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FROM FRAMEWORK TO PRACTICE: LES_SONS, A PRODUCT SOUND TOOL FOR DESIGN EDUCATION

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ABSTRACT

This paper addresses the integration of sound into product design and engineering. Recognizing a gap in design education, the study focuses on introducing product design and engineering students to the principles of product sound design (PSD). By means of interviews with experts and literature research, a three-level framework is developed, addressing product features, object composition, and environmental context. This framework can assist students in understanding how engineering decisions influence sound perception at the product level, how material and structural choices affect sound at the object level, and how environmental factors shape the overall auditory experience. The framework served as the foundation for conceptualizing `Les_Sons`, an educational software tool that mirrors these levels in its architecture. `Les_Sons` supports students in exploring and modifying product acoustics through component and material selection. The paper stresses the role of tools like `Les_Sons` for product sound design education, in order to practice and enhance collaboration and shared understanding in multidisciplinary contexts.

Keywords: *Product sound design, education, consequential sounds, tool, interdisciplinary*

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1. INTRODUCTION

Sound is an integral aspect of product experience, influencing user perception, emotional response, and functional interpretation [1, 2]. Product sounds are typically distinguished in consequential and intentional sounds. The former can be defined as unintended or emergent acoustic properties that arise from material interactions, structural configurations, and environmental influences, typically involving sources, transmission of sound in the product, radiation, and reception by the listener [3, 4]. The latter class includes all those sounds which are deliberately added for functional or aesthetic purposes, produced by means of a loudspeaker or piezo elements [5, 6]. The distinction is important, as designing for consequential sounds requires an understanding of how a product's physical and mechanical properties influence its sound emissions, whereas intentional sounds are typically engineered separately to communicate specific information or enhance user interaction (e.g. notifications, warnings, continuous feedbacks) [7].

Despite its importance, product sound design (PSD) remains under-represented in product design and engineering education [8]. While traditional engineering curricula emphasise the mechanical and structural properties of materials, they often overlook how these properties contribute to the acoustic signature of a product and, consequently, to user experience [9, 10]. Addressing this gap requires a more systematic integration of PSD principles and methods into educational models, emphasising both theoretical and applied learning experiences.

Several PSD models have been proposed, essentially as variations of the more general << **Problem Analysis** → **Conceptual Design** → **Embodiment Design** → **Detail Design** >> process [11, 12], and with varying degree of articulation of the design stages within the general design cycle [13–16]. What these models have in common is the set of multidisciplinary expertise that are necessary to tackle sound in product design projects, including psychoacoustics, acoustics and material science, musicology, engineering and user-centered design approaches [13, 17].

Several pedagogical frameworks and tools for PSD exist that fully acknowledge these expertise and disciplines, although mostly stressing the experiential aspects of intentional sounds in interaction [18–23]. Students, particularly those in industrial design engineering, benefit from exposure to frameworks and tools that help them analyse, manipulate, and conceptualise product sounds.

It is beneficial to consider sound from the very beginning of the product development and not as an afterthought or a by-product to be corrected at a later stage of the engineering process. To address this gap in design education, we investigate and propose a framework and a prototype tool that facilitate the communication and the experiential understanding of how engineering decisions in material and structural choices impact sound perception at product level. By concentrating on consequential sounds, we emphasise the role of sound as an inherent aspect of product behaviour rather than an auxiliary feature.

In this paper, we first outline relevant issues in the PSD practice through semi-structured interviews with experts in product sound quality and design; then, we introduce a holistic PSD framework that integrates the characterisation of product and acoustic properties from the multidisciplinary perspective; finally, we describe the conceptual design of `Les_Sons`, an audio editing tool for consequential sounds, thought to actionalise the framework in the educational setting. We conclude with reflections about the need of design approaches and tools that fully account the central roles of listeners and their cultures, professionals and end-users, in the design process and set the agenda for the evaluation of `Les_Sons` in context.

2. FROM PRACTICE TO EDUCATION

The goal of the expert interviews is to gather insights into the PSD practice, to distil guidelines and directions for the educational framework. Four experts, reported in table 1, took part in individual interviews of approximately 45 minutes, on 1) collaboration and multidisciplinary teams, 2) methods and techniques, 3) the impact of sound on the product experience, 4) sound quality evaluation, 5) educational paths to enter the field of PSD. The interviews were recorded, analysed and summarised in themes.

Table 1. The participants profiles in the interview

Participant & Role	Affiliation
Director - Product Manager	Ansys Sound
Senior Lead Engineer (acoustics)	Arçelik Global
Lead Engineer (acoustics)	Arçelik Global
Professor in Acoustics and Haptics	TU Dresden

We need accessible tools for interdisciplinary collaboration: Integrating product sound within design teams presents challenges due to specialized expertise and communication barriers. Psychoacoustics experts may struggle to translate perceptual metrics into engineering parameters [24], while professional software often prioritises functionality for experts rather than fostering accessibility for broader team collaboration. Various approaches help bridge this gap: vocal imitation allows for quick communication of auditory concepts and sensations [25], sound processing (i.e. audio filtering) can be used to position the acoustic issue and potential acoustic changes, and psychoacoustic measurements can ensure that sound design decisions align with user perception [26, 27].

Experts emphasise that simplified representations, such as spectrograms, make cross-disciplinary discussions accessible to all stakeholders, although they often lead to poorly detailed communication, limiting the depth of sound integration in project communication. This underscores the necessity for accessible tools that enhance interdisciplinary collaboration and ensure that sound considerations are effectively incorporated into product development.

Materials and geometry effects on sound cannot be ignored (yet): In the analysis stage, recording existing product sounds is key to identify frequency ranges and peaks for adjustment. Reverse engineering and comparing previous models and competitors products help pinpoint which components generate sound in a product and enhances the understanding of how engineering decisions influence sound. When disassembly is not preferred, acoustic cameras provide a non-intrusive method to locate sound sources and analyse their impact [28]. Function analysis can serve to ensure that the sound as a functional element aligns with the product's function. For example, a silent dishwasher might be perceived as faulty, whereas the operating sound informs the user that it is running [29].

Solution-wise, Active Noise Control (ANC) systems are improving, but they require still that the head position is known and fixed relative to the sound source, e.g., in cars or with headphones [30]. This technology remains expensive due to the need for additional electronics. Consequently, according to experts, physical adjustments, such as changes in materials and geometry, are likely to remain the most effective and sound-relevant approaches in the next 20 years. For example, when dealing with resonance problems, material modifications are typically made for smaller components, while larger components may undergo geometric modifications, e.g. by adding ribs or dents to adjust elasticity or stiffness [31].

Finally, sound virtualisation is currently limited due to the complexity of sound transmission through materials, compared to stress-induced deformations. At present, it is only feasible for single components or sub-assemblies like engines [32, 33]. Experts predict it will take another decade of development before sound virtualisation for entire products can be used to test multiple product configurations.

Design sound, address all the senses: The experts emphasise the subjectivity of sound appraisal and the multi-sensory nature of the product experience. According to the experts, acoustics and haptics should be considered together, as vibrations within a product may not only be audible but also perceptible through touch. Additionally, cultural factors should be considered, as some cultures may be more or less accustomed to noisier environments (e.g. residents in quieter cities may be more sensitive to noisy products) [34, 35].

In this respect, when searching for a new product, consumers can be made aware of product sounds in various ways. The EU energy label displays the product's noise level in decibels (dB), in addition to energy efficiency. However, simply providing the noise level may not be sufficient to shape the consumer's attitude toward the sound of the product [36]. As a result, some companies opt to use sound quality labels, like the SLG, awarded by independent certification bodies. These labels are based on jury tests that assess the perception of the product's sound. While not mandatory, these certifications are more effective in informing consumers about the pleasantness of the product's sound.

Sound quality evaluation - "One size doesn't fit all": Evaluating how sound will be experienced in an objective way is challenging. Consequently, jury tests are used to assess the subjective sound quality of a product, and provide valuable insights into how the end user is likely to perceive the sound. Although the study of sound perception has been ongoing for over a century, the interviewees agree that the full understanding of human listening is still in the early stages. They also speculate about the future application of computational models of human hearing to evaluate the sound quality in a way that aligns more closely with the physical experience of sound by humans [37].

Interdisciplinary and practice-based learning: The experts shared some reflections about educational paths to enter the field of PSD. Overall, they all stress the value of "simplicity" as a guiding principle to approach acoustics in order to build a solid foundation, e.g., by starting from practical examples grounded in everyday situations; learning sound processing on more accessible visual-programming software such as Pure Data or MAX; familiarising with sound analysis using off-the-shelf tools such as Adobe Audition, Audacity, Sonic Visualizer, which offer a good understanding of the same concepts used in more complex and advanced sound analysis and simulation tools.

Summary for PSD framework conceptualisation: The specialised expertise required in PSD raise challenges in communication between stakeholders, calling for appropriate representational tools to facilitate a common ground between them. An interdisciplinary approach to PSD education is suggested. Alongside theory, a basic introduction to acoustics with real-life examples can spark interest, supported by practical activities like sound recordings and acoustic measurements.

Design goals should reflect the product's function and acknowledge that sound is experienced alongside other senses, which varies across users and cultures. Once design goals are defined, reference sounds can be created, and while simulations are limited to single components, editing recordings of disassembled products can provide insights. Finally, sound evaluations are done through jury tests, which could be replaced by computational models in the future.

3. THE PRODUCT SOUND DESIGN FRAMEWORK

Navigating design choices regarding sound and determining a design goal for how sound should be listened to and experienced may be daunting for a young designer. We used the expert consultation to iteratively develop a framework that 1) integrates multiple PSD models into a comprehensive view; 2) is inherently interdisciplinary, incorporating contributions from design, engineering, acoustics, psychology, psychoacoustics, and musicology; 3)

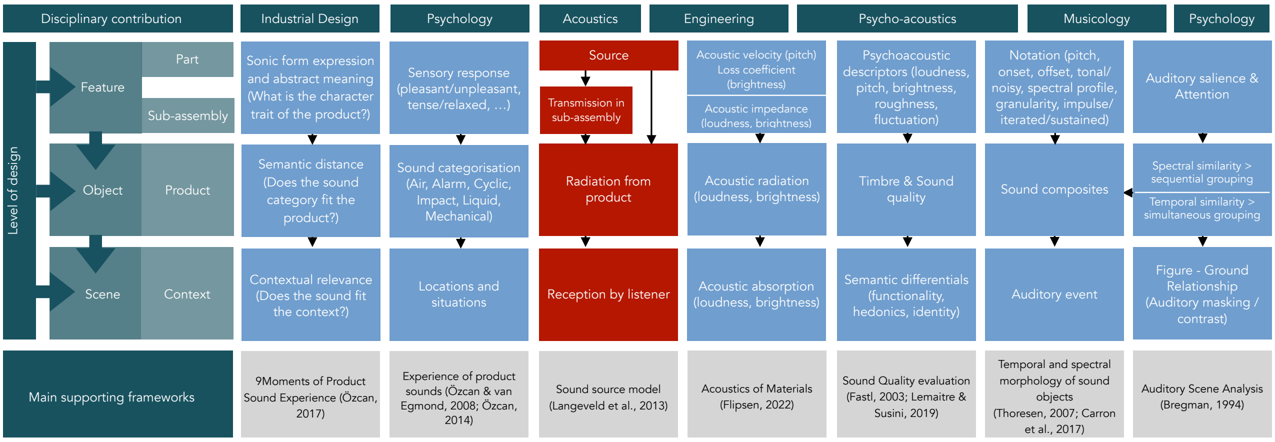

Figure 1. A comprehensive PSD framework. The three levels of design represent the common thread between existing approaches, and a magnifying glass to construct interdisciplinary perspectives on product sounds.

empowers product designers, by bridging analysis and conceptualisation in product design visions. Our vision is to provide a hierarchical framework to navigate product sound design choices to be able to assign a fitting methodology for analysis, design and evaluation.

To accommodate these three characteristics, the framework, shown in Figure 1, details product sounds on three levels of design, that is 1) **product features**, 2) **object composition**, and 3) **scene**. Each level is characterised from the perspectives of a) *experience of product sounds* [13, 38, 39]; b) *sound source model* [4]; c) *acoustics of materials* [40]; d) *sound quality evaluation* [26,41]; e) *temporal and spectromorphological description* [42–44]; f) *integration into the auditory scene* [45].

The **features level** takes in account the contribution of single components or sub-assemblies of a product across the different perspectives. This level characterises product parts in form-giving terms, including aesthetics (i.e., liking or disliking), basic emotions triggered by the acoustic quality of the sound (e.g., feeling frightened or calm) and basic semantics dimensions of product sound types (e.g., air-like, mechanical) [38, 46]. The sonic form is tightly linked to the source model and the sound transmission in sub-assemblies [4], which in turn depends on the acoustics of materials [40]. Eventually psychoacoustic descriptors link sonic forms and source models via appropriate spectro-temporal notations and lexicons [42, 43].

The **object composition level** reflects the influence of structural and material choices in terms of interaction of physical parts and sound features, including for instance the influence of the casing. At this level, the sound and the function of the product are characterised and assessed as a whole, where the semantic distance describes the fitting of the sound type with the product [3, 38]. This stage particularly emphasises the radiation aspects. Spectro-temporal notations, lexicons, and ASA principles serve as representational tools to describe how sounding parts group and integrate in composites [43,45].

Finally, the **scene level** takes in account those environmental factors that contribute to shape the overall auditory experience in context. This level moves forward the focus from the sound source and its radiation towards the reception by the listener, stressing a rather listener-centered viewpoint on PSD. The scene level characterises how sonically interacting with the product fits into the context of use, situations and locations. At this level, the sound quality evaluation focuses on the listeners preference judgements with respect to the pleasantness, as well as the functionality, identity (i.e. coherence), and ecology (i.e. harmonious embedding in the environment) of the product sound [26, 27].

As seen from the disciplinary contribution, the three-level distinction helps predicting how engineering decisions shape sound quality and user experience at different product levels, by providing a magnifying lens on how components and material properties impact the overall sound (acoustics and engineering), on how sounds combine into a composition (psychoacoustics and musicology), and on the user perception in context (psychology).

The PSD framework was tested in several talk-aloud sessions with product design engineering students [1]. User research revealed the need for greater awareness of how design decisions impact sound. Making these implications audible can guide the design process, positioning the framework as a foundation for tools that support audible product conceptualization. For this purpose, we conceived `Les_Sons`, a software tool aimed at operationalising the PSD framework particularly in the context of product design engineering education. We describe `Les_Sons`'s architecture in the following section.

4. Les_Sons

Goal of `Les_Sons` is to provide a structured yet flexible approach to analysing and conceptualizing product sounds, aligning with the PSD framework's holistic perspective. Given its focus on education and early-stage design, one main requirement was to balance creative flexibility with actionable insights. Therefore, `Les_Sons` employs a limited toolset to reduce learning barriers, and avoid overwhelming users with excessive parameters. As shown in Figure 2, `Les_Sons`'s architecture closely follows the "*source* → *transmission* → *radiation* → *listener*" path and structures the sound design process across the three levels, feature, object, and scene. `Les_Sons` has been developed in MAX and is freely available for download at: `https://github.com/Timdeltrap/Les_Sons`. `Les_Sons` comes bundled with a library of calibrated recordings of five different shavers to provide the user with illustrative examples to start with. Users can eventually develop and add their own sound libraries. A video tutorial is available at `https://www.youtube.com/watch?v=Q_ZCD8cKsXk`.

Feature level (source): Sources can be sustained (e.g. a motor sound) or impulsive (e.g. a switch). Users can manipulate psychoacoustic qualities through engineering-related design decisions. For example, given an electric motor sound sample, it becomes intuitive to achieve a wide design space by simply manipulating pitch, playback speed, loudness and envelope, whereas a band-pass filter is used to emphasise the brightness. Impulsive sources are modelled instead using a peak-notch filter, where the loss coefficient of several materials can be applied. The Q factor is calculated as the reciprocal of the loss coefficient property, whereas the filter frequency is the product of the sample fundamental frequency and the acoustic velocity ratio between the velocity of the material of the sound sample and the velocity of the selected material [47]. The perceptible results are changes in pitch and brightness.

Feature to object (transmission): This step takes in account the internal transmission of sound from the source to the components in the body of the product as an effect of the acoustic impedance resulting from the connector(s)' materials, which in turn has an effect on the sound intensity. In `Les_Sons`, the impedance mismatch effect is generalized through a material selector. This tool calculates the sound attenuation due to differences in impedance between the source, a connector, and the casing materials.

Object: Sound elements are arranged into a composite, considering the interactions between the features and the effect of the casing. In this stage, impulsive, iterated and sustained sounds are integrated in a sound event, e.g. switch (on) - operating motor - switch (off). This level also takes in account the spectral influence of the casing on sound event. A cascade filter is used to simulate the filtering effect of the casing, whose parameters are derived by the spectral difference between the full product sound and the isolated motor recordings, providing an estimate of the casing's impact. Additionally, the tool considers the effect of casing similarly to the radiation in a soundboard. A material selector considers the radiation intensity and the acoustic velocity of the selected material, to adjust the overall loudness and brightness respectively [40, 47].

Scene: The scene level integrates user interactions, environmental acoustics, and ASA principles, providing the designer with an impression of how the product may function and sound in a real-world context. User interactions, such as grasping a product, can alter its sound characteristics by adding mass and stiffness, affecting brightness and roughness. Interactions with external objects, like a resonating tabletop, also impact sound. To model this, `Les_Sons` makes use of a cascade filter, similarly to the one used for the casing effect. A combination of high-shelf and low-shelf filters approximates how grasping modifies the product's sound. The resulting product sound can be spatialised to provide the auditory sensation relative to the listener position. Finally, this stage allows to include ambient sounds to enhance realism and account for masking effects, where louder environmental noises can occlude product sounds or cause missed cues. Room acoustics significantly affects how sound travels from an object to the user, influencing reverberation, loudness, and brightness. A convolution reverb with several impulse responses is applied at scene level to blend sound events and ambient sounds in plausible acoustic environments [48].

[1] A detailed report can be found in the Master thesis of the second author.

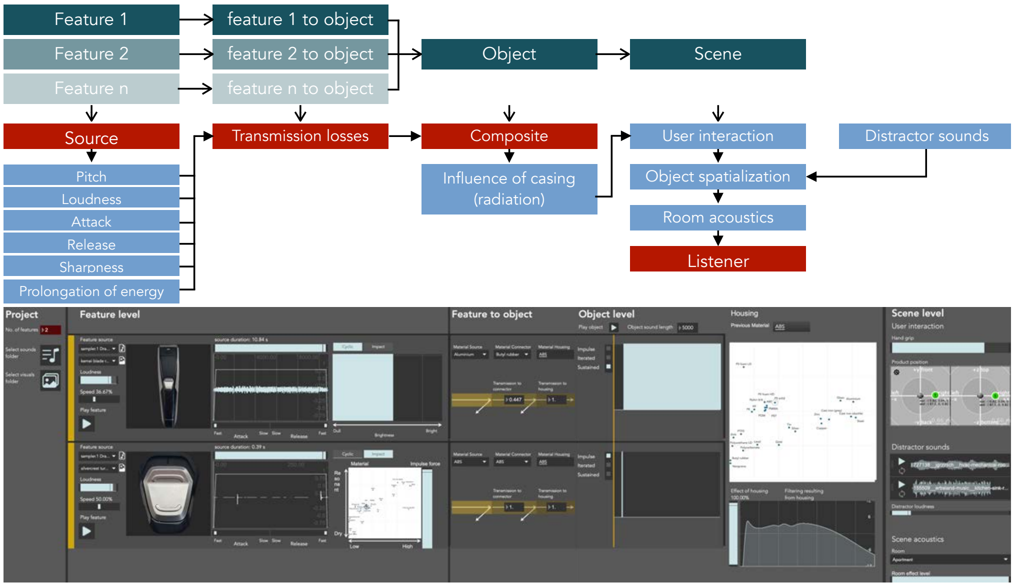

Figure 2. Implementation of the PSD framework into the `Les_Sons` architecture (top) and GUI (bottom), across the "source → transmission → radiation → listener" path and the three levels, feature, object, and scene.

5. PERSPECTIVES AND CONCLUSION

`Les_Sons` is designed to facilitate the integration of sound into the early-stage of product design. The overall rationale is to lower the barrier for students and designers, making it easier to incorporate and address consequential sounds in their design process. This initial accessibility is crucial, since simply raising awareness of sound design possibilities can increase the likelihood that designers will consider sound as a fundamental aspect of their products.

Interdisciplinary contributions based on expert consultations and literature research have been integrated in a comprehensive PSD framework, which served to outline `Les_Sons`'s architecture and user interface. Accordingly, the simplification of acoustic properties is instrumental to enable effective communication between product designers and other experts, while offering a quick way to test design ideas grounded in informed design engineering decisions. This interdisciplinary and context-dependent rationale makes `Les_Sons` different from other existing sound design tools that may focus instead on specific aspects such as audio technology, creative expression, single type of expert users or broader purposes [49, 50]. The organization of `Les_Sons` into feature, object, and scene levels offers structured steps and clarity on how different elements contribute to a product's overall sound character. Hence, the primary goal of the tool is to provide "tangible", audible examples around which building a shared ground for achieving a desired auditory outcome, and not to create fully accurate simulations of product sounds.

Both framework and tool have been informally tested with product design engineering students. Both proved to be useful to navigate design decisions while introducing sound design concepts from the different disciplinary perspectives. The students stressed the difficulty to grasp and use purposefully the technical vocabulary when producing design vision statements, whereas the tool allowed to make up for this shortcoming. However, a more structured investigation of the tool's potential is necessary, for example with respect to its creative flexibility in constrained design engineering tasks, performed individually and in team [51]. Further, given the educational purpose of the tool, a longitudinal study can be devised to assess its effectiveness in practice-based learning. Results are expected to feed the specification of the framework into an analytical tool and the user-centered development of `Les_Sons`.

Modularity and flexibility are key to model complex systems. For example, objects made of features could be reloaded as features in new projects, enabling the exploration of iterative and modular sound design. Similarly, structured sound libraries of targeted products, including sub-assemblies and user-product interactions could be realised according to standards and made available. Finally, the success of any sound design tool depends on their dissemination and effective integration in the workflow of professionals. Parallel to the development of the collaborative and interdisciplinary aspects of `Les_Sons`, we plan to improve the usability of the prototype.

Overall, our goal as researchers and educators is to establish and spread a design culture on sound and listening, where multidisciplinary input, methodology and tools are key to address the complexity of contemporary (sound) design problems.

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