We are IntechOpen,
the world's leading publisher of Open Access books
Built by scientists, for scientists

4,800
Open access books available

122,000
International authors and editors

135M
Downloads

154
Countries delivered to

Our authors are among the

TOP 1%
most cited scientists

12.2%
Contributors from top 500 universities

CLARIVATE ANALYTICS
BOOK CITATION INDEX
INDEXED

WEB OF SCIENCE™

Selection of our books indexed in the Book Citation Index
in Web of Science™ Core Collection (BKCI)

Interested in publishing with us?
Contact book.department@intechopen.com

Knowledge in Sound Design: The Silent Electric Vehicle —A Relevant Case Study

Nicolas Misdariis and Andrea Cera

Additional information is available at the end of the chapter

Abstract

This article builds on a large industry-driven sound design experiment focusing on the underexplored area of sound signature for silent electric vehicles. On the basis of some retrospective observations, and in the conceptual framework of design research, we propose a post-analysis that leads to provide insights on sound design as a discipline, considering its status, the status of its performers (sound designers), and its specific position between science and arts. The main aim of the article is to contribute to increase the general knowledge on sound design and to study it from the perspective of its principles, practices, and procedures.

Keywords: sound design, design, science, creation, industry

1. Introduction

This paper builds on a relevant and emblematic case study, the exterior sound signature for silent electric vehicles, in order to draw knowledge on sound design as a "coherent discipline of study in its own right" [1]. We postulate that sound design is a highly polymorphous and heterogeneous practice which still suffers from clarity of definition as well as lack of theoretical knowledge. We put this issue in the larger and conceptual context of design research [2] which will help to propose a formalized approach of the science of sound design, that is, by analogy with the design field [3]—the study of the principles, practices, and procedures of the discipline.

1.1. The case study: silent electric vehicles

In sound design, a recently resurgent industrial object appears to be an emblematic case study: the electric vehicle (EV). This mechanical machine is a moving and silent object in a noisy environment, a kind of *Unidentified Moving Object*. As such, it leads to global challenges with regards to user experience: co-existence with other noisier vehicles therefore representing a

danger for elements in the vicinity (e.g. pedestrians), ergonomics for drivers as no audio feedback informs them about the vehicle functioning, and drastic modification of the soundscape, especially in urban context. Despite some propositions for non-sonic solutions [4], the more broadly accepted—and even required [5]—view is that the EV's should produce appropriate synthetic sounds. This is an unexpected windfall for sound designers; it corresponds to a complex problem involving sound quality, ergonomics, esthetics, acceptability, and sound branding. However, some important issues in sound design need to be solved in a joint effort among creation, research, and development: (i) relevance, consistency, and suitability: a controlled sound for a given quiet object; (ii) innovation and creativity: a controlled sound for a fairly new object; (iii) ecology and integration: a controlled sound for a potentially controlled environment. The central question still being: what would be the most appropriate sound for a silent vehicle?

1.2. The context: science of sound design

Today, sound design covers a large range of practices and application fields. As seen on Wikipedia page[1], its origin can be traced to sound-image relationship, the field where the profession was born in the early 70s. But, it can also concern manufactured products (*tangible* world), human-computer interfaces (*digital* world), or architectural, environmental, and even commercial spaces (*spatial* world). Therefore, sound design can correspond to a multiplicity of definitions considering, for instance, sonic material as "an element of user experience" and "a specific manner of embodying design solutions" [6], or more simply, the medium to "make an intention audible" [7].

From this perspective, replacing sound design in the broader scope of design invites opportunities to put this subcategory within a broader reflexion on models of design research (research-by-project versus research-by-creation [8]), concepts of science of design (from scientific design to science of design [3]) and, more globally, issues related to the role of design between the sciences and arts/humanities (design as a "third area" or a third culture, as outlined by Archer [1]). Concretely, this attempt to transpose initial design research paradigms aims at proposing a conceptual framework for the science of sound design and at arguing in three main axes, as outlined by Cross [9] (cited in [2]):

- people: status and practices of the sound designers;

- process: innovative methods and tools in sound design;

- products: forms, formats, and status of the designed sounds.

This paper will document these parts with analyses and results of the electric vehicle sound design project that appears to be a relevant observation point for nourishing this investigation.

2. Project description: on what we build on

The EV sound design project lasted almost 3 years (2009–2012) and mainly focused on one model of Renault's electric range ("Zoe"). After a formalized presentation of its main inputs, this section will give the synopsis of its process (for further details please refer to [10, 11]).

---

[1]https://en.wikipedia.org/wiki/Sound_design

First, the project was based on several inputs from different sources of inspiration: scientific from a state-of-the-art in the research field, environmental with regards to the context of use, and singular with regards to a specific corpus of inspiration. For the sake of formalization, these inputs may be associated with three different way of reasoning: *deduction*, *induction*, and *abduction*. Several references provide the definitions of these three concepts (see for instance, the Merriam-Webster dictionary webpage[2]) but the most concise one is seemingly provided by Cross [12], based on the work of the philosopher Peirce [13, 14]: "*deduction* proves that something must be, *induction* shows that something actually is operative, *abduction* suggests that something may be". In accordance with Cross' arguments, this distinction—and especially the statement of the abductive approach—is also a way to highlight a certain specificity of the sound design process.

2.1. Initial inputs: sources of inspiration

In reference with the seminal works of Schafer [15] and Krause [16], we first looked at the acoustic ecology theory that states the existence of a sonic organization in nature, in order to ensure the audibility of every species. Such structure is found in several dimensions (frequency, intensity, and timbre) or time scales (seasons, day/night cycle) and prevents masking or grouping phenomenons. By analogy, considering, the electric vehicle as a new sound species in a new (urban) ecosystem, we addressed the following questions: what is the structure of the urban soundscape? Are there overloaded zones or, inversely, are zones able to host EV sound signature components, allowing them to emerge in ecological conditions? From analysis of various soundscapes, we then *deduced* some basic rules either in terms of frequency zones to favor/avoid or temporal morphology to elicit, as follows: a static and ordered sound should be able to emerge by its regularity from the ever changing soundscape (mainly made by irregularities of traditional engines).

Due to the lack of scientific studies on the topic—at least when the project started—it was difficult to do a traditional state-of-the-art review. Nevertheless, we compiled a list of existing works, and in particular, two experimental studies from Wogalter et al. [17] and Nyeste and Wogalter [18] (see [11], for a more detailed review). In their joint studies, they tried to define sound categories that might provide acceptable auditory cues for quiet vehicles, respectively, in terms of object association and acceptability. From these results, we finally *induced* typical sound categories to be ideally considered: music, whistle, beeps, horn, clicking sounds, exhaust pipe, or engine sounds, and among them, the fact that engine sounds (together with hum and white noise) is the most acceptable and preferred sound type. These conclusions also highlight the difference between functionality and acceptability, especially obvious in the case of the white noise signature.

The lack of scientific references mentioned above led us to explore another source of data: the cinematographic field (science-fiction movie genre dealing with mobility). This unconventional approach was based on the hypothesis that public expectations of the EV's sound—and hence its acceptability—could partially be shaped by the work that sound designers did in this area of motion picture sound production. To a certain extent, this approach can also be seen as *abductive* reasoning, relying on Cross' comment about this concept: "[a hypothesis] of what

---

[2]https://www.merriam-webster.com/words-at-play/deduction-vs-induction-vs-abduction

may be, the act of producing propsals or conjectures" [12]. We focused on jet sounds of the Lola T70 in THX 1138 [19], gentle drones of converted vintage cars in Gattaca [20] and humming sounds that appear in the next generation vehicles in Back to The Future [21]. For these new forms of engines, we observed that sound designers tended to shy away from reality and gravitate toward more synthesized sounds including drone-like, continuous sounds with timbral qualities adapted to the vehicle's shape and performance. Nonetheless, even if they could also be used for other percepts (e.g. fluidity in [22]), examples coming from motion pictures must be considered carefully. Their caricatural and ephemeral nature (conveying clear meaning in few seconds) contrasts greatly with the more ubiquitous and constant sonic presence of a car sounds in everyday life.

2.2. Project chronicle: synopsis

For the project, different modes of interaction with the industrial partner were implemented: a decision committee from different departments (Product, Engineering, and Design), an expert team involving key persons from the project and a technical group mainly in charge of the development phase. On this basis, around 100 successive propositions (see [23] for details) were made using a mixed empirical and methodological approach: on one hand, a trial-and-error paradigm mainly driven by the expert team, and on the other hand, evaluations produced by the technical group or resulting from standard experimental procedures. In fact, at a certain stage of the project, two types of listening tests were conducted in order to: (i) assess the functionality of the propositions, that is, their ability to signify the approach and the presence of the vehicle and (ii) qualify the propositions in terms of hedonic judgment, emotional response, and evocation.

From a global point of view, the synopsis of the process that leads to the industrialized solution can be described with the following steps (see [10, 23] for a more detailed description):

- *sound synthesis*: given the specifications, a four-buffer wavetable synthesis controlled by the vehicle speed was chosen. And because of the strong interactivity component of the project, a prototype of this sound engine was developed in the Max[3] audio signal processing real-time environment.

- *sound rendering*: as traditional stereo setup did not appear to be realistic enough, an immersive device was developed (quadraphony + Spat© [24]) resulting in more flexible and realistic representation of sound trajectories within urban soundscapes. However, as the visuals also seemed to be crucial—above all for sound/object association—we added graphics to the rendering system.

- *prototypes*: during the project, a mixed form of prototyping was tested out. First, we embedded the whole setup (sources, amplifier, and loudspeaker) in a common electrified vehicle. This allowed us to get actual acoustic dimension of that target environment and a direct usage feedback, especially with regards to this sound/object association. Second, we considered the successive prototypes of the target EV itself (Zoe). This allowed us to check

---

[3]https://cycling74.com

the control laws of the sound engine and to do the fine tuning of the sound materials, especially with regards to medium-low frequencies.

- implementation: the final results of our research results which included translation of sound engine prototypes, were embedded in a chip rendered via EEPROM native languages.

3. Post analysis: what we learned

In the previous section, we gave a summary of the EV sound design project focusing on its uniqueness and complexity. In this section, we will formalize what we learned from this experience in order to contribute to a better definition of sound design as a discipline. Our analysis thus follows a structure and research design approach proposed by Cross [9] that focuses on acquiring knowledge on "people" (sound design epistemology), "process" (sound design methods), and "products" (sound design artifacts) (cited in [2]).

3.1. Knowledge on people: status of the sound designer

The project chronicle described above shows a complex process involving human interaction and technical issues for achieving an industrialized solution. In this context, the question of the amount of space left for individual creativity and authorship naturally arises. What is the role of the sound designer in a network of people who not only decide on, but also contribute to the design process?

A first attempt to answer this question could point out the ability of opening multiple versions of a work and creating a labyrinth of links where the network can slowly navigate until a given destination is reached. This *ability to open* does not only mean that the sound designer has to create as many sounds as the collective asks for him. For some serious issues, he also has to put aside his convictions about what a *good sound* should be and to embrace new esthetic parameters, especially when a conventional valid rule could be void in a particular context. On the other hand, he sometimes has to show the ability to work pedagogically by producing sounds able to explain that what is driven by curiosity may not be optimal—in other words, convince co-workers through efficient demonstrations. In both cases, the sound designer has to approach his peers with a stealthy attitude, a self-effacing posture which assures that every voice of the network is considered and that light or heavy issues are treated with the same respect.

An example of simple *curiosity* was the request to create a musical sound-logo as the EV sound signature. It seemed clear that this request was doomed to failure for annoyance, intrusivity, and ecology reasons. Nonetheless, instead of simply rejecting this idea, we created a small number of sound-logos and had them approved by the expert team. But after having implemented them on a prototype, our partners immediately pointed out the awkwardness of the result and proposed an alternative: to use the sound-logo only when the car is at idle and to switch to a continuous sound bearing timbral similarity with the sound-logo when the car is

in motion. This second idea was also rejected, but it allowed us to experiment the possibilities of a clear harmonic content in continuous sounds. Finally, some of these findings migrated to the final result: without this detour, they would not have been included at all. Moreover, the partner was definitely convinced that musical metaphors must be used very carefully.

An example of *serious issue* was the use of discrete, granular, or highly impulsive sounds (clicks). From our perspective, a sound having some roughness, granularity, micro-rhythmicity in the upper spectral registers would have been a good candidate for spatial localization. But every time we proposed these kinds of sounds, we encountered clear resistance from our partners. We understood the nature of the problem when we learned that many professionals from the automotive industry share an instinctive aversion for anything sounding like an audible vibration, regardless of sound type. In other words, this feeling seemed to be embedded in their overall evaluation system: a car has to project an aural image of smoothness.

As these examples show, the presence of a didactic and self-effacing author is essential. In the first case, to ensure a convincing quality of the sound-logos, in the second case, to rebound from the rejection of propositions, and to learn how to use scalable constraints for creating relevant evolutions of original ideas.

3.2. Knowledge on process: status of the sound design

For nearly 15 years, research in sound design has tended to formalize tools, methodologies, and concepts that enrich its disciplinary field (see [25] for a detailed review). Among these developments, a project methodology has been defined by the Ircam's PDS team. This approach, coming from a standard 'V' cycle model, is composed of three steps: 'Analysis' (of the problem), 'Conception' (of solutions), and 'Validation' (of propositions). It also involves a retroactive loop that enables the methodology to iterate the conception step from the validation results in order to propose new solutions better fitting with the initial problem (**Figure 1**). This approach turned out to be relevant from a conceptual point of view and was implemented several times in our academic research [26] and pedagogical actions [27].

Thus, with regards to its unprecedented object (electric vehicle) and its strong industrial connotation (mass production), the present study gives the opportunity to provide analytical insights into this methodology and, in a way, provide frame to assess its level of practicability in realistic contexts.
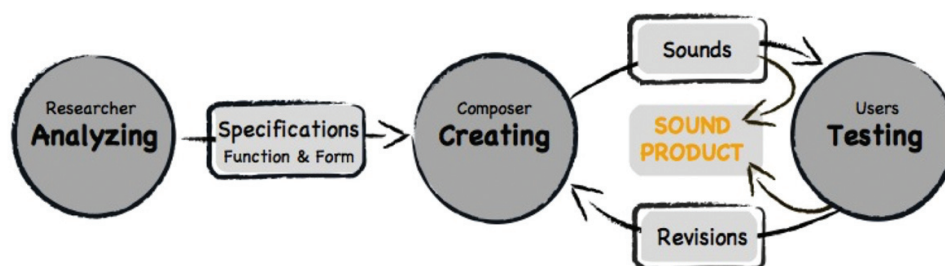
Figure 1. Sound design methodology, from Ircam/PDS team.

As previously mentioned, the 'Analysis' step could not have been achieved in a traditional manner due to the topic specificity. Getting information on what already existed in terms of the EV's sound signature was almost impossible because of the rather pioneering position of the project and forced us to look at other disciplines such as the moving image industry. Then, we did not really induce acoustic specifications from existing EV signal specimens but rather stated hypothesis from the collected marginal data. Nevertheless, this somewhat unusual approach had a positive side-effect opening up creative opportunities due to the lack of historical examples in the field. In fact, trying to expand the present is oftentimes less innovative than starting from the ground up. This is, in substance, what Hug claims—in the field of game sound design—about the "simulation of reality" and the necessity to go beyond this "unnecessary limitation" in order to propose "new directions of innovation" [28].

On another hand, the 'Evaluation' step was likewise altered due to our uniquely defined research setting. In fact, the theoretical process contains a feedback loop that increments a conception-validation module: conception being iterated in the light of validation results compared to the initial specifications. In practice, this step often mutates into a selection step (rather than an iterative evaluation), primarily due to time and cost constraints. Thus, the refinement process, expected from this loop, is more a *funnel-shaped* approach where propositions are successively selected on the basis of both objective measurements—coming from experiments—and subjective assessments—coming from decisions. To summarize, the evaluation step rather appears to be delivering advisory outputs instead of prescribing and guiding additional conception rounds, in practice.

3.3. Knowledge on products: status of the designed sound

Finally, an interesting validation of the designed EV sound signature occurred a few years after the end of the project, in 2014, showing the legitimacy of a complete and controlled sound design approach for such a complex framework.

In 2011, an important three-year European project called eVADER[4] aggregated a mixed consortium of various research labs, automotive industry partners, and suppliers to work on electric vehicle alert system for detection and emergency response. The main goal of this project was to propose and develop a sustainable answer to the issue of the EV's sound, which additionally provided an experimental framework for further legal specifications.

One specific task undertaken during this project was to propose the design of experimental stimuli built on acoustic parameters and rules based on relevant perceptual and cognitive principles including auditory sensitivity, stream segregation, masking or saliency and, more generally, on the auditory warning strategies compiled from the state-of-the-art (see [29]). The experimental part of this work conducted listening tests with regards to two main criteria: *detectability* measured by a response time protocol and *unpleasantness* assessed on a semantic scale (see [30, 31] for further details). The results of these tests finally led to locate in a detectability/unpleasantness space the basic rule-based stimuli (**Figure 2**).
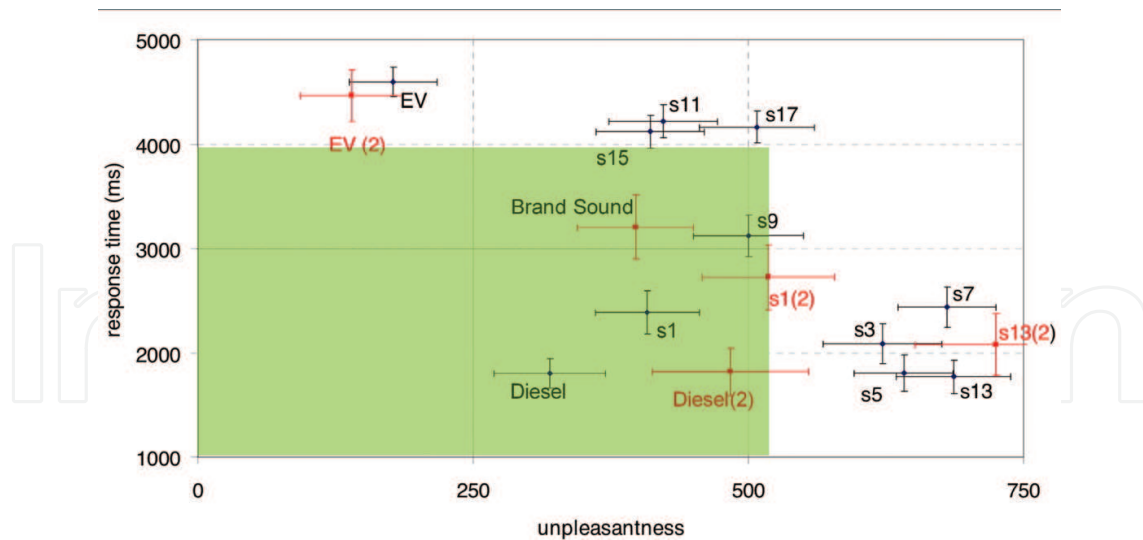
---

[4]http://www.evader-project.eu

Figure 2. Detectability versus unpleasantness obtained after perceptual experiments in eVADER project (taken from [32] —with the agreement of the author). Black points (•) indicate results from a first experiment only involving basic stimuli. Red points (•) indicate results from a second experiment including the "*Brand Sound*". The *green zone* represents the "better compromise between detectability and unpleasantness".

In the final phases of eVADER project [32], the basic stimuli were mixed with the sound signature resulting from the project reported in the present article (called "*Brand Sound*"). As a result, this last test showed that the *brand sound* seemed to be better—or at least equally well —positioned in the data space than most of the inital basic stimuli enabling it to be fully included in the sweet zone corresponding to an optimal combination of both detection and pleasantness (**Figure 2**).

In a summary, these findings point towards to important observations: first, that (well) designed sounds can bear comparison with laboratory stimuli, that is, sounds designed on the basis of formal rules. And second, that the sound design process—that is, the integration of an artistic practice into a scientific/technical approach—can augment the conception of sound signals, moreover compatible with both functional and esthetics needs. This result can also promote the idea of a "*designerly way of thinking*" in sound design, inherited from the concept stated in the broader discipline of design [33]. In fact, this somewhat illustrates one argument from Cross' seminal paper: the specific values of the design culture ("practicality, ingenuity, empathy") especially compared to those of the scientific culture ("objectivity, rationality, neutrality").

4. Conclusions

The project dealing with sound signature of electric vehicle led to collaboration between partners in the automotive industry, a research team, and a composer. It resulted in the implementation of a realistic and controlled sound design solution on an industrial product.

The range and richness of this *research-by-project* approach—as defined by Vial [2]—are mainly due to the uniqueness of the topic: to give a sound to an ideally silent object. It highlights

elements of an applied research in sound design by opening questions about various issues induced by the discipline, such as status of the sound designer and designed sound, or the relevance of sound design methods. Consequently, it also provides opportunities for further thought on sound design by trying to put it in the larger context of design—its founding discipline—and observing it through the prism of the science of sound design.

Author details

Nicolas Misdariis[1]* and Andrea Cera[2]

*Address all correspondence to: misdarii@ircam.fr

1 STMS Ircam-CNRS-UPMC, Paris, France

2 Independent Composer/Sound Designer, Malo, Italy

References

[1] Archer B. Design as a discipline. Design Studies. 1979;**1**(1):17-20

[2] Vial S. Qu'est-ce que la recherche en design ? Introduction aux sciences du design. Sciences du Design. 2015;**1**:22-36

[3] Cross N. Designerly ways of knowing: Design discipline versus design science. Design Issues. 2001;**17**(3):49-55. DOI: 10.1162/074793601750357196

[4] Sandberg U, Goubert L, Mioduszewski P. Are vehicles driven in electric mode so quiet that they need acoustic warning signals. In: Proceedings of the International Congress on Acoustics (ICA 2010); 23-27 August 2010; Sydney (Australia).

[5] QRTV-UNECE/WP29/GRB. Draft recommendations for a Global Technical Regulation regarding audible vehicle alerting systems for quiet road transport vehicles [Internet]. 2012. Available from: https://www.unece.org/fileadmin/DAM/trans/doc/2012/wp29grb/ECE-TRANS-WP29-GRB-55-inf14e.pdf [Accessed: 7 March 2017]

[6] Robare P. Sound in Product Design, Master thesis in Interaction Design [Master thesis]. Pittsburgh, USA: Carnegie Mellon University School of Design; 2009

[7] Susini P, Houix O, Misdariis N. Sound design: An applied, experimental framework to study the perception of everyday sounds. The New Soundtrack Journal. 2014;**4**(2):103-121

[8] Vial S. Court traité du design. 1ère éd ed. Paris: PUF; 2010

[9] Cross N. Forty years of design research. Design Studies. 2007;**28**:1-4. DOI: 10.1016/j. destud.2006.11.004

[10] Misdariis N, Cera A, Levallois E, Locqueteau C. Do electric cars have to make noise? An emblematic opportunity for designing sounds and soundscapes. In: Proceedings of the Congres Français d'Acoustique (CFA); 23-27 April 2012; Nantes, France. 2013

[11] Misdariis N, Cera A. Sound signature of quiet vehicles: State of the art and experience feedbacks. In: Proceedings of the Internoise Conference; 15-18 September 2013; Innsbruck, Austria.

[12] Cross N. Design Thinking: Understanding how Designers Think and Work. 1st ed. Oxford: Berg Publishers; 2011

[13] Peirce CS. Abduction and induction. Philosophical Writings of Peirce. 1955;11

[14] Fann KT. Peirce's Theory of Abduction. Springer Science & Business Media; 2012

[15] Schafer RM. The tuning of the world. 1st ed. Vol. 1977. New-York: A. Knopf Ed. 301 p

[16] Krause BL. The niche hypothesis: A virtual symphony of animal sounds, the origins of musical expression and the health of habitats. The Soundscape Newsletter. 1993;**6**:6-10

[17] Wogalter M, Ornan R, Lim R, Chipley M. On the risk of quiet vehicles to pedestrians and drivers. In: Proceedings of the 45th Annual Meeting of the Human Factors and Ergonomics Society; 8-12 October 2001; Minneapolis, Minnesota, USA.

[18] Nyeste P, Wogalter M. On adding sound to quiet vehicles. In: Proceedings of the 52nd Annual Meeting of the Human Factors and Ergonomics Society; 22-26 September 2008; New-York, USA.

[19] Lucas G. THX 1138 [film]. USA: American Zoetrope, Warner Bros; 1971

[20] Niccol A. Gattaca [film]. USA: Columbia Pictures Corporation; 1997

[21] Zemeckis R. Back to the Future—Part II [Film]. USA: Universal Pictures, Amblin Entertainment, U-Drive Productions; 1989

[22] Alborno P, Cera A, Piana S, Mancini M, Niewiadomski R, Canepa C, Volpe G, Camurri A. Interactive sonification of movement qualities – A case study on fluidity. In: Proceedings of ISon 2016, 5th Interactive Sonification Workshop; 2016.

[23] Misdariis N, Cera A. Recherche-projet en design sonore: le cas emblématique du véhicule électrique. Sciences du Design. 2017;**1**:115-130

[24] Jot JM, Warusfel O. Spat: A spatial processor for musicians and sound engineers. In: Proceedings of the Conference on Acoustics and Musical Research; 19-21 May 1995; Ferrara, Italy.

[25] Rochesso D. Sounding objects in Europe. The New Soundtrack Journal. 2014;**4**(2):157-164

[26] Tardieu J. De l'ambiance à l'information sonore dans un espace public : méthodologie et réalisation appliquées aux gares [thesis]. Paris, France: Université Pierre et Marie Curie; 2006

[27] Houix O, Misdariis N, Susini P, Bevilacqua F, Gutierrez F. Sonically augmented artifacts: Design methodology through participatory workshops. In: International Symposium on Computer Music Modeling and Retrieval. Lecture Notes in Computer Science (LNCS), 2014; pp. 20-40. Springer International Publishing

[28] Hug D. New wine in new skins: Sketching the future of game sound design. In Grimshaw M. Director. Game Sound Technology and Player Interaction: Concepts and Developments. 1st ed. Hershey: IGI Global (New-York, USA; 2010. p. 384-415. DOI: 10.4018/978-1-61692-828-5.

[29] Robart R. Parameter selection and stimuli design proposal (eVADER WP2 Deliverable D2.1). [Internet]. 2012. Available from: http://www.evader-project.tu-darmstadt.de/eVader/delivrables/WP2/eVADER_WP2_D2.1_ 14_6_2012.pdf [Accessed: 7 March 2017]

[30] Robart R. Perceptual test 1: detectability (eVADER WP2 Deliverable D2.2). [Internet]. 2012. Available from: http://www.evader-project.tu-darmstadt.de/eVader/delivrables/WP2/eVADER_WP2_D2.2_6_11_2012.pdf [Accessed: 7 March 2017]

[31] Parizet E. Perceptual test 3: unpleasantness (eVADER, WP2, Deliverable D2.4). [Internet]. 2013. Available from: http://baerbel.szm.maschinenbau.tu-darmstadt.de/evader/delivrables/WP2/eVADER_WP2_D2 4_INSA.pdf [Accessed: 30 March 2016]

[32] Schmitt T. Example of warning sound suitable for Nissan, Renault and PSA (eVADER WP6 Deliverable D6.5). [Internet]. 2014. Available from: http://baerbel.szm.maschinenbau.tu-darmstadt.de/evader/delivrables/WP6/eVADER_WP6_D6_5_23_09_2014.pdf [Accessed: 30 March 2016]

[33] Cross N. Designerly ways of knowing. Design Studies. 1982;**3**(**4**):221-227