i.e. 1. Representational, 2. Processual, 3. Bridging, 4. Enactment functions) and their features. Table 3 summarises its structure with explicit reference to the key literature discussed in Section 2. We are interested in exploring if this framework is robust enough to characterise Sonic Boundary Objects, that is design artefacts and representations that leverage the plasticity of listening as a means to foster cooperation through common understanding in a multidisciplinary sound design team.

Table 3 A comprehensive analytical framework combining BO and IO features

Dimension s	Features	Rationale	Key References
1. Representa		(Why - problem space) - Material form of the object and what it stands for.	Vinck, 2012 Bergman, Lyytinen & Mark, 2007

tional function	Form / Medium	What is the object's physical or digital form?	Star, 1989
	Abstraction vs. Concreteness	How detailed or specific is the representation? Abstract: ideal type, vague and adaptable. Concrete: highly specific and unambiguous	Gerling, 2020 Spee & Jarzabkowski, 2009
	Target	What does the object represent? (e.g. the final, absent object, a critical function, a process, a user / persona)	
2. Processual function		(How - solution space) - Object's active role within the design process	Star, 2010 Bergman, Lyytinen & Mark, 2007
	Mediation (Passive vs. Active)	How does the object carry intent? Passive > simply transmits instructions or goals without changing them. Active > Resistant, creative or destructive, it is not a neutral channel.	Vinck, Jeantet, & Laureillard, 1996 Balint & Pangaro 2017
	Translation / Transformation	Does the object change the idea as it moves between forms and actors?	Vinck, 2012 Balint & Pangaro 2017
	Generativity	Does the object help create new knowledge? > acts as a conjecture, supports collaborative knowledge creation	Boujut & Blanco, 2003 Fleischmann, 2006 Gerling, 2020 Balint & Pangaro 2017
	Temporality	Where in the process does it live? (e.g. rough, traceable unfinished in early stage vs. enabled trace, validated and finalised; temporal marker in the design process creating irreversibility - a signed-off plan)	Boujut & Blanco, 2003 Vinck, 2011 Lee, 2007
3. Bridging function		(Why - problem space) - Sociological function of connecting different groups of stakeholders.	Star, 2010 Fleischmann, 2006 Tharchen, Garud, & Henn, 2020
	Target audience	Which social worlds or communities of practice does it connect?	
	Nature of the boundary Syntactic: language or format Semantic: meaning Pragmatic: interests	What kind of gap does it bridge?	Boujut & Blanco, 2003 Subrahmanian et al, 2003 Bergman, Lyytinen & Mark, 2007 Spee, Jarzabkowski, 2009
	Plasticity / Robustness	How does it balance the needs of the different groups? Plastic enough to adapt to local needs and constraints. Robust enough to maintain a common identity across sites	Star, 1989 Vinck, Jeantet, & Laureillard, 1996

	Openness / Closedness	Full interpretative flexibility vs. Prescription in accordance to the author's intention	Vinck, Jeantet, & Laureillard, 1996 Boujut & Blanco, 2003 Vinck, 2011 Lee, 2007 Gerling, 2020
4. Enactment function		(How - solution space) - Agency of the object in the social and political dynamics	Fleischmann, 2006 Bergman, Lyytinen & Mark, 2007
	Mobilisation	Does the object cause people to act? (e.g. mobilising vs. conscriptive, enlisting and organising human participation)	Spee, Jarzabkowski, 2009
	Legitimation / Validation	Does the object establish or test authority through equipping? Does it legitimise design knowledge? Is it used for knowledge validation or assessment?	Vinck, 2011 Subrahmanian et al, 2003 Gerling, 2020 Spee, Jarzabkowski, 2009
	Negotiation Stabilising vs. Destabilising	How does the object manage boundaries? Coordinating (classic BO, stable and standardised) vs Negotiating (unstable, challenging boundaries)	Lee, 2007 Fleischmann, 2006 Balint & Pangaro 2017

4. Exploratory study

To give an indication of how this framework captures information about SBOs, we first applied the framework to a set of projects developed by the authors. Then we decided to expand the set and explore how the framework would work with a larger number of tools. Here, we carry out an exploratory study on a curated selection of 22 projects of sound design tools for *Auditory Information*, *Soundscape*, *Product Sounds*, and *Sonic Interaction*, reported in Table 4. As a selection criteria, we searched for journal and conference articles about tools for sound design practices, explicitly centering the discussion on the design rationale rather than solely describing the system architectures.

Table 4 A curated list of sound design tools.

Family	Tool	Design rationale	Reference
Auditory Information	TaDa!	Method focusing on designing auditory representations to meet information requirements, integrating task analysis, a database of sound examples, a rule-based design aid, interactive sound design tools.	Barrass, 1996
	SpeaK lexicon	Normative lexicon and computer interface for communication on sound features in a sound design process.	Carron et al, 2017
	SONOUNO	Sonification tool and multimodal display enabling greater inclusion in astronomical investigation and training courses.	Casado & Garcìa, 2024
	Scenario-based	Creative support Tools to assist sound designers	Kamath et al, 2024

	GenAI		
	Data Sonification Canvas	Concept design tool to assist designers in making explicit the communicative intentions and design decisions in the creative process of data sonification.	Lenzi & Ciuccarelli, 2024
Soundscape	The Ambience Table	Intuitive tabletop interface that allows users to design and interact with the ambient sounds of birds, wind and traffic for home movies and indie games.	Jönsson et al, 2013
	Sonic Ruptures	Soundscape design tools for creating small sound environments in urban places, based on translating ambiance, biophilic sound design, and more-than-human listening	Lacey, 2022
	VR NoiseMap	VR application to present noise maps data in audible form, for landscape architecture and planning	Luoma, Fricker, & Schlecht, 2023
	VR Architectural Sound Design	VR tool for sketching sound in the architectural design process, potentially to assist architects in co-working with acousticians	Nedlich, Nykänen, & Hellström 2022
Product Sound	Psst!	Tool to assist inexperienced product sound designers to sketch product sounds during conceptualization	Jansen, Özcan & van Egmond, 2011
	FlyoversSynth	Tool for online, interactive sound quality analysis and target sound design of aircraft flyovers.	Marki et al, 2011
	EVE	Explorative Vehicle Evaluation is a user-centered method and tool for designing and assessing the vehicle sound experience	Schulte-Fortkamp, Genuit, & Fiebig, 2007
	Les_Sons	Educational tool to assist students in understanding how engineering decisions influence sound perception, and practice collaboration and shared understanding in multidisciplinary contexts.	Delle Monache, et al, 2025
	Interactive NVH	Interactive simulation tool of real world driving experience to assess customers preferences to on-road vehicle sounds	Jennings, et al, 2010
	SoundBe	Innovative tool to aid designers dealing with sounding objects, in order to integrate sound-materials aspects into the meta-projectual phase	Dal Palù, et al, 2014
Sonic Interaction	SDT	Palette of virtual lutheries and foley pits, with polyphonic features and connectivity to multiple external devices and sensors to facilitate the embedding of sonic attributes in interactive artefacts.	Delle Monache, Polotti & Rocchesso, 2010
	GST	Tools for designing expressive gestural interactions with sounds, with modularity, and versatility, accessible to non-experts.	Caramiaux, at al, 2022

SeED	Voice-driven process and tool for embodied sound sketching, supporting the externalisation of sonic concepts.	Delle Monache, et al, 2018
Scen_Gen AI	Prototype of an AI-powered sound design tool with four GenAI applications and four supporting features, tailored to sound and UX designers.	Choi, et al,. 2024
SonifyIt	Tool to rapidly design and iterate on transformative robot sound, accessible to sound designers for ease of collaboration	Zhang, et al, 2022

4.1 Methodology

Based on the BO/IO analytical framework presented in Section 3, we conducted an AI-assisted thematic analysis (Cevik, Fikri & Abu-Zidan, 2025; Dai, Xiong, & Ku, 2023; Bennis & Mouwafaq, 2025) of the 22 sound design tool projects (i.e. articles, Table 4). Using Gemini 2.5 pro, we first created a context providing the detailed framework, with key dimensions and features, in a 10-point rating scale (see table 5), then we prompted the system to study and rate the 22 tools upon dimensions and features. The AI-based approach was used mainly to minimise possible influence by the authors, especially on those projects and tools in which they have been previously involved.

Hence, results were meta-reviewed by the 3 authors to confirm or adjust the scores. The raw data consisted of the 12 ratings of the 22 sound design tools. The average standard deviation within the four categories (Auditory Information mean SD = 1.78, Product Sound mean SD = 1.68, Sonic Interaction mean SD = 0.6 and Soundscape mean SD = 0.73) provides a rough approximation of the within-categories agreement. Hence, we averaged the data within each of these categories to have a first overview on the SBO characterization of sound design tools according to their design purpose.

Table 5 Analytical framework in a 10-point rating scale

Dimension	Feature	1 = Low/Passive/Rigid	10 = High/Active/Flexible
Representational	1. Concreteness	Highly Abstract (vague, "ideal type")	Highly Concrete (specific, "finished prototype")
Processual	2. Mediation (Activity)	Passive ("commissioning," a simple carrier)	Active ("mediating," transforms the idea)
	3. Generativity	Low Generativity (closed, for final review)	High Generativity (exploratory, "scribbling")
	4. Finality	Rough (early-stage, unfinished, open)	Final ("enabled trace," signed-off, closed)
Bridging	5. Syntactic Bridging	Low (Does not bridge language/format gaps)	High (Creates a new common language)
	6. Semantic Bridging	Low (Does not bridge gaps in meaning)	High (Actively translates meaning)
	7. Pragmatic	Low (Does not bridge gaps	High (Forces negotiation of

	Bridging	in interests)	interests)
	8. Plasticity	Robust (rigid, standardized)	Plastic (adaptable, flexible)
	9. Openness	Closed (prescriptive, one intended use)	Open (high "interpretive flexibility")
Enactment	10. Mobilization	Low (passive, does not "conscript" action)	High (active "call to action")
	11. Legitimation Focus	Low (e.g., a personal note)	High (a formal tool for "knowledge validation")
	12. Negotiation (Activity)	Coordinating (stable, reinforces standards)	Negotiating (destabilizing, "pushes boundaries")

We emphasise the exploratory nature of this AI-based thematic analysis (i.e., finding traces of Boundary/Intermediary Object characteristics in existing design tools), as a first attempt towards its application in larger contexts. We have a future aim to offer an archive of SDD projects based on an automated categorisation of SDD features in project descriptions, using Large Language Models.

4.2 Results

The radar charts in Figure 1 depicts the average ratings for each sound design tool categories along the 12 dimensions elicited to characterise a Sonic Boundary/Intermediary Object. We can observe invariants and differences among the four sound design categories. Notably, there are several features whose scores are fairly shared across all the 22 tools, with slight variations, in particular **Mediation**, **Syntactic bridging** and **Legitimation** focus. This highlights that all tools are fairly active mediating, acting as a classic coordinating BO (enabling boundary standardisation, rather than destabilising it), by attempting to provide a purposeful *language* (syntax). All tools are rather thought for early - middle stages of the design process, with low degree of finality, thus showing a design rationale for intermediate steps of the process. This might also be ascribed to the fact that the majority of the tools are research output, not necessarily completed or ready to be marketed.

This is reflected in the low **Concreteness** feature, which can be read together with the aim of mid-high Legitimation focus, to create knowledge and common understanding. Of interest the four groups notably differ on **Generativity**, the *Sonic Interaction* and *Soundscape* groups showing a higher creative and exploratory rationale, and the *Auditory Information* showing a rather problem solving approach (how to convey information with non-speech sound). The *Product Sound* group sits in the middle with varying approaches. Along this differentiation, we can interpret the different scoring across the **Openness** and **Plasticity** features, where tools in the *Auditory Information* and *Product Sound* groups coherently restrain interpretative flexibility (Openness) by means of more prescriptive and standardised approaches (lower Plasticity).

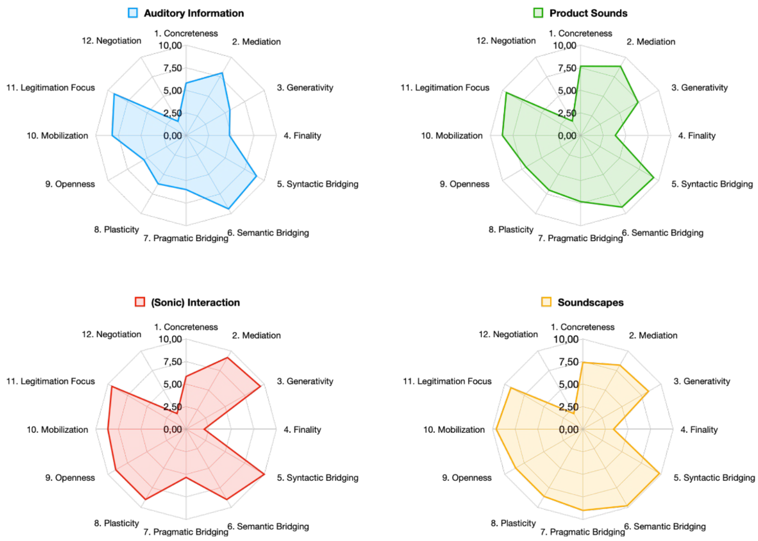

Figure 1 Radar charts of mean values of the 12 features for the design tools across Auditory Information, Product Sounds , Sonic Interaction and Soundscape.

Pragmatic bridging is one main feature which is prominent in one group only (*Soundscape*), suggesting a particularly different nature of these tools compared to others. Pragmatic bridging refers to the sociological function of connecting different groups of stakeholders, with a focus on the gaps related to interests and political dynamics, which is coherent with the social and political scale of soundscape concerns, compared to the loci of sonic interaction and auditory information design.

Following these qualitative insights, we used Principal Component Analysis (PCA) to further understand how the tools and their categories relate to the reduced features.

Component Loadings

	PC1	PC2	PC3	Uniqueness
9. Openness	0.955			0.080
8. Plasticity	0.934			0.093
3. Generativity	0.918			0.052
12. Negotiation	0.871			0.222
4. Finality	-0.849			0.077
10. Mobilization	0.551	0.591		0.178
2.Mediation	0.449		-0.722	0.172
11. Legitimation Focus		0.869		0.249
1. Concreteness		0.747		0.330
5. Syntactic Bridging		0.741		0.466
7. Pragmatic Bridging		0.444	0.699	0.178
6. Semantic Bridging			0.713	0.508

Figure 2 Left: Path diagram representing the relations between original features (variables) and the new principal components (PCs). Right: Loadings and uniqueness values of BO/IO features (variables) with the components.

The PCA resulted in three Principal Components, shown in Figure 2, that is *PC 1* including Openness, Plasticity, Finality (-), Generativity and Negotiation, *PC 2* including Syntactic Bridging, Legitimation Focus, Mobilisation and Concreteness, and *PC 3* including Pragmatic Bridging, Semantic Bridging and Mediation (-):

- **PC1 Finality vs Generativity**: the higher the Negotiation (pushing the boundaries, disruptive etc) the higher the Plasticity, the higher the Openness, higher is the Generativity. Generativity is extremely high when the others are high, therefore we selected *Generativity* as a candidate. *Finality* loads negatively, the more a BO is closed, structured, and validated, the more it represents the final object in the last stages of the process, e.g. the fine-tuned sound prototype embedded in a vehicle is unlikely generative, open and malleable.

- **PC2 Formalisation and Legitimation**: Legitimation focus, Concreteness and Syntactic bridging are the components that score higher in PC2. We interpret this component loading as a degree of SBO to formalise the boundaries with a focus on knowledge assessment and validation, rather than creation.
- **PC3 Simple mediation vs Deep Bridging:** This component is mainly composed of three features, Pragmatic and Semantic Bridging loading positively, and Mediation loading negatively. Its interpretation is quite straightforward characterising SBOs in terms of the focus of the sound design tools, in which *Simple Mediation* highlights perceptual, sensory or aesthetic aspects (e.g. sound in the action-perception loop) and *Deep Bridging* focuses on concerns of meaning in context (e.g. participatory processes in urban sound planning, where connecting communities of practice is crucial).

The tools, colour-coded by category, are represented across the three *PCs* in Figures 3, 4, 5. Results suggest that tool categories score higher on certain dimensions although not always consistently.

For example in Figure 3, design tools for *Product Sounds*, *Sonic Interaction*, and *Soundscape* are designated to be more *Generative* and result in less *Finality* (PC1) in the outcomes whereas *Auditory Information* design tools are the opposite. However, within this category, there is less agreement on PC2, showing that some tools are more conceptual than others (i.e. TaDa! and Sonif_Canvas), while others are more prone to consolidate, and validate knowledge (i.e. SpeaK lexicon, and SONOUNO).

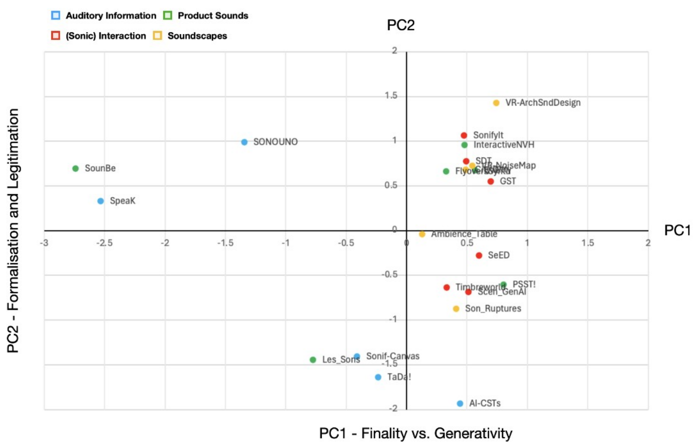

Figure 3 PCA Scatter plot of sound design tools in the "Finality vs. Generativity" and "Formalisation and Legitimation" dimensions.

Figure 4 provides a more interesting and clearer picture in the division of the tools across PC1 (Finality vs Generativity) and PC3 (Simple mediation vs Deep Bridging). Coherently, *Soundscape* design tools seem to be more generative and deep-bridging; *Sonic Interaction* design tools are generative and highly mediating, explorative, and transformative BO; *Auditory Information* design tools offer representations that are more closed and concrete, hence finalised and standardised for the purpose of enhancing knowledge bridging and validation both at conceptual (TaDa! and Sonif_Canvas) and prototyping levels (SpeaK, SONOUNO).

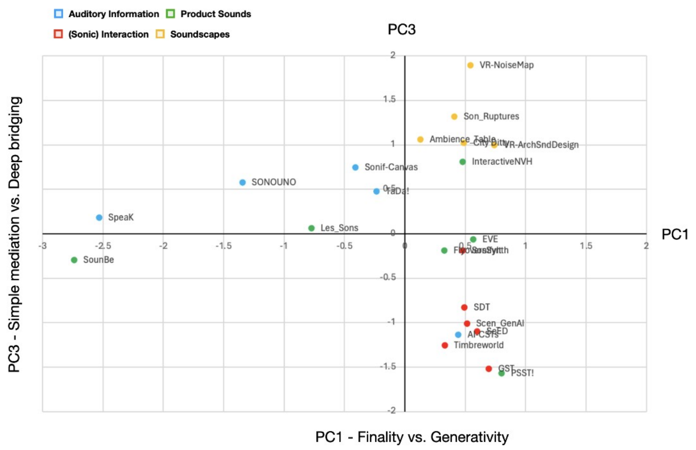

Figure 4 PCA Scatter plot of sound design tools in the “Finality vs. Generativity” and “Simple mediations vs. Deep bridging”.

Figure 5 stresses instead the hybrid nature of *Product Sound* design tools in terms of bridging capacity, as well as the different formalisation degree of *Auditory Information* tools.

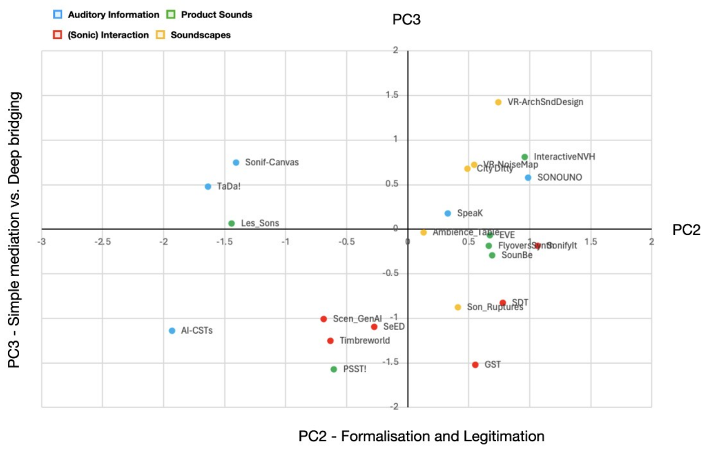

Figure 5 PCA Scatter plot of sound design tools in the “Formalisation and Legitimation” and “Simple mediations vs. Deep bridging”.

5. Discussion

5.1 Design tools as Sonic Boundary / Intermediary Objects?

The framework seems to capture distinct, meaningful profiles for these projects. The tools are not a random collection; they cluster into two clear "families" based on their core philosophy, that is how they support listening intentions in different ways, which ratings and PCA data confirm.

5.1.2 Top-Down / structured tools (the translators)

These tools are best understood as structured bridges. Their primary function is to solve the "semantic gap" by reducing ambiguity and creating a shared language. The listening intention is to provide a stable, common ground for heterogeneous groups (e.g., designers, engineers, clients, and the public) to stand on. They share some core BO/IO Characteristics:

- High on *Bridging* and *Legitimation* (features 5, 6, 7, 11): These tools excel at creating a new common language (Syntactic Bridging) , translating abstract concepts into concrete experiences (Semantic Bridging), and forcing negotiation to align interests (Pragmatic Bridging). They are tools of validation and legitimation.
- Low on *Openness* and *Generativity* (features 3, 8, 9): They are not blank canvases. They are "closed" or "robust" by design. Their purpose is to constrain interpretation around a shared standard, not to encourage infinite, "ill-structured" exploration.

Examples from this family include SpeaK, SounBe, and Timbreworld. They take a chaotic, subjective concept (timbre) and translate it into a stable, shared vocabulary. The simulator tools (Interactive NVH, City Ditty) are high-fidelity legitimation tools. Their purpose is to build a shared experience, plausible and realistic that can be used for final sign-off. The framework tools (Les_Sons, Scenario-Based GenAI) are process-oriented tools.

5.1.3 Bottom-up / open tools (the sketchpads)

This family includes SeED (Vocal Sketching), Gestural Sound Toolkit (GST), and SonifyIt. These tools are generative mediators. Their primary function is to embrace ambiguity and empower designers to create new sounds from scratch. The listening intention values flexibility, embodied action, and emergence over pre-defined standards. Some Core BO/IO Characteristics:

- High on *Openness* and *Generativity* (features 3, 4, 8, 9): These tools score perfectly (or near-perfectly) on being Generative, Rough, Plastic, and Open. They are blank canvases designed for "scribbling" and "rapid prototyping".
- High on embodied *Mediation* (feature 2): They are active mediators that translate embodied action - voice, gesture, or live data streams - into sound. The process is the product.
- Knowledge-building: Shared knowledge is not provided by the tool; it emerges from the collaborative act of using the tool.

SeED and GST are true sketchpads, built to be malleable and responsive, using the human body as the primary input. They are designed to include non-programmers by providing plug-and-play building blocks that can be combined in infinite ways; SonifyIt is a live mediator between the social worlds of roboticists and sound designers.

5.2 Soundary Objects

The investigation into the capacity of sound design tools to function as Sonic Boundary/Intermediary Object has shown that the apparent conflict between the ephemerality of sound and the required stability for boundary work is resolved in the plasticity of listening. By reflecting on the earlier discussion of sonic objecthood (Schaeffer, 1966) and flexibility of interpretation (Lemaitre et al., 2010), we are establishing a foundation for **Soundary Objects**: sonic objects embodying listening intentionality, with the capacity to serve and act like BOs and IOs in sound-driven design contexts.

6. Conclusions

We have examined the plausibility and forms of BO/IOs in the field of sound design and research. We have shown how listening intentions (i.e., plasticity) articulated in the rationale of four sound design tool categories (*Auditory Information, Soundscape, Product Sound, Sonic Interaction*) can be analysed across BO/IO dimensions and features. We found strong commonalities, particularly in terms of *Mediation*, *Legitimation*, *Bridging* and *(non–)Negotiation* aspects, and significant differences in terms of *Openness*, *Plasticity* and *Pragmatic bridging* – the former feature relying on the prescriptive nature of an SBO, and the latter relying on the power of bridging gaps of interests in the design process. The categorical difference in a tool's capacity to become a Sonic Boundary/Intermediary Object lies in its balance of plasticity versus robustness and the temporal scale of cooperation it supports. We plan to consolidate this analytical framework in a tool to design sonic boundary objects. To do so, we plan to run an appropriate factor analysis to consolidate both dimensions and features, before extending the analysis to a larger set of tools, including commercial ones.

Acknowledgements: The work described in this paper is part of the project Participatory Designing with Sound (PaDS, 2020 - 2022), which received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Skłodowska-Curie grant agreement No. 893622.

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