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# USING SOUNDSCAPE SIMULATION TO EVALUATE COMPOSITIONS FOR A PUBLIC SPACE SOUND INSTALLATION

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## **Abstract**

While urban sound management often focuses on sound as a nuisance, soundscape research suggests that proactive design approaches involving sound art installations can enhance public space experience. Nevertheless, there is no consensus on a methodology to inform the composition of sound installations through soundscape evaluation, and little research on the effect of composition strategies on soundscape evaluation. The present study is part of a research-creation collaboration around the design of a permanent sound installation in an urban public space in Paris (Niches Acoustiques by Nadine Schütz). We report on a laboratory study involving the evaluation of composition sketches prior to the deployment of the installation on-site. Participants familiar with the public space (N=20) were exposed to Higher-Order Ambisonics recordings (HOA) of the site, to which compositions of the sound installation pertaining to different composition strategies were added using a soundscape simulation tool. We found three principal components relevant for evaluating and comparing sound installation sketches: pleasantness, familiarity and variety. Further, all composition sketches had a significant effect on the soundscape's familiarity and variety, and the effect of the compositions on these two components was stronger when composition strategies involved abstract sounds (sounds which were not clearly identifiable).

## **1. Introduction**

In urban planning, sound is often considered as an environmental burden that should be mitigated. To address the deleterious effect noise exposure has on public health (World Health Organization, 2011), most environmental policies focus on noise control procedures (e.g., Steele et al., 2023; Trudeau et al., 2018). Yet, sound plays a complex role in the way cities are experienced, and reducing sound levels alone does not necessarily lead to an improved quality of life (Kang, 2006; Kang & Schulte-Fortkamp, 2015). Rather than being seen as a nuisance that has to be mitigated, sound can instead be considered as a resource in relation to other urban planning considerations, through the soundscape approach (Kang et al., 2016). Soundscape (defined by the International Standard Organization (ISO) as the “acoustic environment as perceived or experienced and/or

understood by a person or people, in context” (ISO TS 12913-1, 2014) enables more complex representations of sound and allows to envisage both the positive and negative outcomes it can have on the quality of urban environments (Dubois et al., 2006).

In this regard, a growing body of literature has focused on implementing and documenting design plans to preserve or improve existing soundscapes through soundscape interventions (Fiebig & Schulte-Fortkamp, 2023; Moshona et al., 2022). Specifically, there is increasing evidence that the deliberate introduction of new sound elements to existing acoustic environments can benefit urban public spaces. Some of these studies demonstrated that added sounds could positively affect people’s behavior, for instance by fostering social interactions (Adhitya & Scott, 2018; Bild et al., 2016; Franinovic & Visell, 2007; Hellström, 2011), increasing duration of stay and favor activities such as chatting or eating/drinking (Aletta, Lepore, et al., 2016; Lepore et al., 2016), and even by affecting walking pace (Easteal et al., 2014; Lavia et al., 2016) or crowd density and walking patterns (Meng et al., 2018). Other field studies showed that added sounds can improve soundscape evaluation, through global assessments (Cerwén, 2016; De Pessemier et al., 2022) or by increasing evaluations on variables such as *eventfulness* and *excitement* (Jambrošić et al., 2013), *pleasantness* (Steele et al., 2021), *calmness* (Fraisse et al., 2020) or even by reducing the perceived sound level (Steele et al., 2019). In laboratory settings, the effects of adding natural sounds such as birds or streams on soundscape evaluation have been extensively investigated, studies showing for instance that such sounds could be evaluated as preferable (Jeon et al., 2010), reduce perceived loudness and increase *pleasantness* (Hong et al., 2020), increase soundscape quality (Ong et al., 2019) and *eventfulness* (Lugten et al., 2018). Otherwise, a recent study by Oberman and colleagues evaluated the impact of three sound art interventions on soundscape measurement and showed different impacts for each intervention on perceived *pleasantness*, *calmness*, *excitement* and *appropriateness* (Oberman et al., 2020).

A broad range of methods have been used to evaluate the perceptual and affective attributes of soundscape interventions. Among them, soundscape scales have been widely spread and refined in recent years. The most broadly used protocol is the Swedish Soundscape Quality Protocol (SSQP) (Axelsson et al., 2012), featured as the method A in

the ISO/TS 12913-2:2018 (ISO TS 12913-2, 2018). It comprises a set of scales based on principal components underlying soundscape evaluation, *pleasantness* and *eventfulness*, established by Axelsson et al. (Aletta, Kang, et al., 2016). The method proposed in the standard also includes a scale relative to *appropriateness* (ISO TS 12913-2, 2018). Otherwise, Payne and Guastavino proposed the Perceived Restorativeness Soundscape Scale (PRSS) to assess the restorative potential of sound environments in terms of *being-away*, *extent-coherence*, *compatibility* and *fascination* (Payne, 2013), while Welch et al. developed a set of seventeen semantic differentials to measure the affective properties and the qualities of soundscape, through a study involving creative writing (Welch et al., 2019). The use of both the SSQP and the PRSS led to statistically significant results when evaluating or comparing sound art interventions (e.g., Oberman et al., 2020; Steele et al., 2019, 2021). However, the study led by Oberman and colleagues showed that the SSQP alone could provide ambiguous responses regarding the impact of sound interventions on the *eventfulness* component and could be optimized (Oberman et al., 2020). If soundscape scales provide a subjective evaluation of soundscape among a set of predetermined criteria, more in-depth information about the various associations, emotions and feelings associated with the perception of sound environments in the presence of sound art can be obtained through qualitative methods such as ethnographical research (e.g., Lacey et al., 2019) or open-ended interviews (e.g., Bild et al., 2016). Ultimately, quantitative and qualitative data collection methods can be integrated together through methodological triangulation (ISO TS 12913-2, 2018; ISO TS 12913-3, 2019).

To collect soundscape data, laboratory and in-situ methods coexist, each having their own advantages and limitations (Aletta, Kang, et al., 2016). Laboratory experiments involve the simulation or reproduction of soundscapes and provide more control on the sound environment. Among the existing soundscape reproduction or simulation techniques, Ambisonics (see Moreau, 2006) has been increasingly used in the recent years and is usually considered ecologically valid (Davies et al., 2014; Guastavino et al., 2005; Tarlao et al., 2022). Generally, studies involving the simulation of soundscape interventions artificially integrate added sounds to a pre-recorded sound environment (Hong et al., 2020; Jeon et al., 2010; Lugten et al., 2018; Ong et al., 2019), and similar technologies

have been proposed as soundscape simulation tools to help professionals of the built environment anticipate the impact of urban design decisions on soundscape (Tarlao, Steele, et al., 2023; Yanaky et al., 2023), or as a tool for soundscape composition (Sarwono et al., 2022). Still, the only laboratory study evaluating the impact of sound art interventions on soundscape recorded them *in situ* and compared them with recording positions in which they were not audible through a virtual soundwalk approach (Oberman et al., 2020).

Overall, studies on the impact of added sounds on soundscape mostly focus on the introduction of either natural sounds or generic music to existing sound environments, and the few studies on the impact of sound art installations on soundscape (Fraissee et al., 2020; Hellstrom et al., 2014; Hellström, 2011; Jambrošić et al., 2013; Lacey et al., 2019; Oberman et al., 2020; Steele et al., 2019) were systematically carried out *a posteriori* i.e. once the sound installations were already deployed. If such studies revealed the potential for sound art to improve urban soundscapes, the methods used provide little room for sound artists to implement perceptual feedback within the compositional process. Yet, people's reception and perception has been an essential consideration for sound artists from the very emergence of sound installation art (see Guastavino et al., 2021 for a review). Similar to the way soundscape researchers emphasize context (Herranz-Pascual et al., 2010; ISO TS 12913-1, 2014), the design of public space sound installations is usually thought of in relation to a multitude of site-specific aspects, including perception (e.g. Tittel, 2009; Vogel, 2013). Hence, evaluating sound installations' impact on soundscape before deployment through soundscape simulation would benefit sound artists by informing their composition at the early stages of creation process.

The relationship between a sound installation and its existing environment can take many forms, depending on the artistic intention and on site-specific considerations. Through this variety, common composition strategies and issues have been theorized in the literature (see Guastavino et al., 2021). Livingston proposed a taxonomic division between strategies for adding sounds in public spaces: *integrated / site-specific / background* (added sounds that subtly blend in with the existing sound environment so that they can stay unnoticeable) versus *oppositional / borrowed / foreground* (added sounds that are clearly noticeable, see Livingston, 2016). Similarly, Botteldooren et al.

proposed three design imperative for soundscape design: *backgrounded* (the introduced sounds stay unnoticed), *supportive* (the added sounds enhance the existing experience) and *focused* (the added sounds become a point of interest, see Kang & Schulte-Fortkamp, 2015). Many creators also investigated the notion of *non-energetic masking* (also called *informational masking*) where added sounds purposely distract listeners' attentions from other sources (Anderson, 2008; Hellstrom et al., 2014; Lacey et al., 2019; Rudi, 2005; Torehammar & Hellström, 2012), and the phenomena has also been studied in the soundscape literature (e.g., Hong et al., 2020; Licitra et al., 2010; Oberman et al., 2020). The existence of shared composition strategies does not imply that there is an obvious way to operationalize them, and approaches can be as diverse as there are sound artists (for instance, see how two approaches to generate *oppositional* sounds may differ in [Anderson, 2008] and [Torehammar & Hellström, 2012]). Nevertheless, recent works showed that different artistic propositions could lead to different perceptual impacts on soundscape (Oberman et al., 2020; Steele et al., 2019), and further work is needed to better understand the link between sound art composition strategies and their impact on soundscape.

The present study was conducted in the context of a research-creation collaboration between the authors in this paper around the permanent sound art installation *Niches Acoustiques*. Created by sound artist Nadine Schütz (the other authors are researchers in the fields of soundscape, music technology and sound design), this laureate project of *Budget Participatif de la Ville de Paris* will lead to the planned, permanent deployment of the sound installation on the forecourt of the new Judicial Court of Paris, France. The overall intention of *Niches Acoustiques* is to create an appeasing, beneficial, and varied auditory foreground which reduces the perceived dominance of annoying and monotonous noises while opening up the courthouse's forecourt to an urban narrative which connects it to the urban neighborhood. The title of the installation, *Niches Acoustiques*, is borrowed from the bioacoustics Niche Hypothesis, according to which the co-existence of diverse species, particularly in densely populated areas, is fostered by the spectral and temporal differentiation of their vocalization patterns (Farina, 2013; Krause, 1993). The 'Acoustic Niches' sound installation project interprets, activates and transposes this principle in a (psychoacoustically informed) spectrotemporal means to

modify soundscape perception by adding distinct sonic ambiances on the forecourt, in a non-intrusive way, with low volumes of the added sounds, and through a ‘complementary composition’ approach. In this context, the notion of auditory foreground refers to added sounds which are acoustically, semantically, and/or spatially distinct from the pre-existing sound environment. The collaboration (including the present study) aims at informing the composition of *Niches Acoustiques* and evaluating the impact of the sound art intervention through soundscape evaluations at different stages of the composition process. We report here on a laboratory study involving the simulation of compositional sketches of the sound installation (in the form of short excerpts) in presence of a reproduction of the forecourt’s existing sound environment using a soundscape simulation tool developed and validated in a previous study (Fraissee, Schütz, et al., 2022). To compare the impact of the different sound installation sketches on soundscape evaluation, participants familiar with the forecourt of the Judicial Court were invited to evaluate each excerpt with a set of semantic differential scales and were then asked to respond to a semi-structured interview. The present study addresses the following research questions:

RQ1: How do public space users evaluate everyday city soundscape modified by the presence of sound art?

RQ2: How do public space users’ soundscape evaluations vary for different sound art composition strategies?

Considering that the composition of a sound installation is highly sensitive to site-specific considerations as well as to its artistic intention, answering the second research question required to provide a classification of composition strategies that can be generalized to other sound art interventions. To do so, the methodology applied by the sound artist during the creation of the sound installation sketches was structured so that they could be gathered into broader composition strategies, and we report here on the impact of these composition strategies on soundscape rather than on an excerpt-to-excerpt analysis. To allow for their comparison, these strategies were subsequently positioned within an *Abstract* (sounds that can’t be ascribed to any real or imagined provenance) / *Referential* (recorded sounds that suggest or at least do not hide the source to which they



belong) dichotomy, as proposed by Leigh Landy (*About the ElectroAcoustic Resource Site Project*, 2023; Landy, 2007). Our intuition, prior to the experiment, was that Abstract sounds would be perceived as being more *oppositional* because of their unexpected nature while Referential sounds would be perceived as being more *integrated* because they could more easily blend in with the existing sound environment.

To wrap up, the goal of this study is not to impose compositional principles to sound artists or to replace the artistic intention—each sound installation having its own artistic statement and design goals—, but rather to systematically evaluate the impact of sound art composition strategies that are broad enough to be transferred to other sound art interventions. The present study also aims at investigating the productivity of the proposed research-creation methodology, specifically assessing the relevance of the soundscape simulation tool for evaluating sound art interventions. Meanwhile, the proposed methodology is intended to help inform the design of Nadine Schütz’s *Niches Acoustiques* sound installation by anticipating its impact on soundscape evaluation.

## 2. Methods

### 2.1. Soundscape simulation tool

The present study uses a soundscape simulation tool previously developed and validated through listening tests. Information about the tool development and validation is presented in (Fraise, Schütz, et al., 2022). The simulation consists of the reproduction of Higher-Order Ambisonics (HOA) field recordings of the **sound environment** on site, along with the auralization of **added sounds**, yielding composition sketches of the sound installation using a 3D acoustic model of the site (simulating early reflections and late reverberation) converted to HOA streams. The resulting soundscape is presented over a loudspeaker array in a listening room for **soundscape evaluation** using semantic differential scales (Figure 1). All components of the simulation, from HOA encoding and auralization to playback and graphical user interface are implemented in Cycling ’74 Max (*What Is Max?*, 2023).

### 2.1.1. Measurement campaign

The data on the sound environment of the Judicial Court of Paris' forecourt was collected during a measurement campaign in spring 2021, detailed in (Fraisse, Nicolas, et al., 2022; Fraisse, Schütz, et al., 2022). We conducted punctual HOA recordings and sound level measurements throughout the public space across five sessions covering different activity levels (weekday morning, afternoon and evening; weekend morning and evening). During each session, 5-minute recordings were made across measurement points gridding the square (Figure 2). At each position, we measured equivalent sound pressure and third-octave levels with a B&K 2250 sound level meter together with 4<sup>th</sup>-order ambisonics recordings with an mh Acoustics em32 Eigenmike (Brüel & Kjær, 2023; *Mhacoustics*, 2023; Moreau, 2006). All measurements were oriented towards the direction opposite to the Judicial Court, at a height of 1.3m.

### 2.1.2. Baseline sound environment

The listening test focuses on the comparison of various sound installation sketches. To ensure smooth transitions between these conditions, we designed a continuous baseline sound environment by concatenating 4<sup>th</sup> order HOA separate excerpts from the measurement campaign (not to be confused with the Referential excerpts presented in Section 2.2). The excerpts were selected to ensure that they were representative of the public space's average level of activity, spatially close enough to each other (see the included positions in Figure 2), and did not contain salient sounds so that participants focus on the added sounds during the listening tests (see Fraisse, Schütz, et al., 2022 for more detail). Excerpts, selected during joint listening sessions with two of the authors, ranged from 30 seconds to around 2 minutes. A total of 38 excerpts were crossfaded in fully random orders using Python's reathon library to generate Reaper scripts (Reathon, 2023). In other words, a Baseline using the same 38 excerpts was generated with a different, randomized order for each participant so that they would listen to a different superposition of the background recordings and the added sounds, and to ensure that the observed effects would be independent of the temporal evolution of the background sound environment. A 3-second crossfade between excerpts was applied to provide short

yet smooth and unnoticeable transitions. In total, the Baseline lasted around 45 minutes, and was looped in the experiment. A 40-minutes sound level measurement of the calibrated Baseline (without the 4 dB padding mentioned Section 2.1.5) was conducted in the listening room using a B&K 2250. We found a  $L_{Aeq,40min}$  of 61.9 dBA and a  $L_{A10}-L_{A90}$  of roughly 6 dBA, confirming that the chosen excerpts were representative of an average level of activity in the parvis while remaining sufficiently stable (Fraisse, Nicolas, et al., 2022).

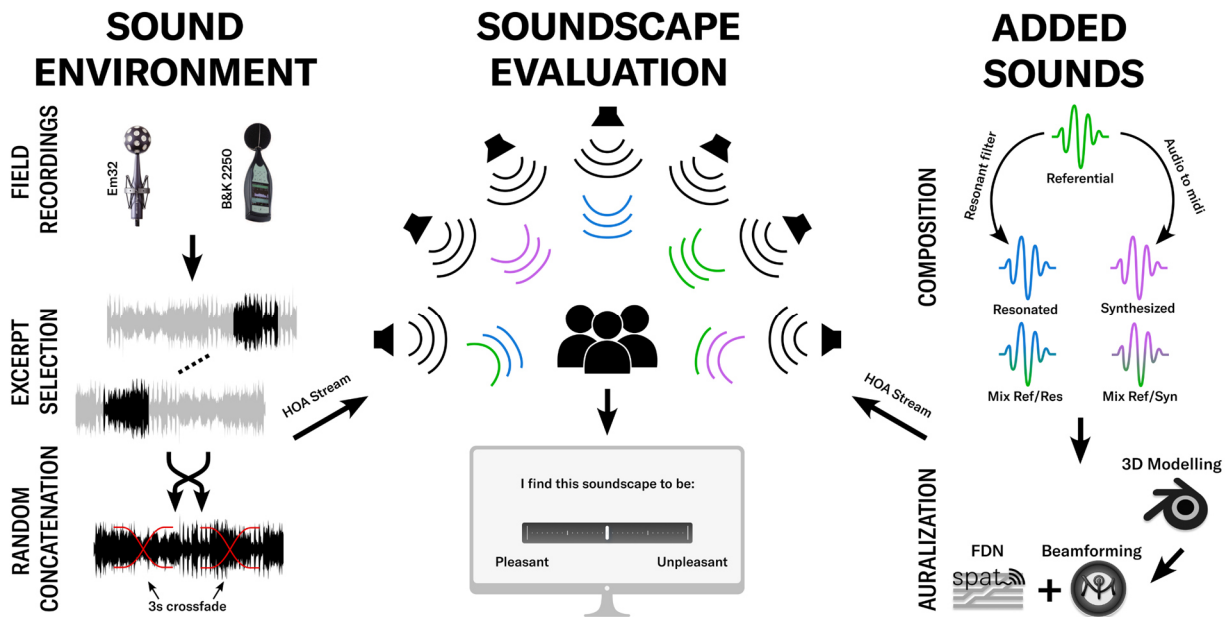


Figure 1. Flowchart of the soundscape simulation tool. The **sound environment** (left) is simulated from HOA excerpts. Monophonic composition sketches of the sound installation in the form of composed **added sounds** are auralized with a 3D modelling of the space (right). HOA streams are fed into a listening room for **soundscape evaluation**.

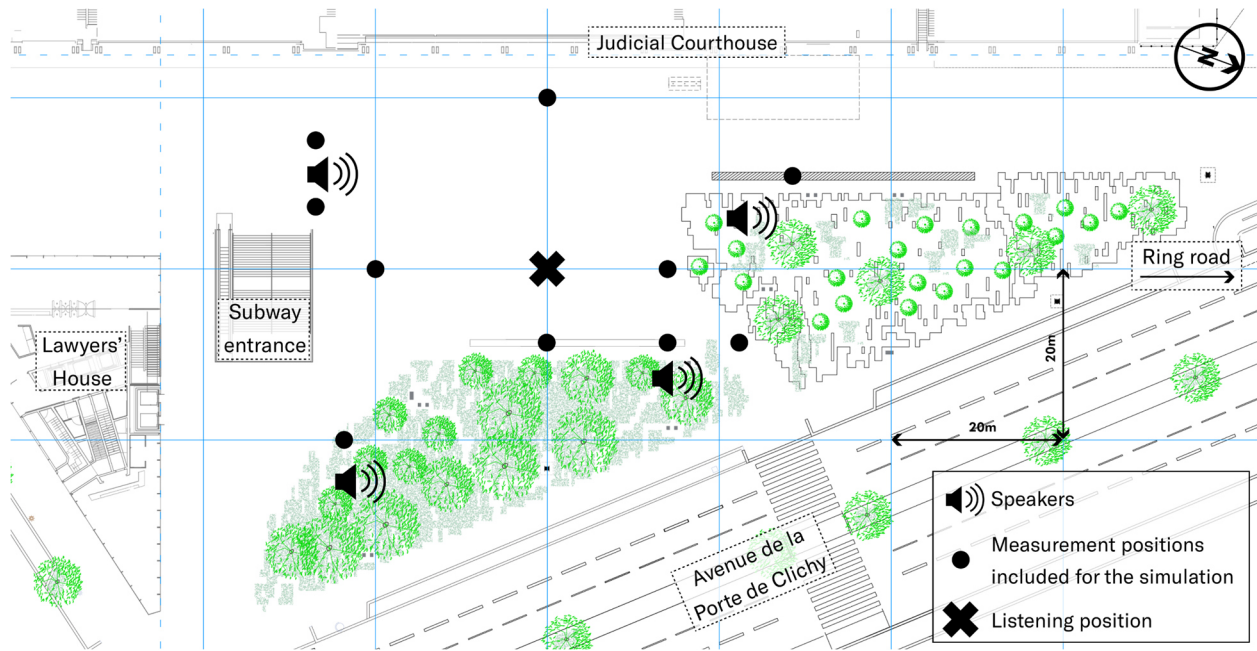


Figure 2. Map of the forecourt in front of the Judicial Court of Paris. The Niche Acoustiques' installation speakers will be mounted on four lighting poles across the forecourt. Punctual HOA recordings and sound level measurements were made across 18 measurement points, of which 11 were included for the soundscape simulation. The simulated listening position is at the center of the space.

### 2.1.3. Added sounds auralization

The auralization method is only summarized here, a complete description of the procedure is available in (Fraisse, Schütz, et al., 2022). Initially in the form of monophonic excerpts, the added sounds were spatialized using IRCAM's EVERTims framework (Poirier-Quinot et al., 2017) integrated in Max's spat~ library (Spat | Ircam Forum, 2023). The 3D model of the forecourt from which the auralization is based on includes the main surfaces of the forecourt, the position of the sound sources (the future sound installation's speakers), as well as of the listener (see Figure 2). Upon reception of the 3D model, EVERTims computes a list of image sources that correspond to the early reflections of the space, while the late reverberation is simulated with a Feedback Delay Network (Poirier-Quinot et al., 2017; Schroeder, 1962). The output of the auralization unit is ultimately encoded into 4th order HOA streams with spat~ (Moreau, 2006). As physical

parameters such as the reverberation time of the court were missing, we fined-tuned the auralization through analytical listening with sound experts, and validated it in a preliminary listening test, as reported in (Fraisie, Schütz, et al., 2022). Finally, the mastering of the auralized added sounds was operated in two steps. First, all excerpts' loudness was normalized with `pyloudnorm`, a Python implementation of ITU-R BS.1770-4 standard for loudness measurement (Steinmetz & Reiss, 2021). Then, the gain was adjusted by ear in presence of the simulated sound environment for each of the excerpts by the second author through a dedicated Max patch, to mimic the protocol that will be carried out during the sound installation's deployment.

#### 2.1.4. Ambisonics reproduction

The experiment was conducted at IRCAM's studio 4, an acoustically-treated listening room, over a hemispherical dome of 24 Amadeus PMX 4 speakers (Amadeus | PMX 4, 2023) placed on four height levels beginning at ear level (Figure 3). Encoding and decoding parameters were chosen during joint listening sessions including three of the authors, who compared *in situ* listening with the reproduced sound environment. The Eigenmike 32 signals were encoded into a 4<sup>th</sup>-order HOA stream with `spat~` using Tikhonov regularization (Moreau, 2006). At the output of the system, the auralized added sounds and the sound environment—both in the form of 4<sup>th</sup>-order HOA streams—were summed and decoded with `spat~` using energy preserving method with *max-r<sub>E</sub>* weighting function (Zotter et al., 2012).

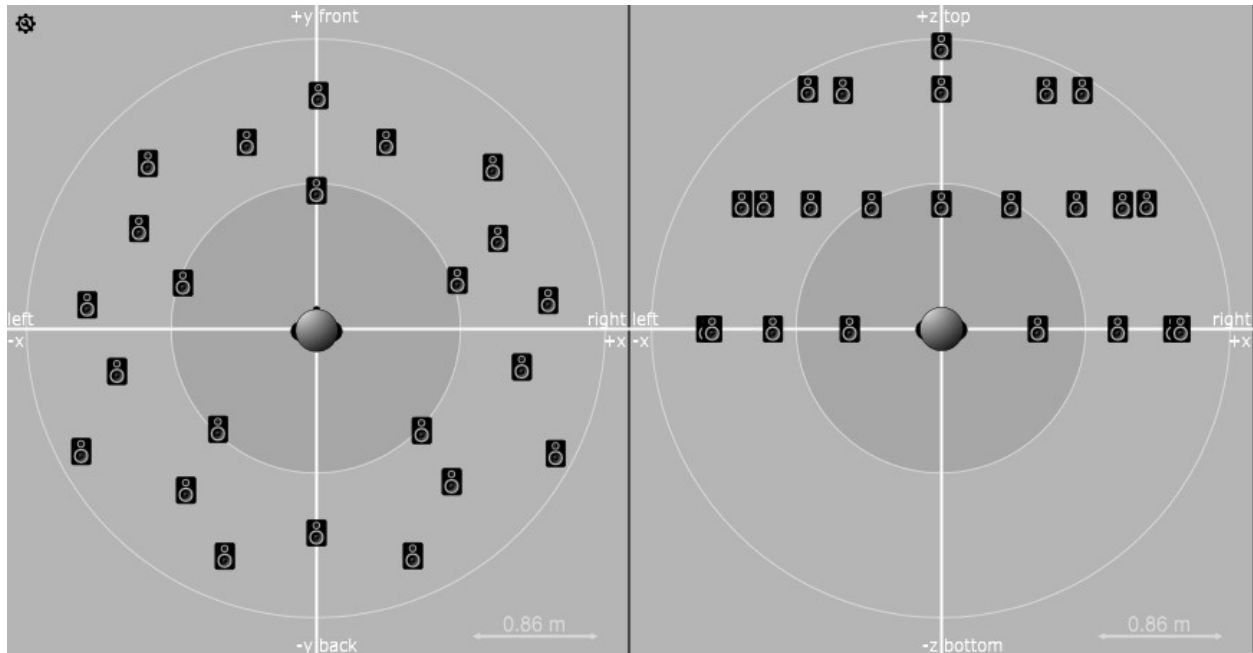


Figure 3. Diagram of the loudspeaker array with simplified head for orientation from spat~. Left: from the top; right: from behind.

#### 2.1.5. Sound level calibration of the baseline sound environment

The 5-minute A-weighted equivalent levels ( $L_{Aeq}$ ) values captured during the measurement campaign were compared with similar measurements in the listening room's sweet spot at a height of 1.3 m to calibrate the reproduction levels of the baseline sound environment (Brüel & Kjær, 2023). However, we decided to reduce the reproduced soundscape sound level by 4 dB with respect to *in situ* measurements, as the level of the reproduced soundscape was perceived by the authors as higher than *in situ*. Observed in several laboratory studies (e.g., Cadena et al., 2017; Oberman et al., 2020; Sudarsono et al., 2016), this phenomenon could be related to the relatively high sound levels *in situ*, with 5-minute  $L_{Aeq}$  typically ranging from 60 to 70 dBA (Fraisse, Nicolas, et al., 2022). A 4-dB reduction was unanimously perceived as the best match to replicate the perceived loudness *in situ*.

## 2.2. Added sounds composition<sup>1</sup>

The artistic design goals of the sound installation have been presented in the introduction. This section focuses on the composition strategies for the sketches (i.e. the sound installation's sound materials) evaluated in the present study. The primary sound content of the new auditory foreground introduced by the *Niches Acoustiques* sound art installation is inspired by the site of the installation and by the artistic intention to reinforce its urban relatedness; they combine sonic fragments recorded in the forecourts' urban surroundings, which are edited into new imaginary sonic landscape scenes and supplemented by their own 'musical shadows'. The present study focuses on these two types of sound materials, the original *Referential* sonic landscape scenes and their more *Abstract* musical shadows, derived from the original scenes through two different editing procedures corresponding to two degrees of (preprocessed) abstraction: medium-abstraction and total-abstraction.

The Referential scenes were based on field recordings (not to be confused with the baseline, they are unrelated to the measurement campaign described Section 2.1.1) in various streets and public spaces surrounding the Forecourt, using stereo and directional mono microphones. These recordings were first cut into semantic and sonic units, differentiating between more continuous textures and more punctual events. Given the intended brevity of the composition excerpts, only a few of these units were used, selected for their semantic and sonic variety. The resulting Referential scenes were composed following a semantic and associative approach, and grouped into two different sound types: narrative scenes, combining various sound events with widely varying dynamics (instruments-paths, birds-games and voices), and natural tones, which present simpler, more continuous sound textures (articulate waters, and wind-rustling foliage).

The medium-abstraction applies resonance effects on the referential compositions using pitch-based harmonic resonators tuned to pure octave chords or triad chords with some deviating notes, band-pass filters inverse to the Baseline's average spectral energy profile, and spectral freezing. The total-abstraction results from a melodic audio-to-midi-based

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<sup>1</sup> Audio excerpts are available in the online version.

synthesis using alternatively Ableton Live 11 Suite's (What's New in Live 11, 2024) built-in Audio-to-MIDI conversion function and Max's IM-I analyzer plugin (mapped to a E minor triad), directing the performance of a virtual instrument (a virtual bell piano included in Ableton Live 11's core library).

In addition to this evaluation of three distinct positions within the artistically imagined referential-to-abstract continuum, the study also explored another composition technique, combining the basic referential compositions with their different abstractions in hybrid, steady mixes—simple combination of excerpts using signal addition—or fluctuating mixes—mixes that are constantly fluctuating between the referential scene and its abstract counterpart using an envelope automation in the form of a triangle wave with a period of roughly 40 seconds (0.025 Hz). These mixes correspond to the ultimate artistic intention to alternate between these different types of sounds in the final installation, based on environmental data captured on-site by acoustic and meteorological sensors.

Altogether, 26 installation excerpts (composed added sounds) resulting from the above-described composition strategies, each 95 seconds long, were presented to the participants. Five concrete, Referential excerpts were chosen based on samples from the original field recordings, and were either event-based (narrative scenes) or texture-based (natural tones).

To reach a reasonable experiment duration, we had to make a selection from all the possible compositional variations derived from these five Referential compositions. Four selected excerpts made with four different resonant and spectral manipulations applied on the Referential excerpts presented a medium-abstraction compositional position (Resonated excerpts, see Figure 4). The four manipulations alternate between and combine in different ways band-pass filters, pitch-based harmonic resonators and spectral freezing. In comparison, total-abstraction was presented by two Synthesized excerpts, created with two different synthesizers (virtual instruments) based on a pitch-based audio-to-midi conversion of the concrete excerpts (see Figure 4).

The remaining mixed excerpts are combinations of Referential and mid-abstraction (Resonated) excerpts and of Referential and total-abstraction (Synthesized) excerpts,



always maintaining the interplay of original referential sound and the abstraction derived from it. These compositions explore the two above-described mixing techniques, fluctuating mixes and steady mixes (see Figure 4). The final selection of 26 excerpts comprises five Referential excerpts, four Resonated excerpts, two Synthesized excerpts, five mixes fluctuating between Referential and Resonated excerpts (Ref/Res Fluctuating), five mixes fluctuating between Referential and Synthesized excerpts (Ref/Syn Fluctuating), and five steady mixes superimposing Referential and Synthesized excerpts (Ref/Syn Steady). To characterize the acoustic levels of the excerpts, a series of 1min30s-sound level measurements was conducted in the listening room using a B&K 2238, in presence of the added sounds alone. Mean LAeq1min30s and LAFmax are reported in Table 1 and show that levels have similar ranges across composition strategies, except for Referential excerpts which have lower sound levels.

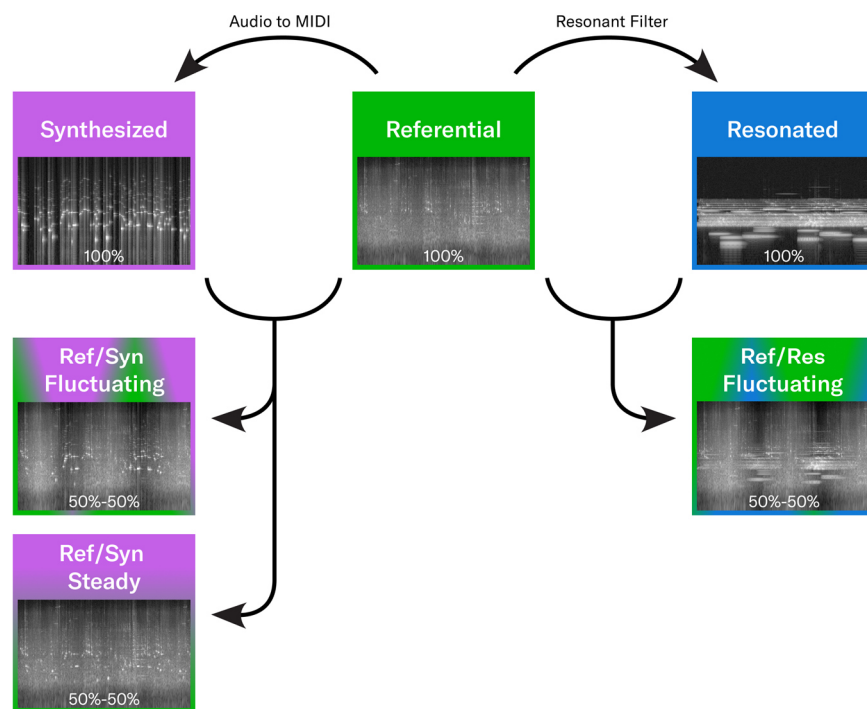


Figure 4. Diagram of the composition process operated on Referential excerpts, illustrated with six of the sound installation sketches' spectrograms obtained from the monophonic excerpts (before auralization) using python. Magenta corresponds to Synthesized excerpts, green to Referential excerpts, and blue to Resonated excerpts.

	Referential	Resonated	Synthesized	Ref/Res Fluctuating	Ref/Syn Fluctuating	Ref/Syn Steady
$L_{Aeq1m30s}$	54.1 (3.4)	61.8 (2.1)	59.7 (0.6)	58.8 (3.7)	58.8 (2.5)	59.4 (2.1)
$L_{AFmax}$	66.2 (8.2)	74.9 (5.5)	74.1 (2.9)	74.1 (6.1)	76.0 (4.2)	72.5 (5.0)

*Table 1. Sound levels in the listening room, in presence of the added sounds only, collapsed over composition strategies: mean and standard deviation. The measurement period is 1m30s.*

## 2.3. Soundscape evaluation

### 2.3.1. Participants

Twenty participants were recruited for the evaluation, including 9 Judicial Court workers (age =  $44.1 \pm 10.2$ ) and 11 residents (age =  $44.8 \pm 13.5$ ). All of them were familiar with the studied space to ensure ecological validity and self-reported normal hearing. Residents were recruited by distributing flyers and displaying posters in the neighborhood, while workers were recruited through an email sent from the borough to the Judicial Court's mail list. All participants reported using the public space several times a month, while a majority used it almost daily (see Table 2). They received a 20€ compensation for their participation.

	Several times a month	Several times a week	Almost daily
Residents	4	3	4
Workers	0	2	7
Total	4	5	11

*Table 2. Participants' profile and attendance of the forecourt. No participants reported using the space less than once a month.*

### 2.3.2. Conditions

Participants were continuously exposed to the baseline sound environment described Section 2.1.2 and evaluated it in the presence of added sounds pertaining to the different composition paradigms described Section 2.2. There was a total of 28 unique conditions,

including the 26 compositions described in Section 2.2 as well as 2 conditions with no added sounds, including only the background sound environment at different, random moments in the experiment (Baseline). In total, the experiment featured 6 composition strategies (Referential, Resonated, Synthesized, Ref/Res Fluctuating, Ref/Syn Fluctuating and Ref/Syn Steady) for a total of 34 excerpts, including 6 duplicates (1×Referential, 2×Ref/Syn Fluctuating, 2×Ref/Res Fluctuating, 1×Ref/Syn Steady) to measure test-retest reliability.

### 2.3.3. Procedure

Participants were seated at the sweet spot of the speaker dome with a rotating chair fixed to the floor (Figure 5 – left) and evaluated the excerpts through a Max interface displayed on a 21.5 inches monitor using an external mouse (Figure 5 – right). In presence of the background sound environment, participants were first presented with a photograph and an aerial view of the studied site (Figure 6) for 40 seconds, while being asked to try to recall the space in their memory. They were then asked to listen to the 34 excerpts and evaluate their soundscape through a set of continuous scales (Figure 5 – right and Table 3). All excerpts and all scales were presented in a fully randomized order. Within each trial, each excerpt was presented to the participants for 15 seconds before the questionnaire appeared to ensure they listened and acclimated to the soundscape. They could then answer the questionnaire for 75 s before the end of the excerpts that lasted a total of 95 s. However, they were able to skip to the next excerpt with a dedicated button (Figure 5 – right, top right corner) that appeared after 50 seconds (including the initial 15 seconds), provided that they had filled all scales. A 10-second transition was set to smoothly switch between excerpts either when participants used the skip button or at the end of the excerpt. Depending on the participant, trials lasted between 60 s and 100 s for a total testing time between roughly 40 minutes and 1 hour.

The participant ran a practice trial with the experimenter before starting the experiment, to help them familiarize themselves with the task. An optional break was automatically triggered at the halfway point of the experiment (after the 17<sup>th</sup> excerpt).

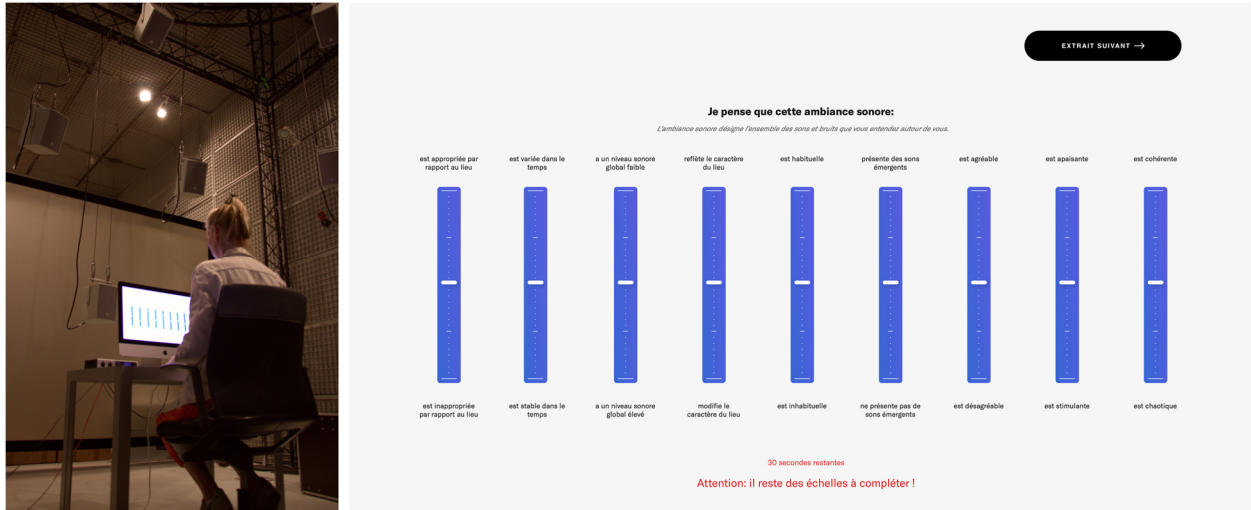


Figure 5. Left: photograph of the listening room illustrating the evaluation procedure (picture: Valérian Fraisse); right: Max interface provided to the participants.



Figure 6. Left: aerial view (picture: Google [2021]); right: photograph of the space (picture: Valérian Fraisse). Both photographs were presented simultaneously, at the beginning of the listening tests.

At the end of the experiment, the experimenter conducted a semi-structured interview (DeJonckheere & Vaughn, 2019) with the participants through an interview guide of six questions (Table 4). Participants were recorded with a Zoom H4N pro (*H4n Pro Four-Track Audio Recorder*, 2023). Interviews lasted from roughly 10 to 30 minutes. The entire study lasted around 90 minutes in total.

#### 2.3.4. Questionnaire

Participants were asked to evaluate soundscapes across nine continuous semantic differential scales (Table 3). The elaboration of the questionnaire is the result of shared reflection between the sound artist (the second author) and the scientific team (all the other authors) to provide an evaluation tool both suitable for comparing soundscape interventions and relevant with regard to the design goals of the installation, while ensuring questionnaire brevity. In short, we needed to investigate not only how the added sounds could affect the perceived affective quality of the Forecourt's soundscape (ISO TS 12913-3, 2019, p. 3), but also their emotional impact (Welch et al., 2019), as well as how they could evoke novelty (i.e. less familiar soundscapes) and variation in an urban soundscape dominated by traffic, as it is one of the goals of the future sound installation. The questionnaire does not comprise scales related to the soundscape's *eventfulness*, as it is believed to be more related to human sounds, especially its French translation (Axelsson et al., 2010; Tarlao, Aumond, et al., 2023). Rather, we used questions relative to *variation* and *emergence*, in an attempt to capture the attributes of *eventfulness* that are not related to notions of human activities or liveliness, but instead to more analytical dimensions related to the perceived number of sources and their dynamics (Tarlao, Aumond, et al., 2023). The order of the scales was fully randomized between participants.

Variable	Positive end (translation EN)	Negative end (translation EN)	Positive end (original FR)	Negative end (original FR)
	<i>To me, this soundscape :</i>		<i>Je pense que cette ambiance sonore :</i>	
Pleasant	<i>is pleasant</i>	<i>is unpleasant</i>	<i>est agréable</i>	<i>est désagréable</i>
Soothing	<i>is soothing</i>	<i>is arousing</i>	<i>est apaisante</i>	<i>est stimulante</i>
Sound Level	<i>has globally a low sound level</i>	<i>has globally a high sound level</i>	<i>a un niveau sonore global faible</i>	<i>a un niveau sonore global élevé</i>
Character	<i>reflects the character of the space</i>	<i>changes the character of the space</i>	<i>reflète le caractère du lieu</i>	<i>modifie le caractère du lieu</i>
Appropriate	<i>is appropriate to the space</i>	<i>is inappropriate to the space</i>	<i>est appropriée par rapport au lieu</i>	<i>est inappropriée par rapport au lieu</i>
Familiar	<i>is familiar</i>	<i>is unfamiliar</i>	<i>est habituelle</i>	<i>est inhabituelle</i>
Coherent	<i>is coherent</i>	<i>is chaotic</i>	<i>est cohérente</i>	<i>est chaotique</i>
Varied	<i>is varied over time</i>	<i>is stable over time</i>	<i>est variée dans le temps</i>	<i>est stable dans le temps</i>
Emergence	<i>has emerging sounds</i>	<i>does not have emerging sounds</i>	<i>présente des sons émergents</i>	<i>ne présente pas de sons émergents</i>

*Table 3. Questions for each of the 34 laboratory conditions. Original French and English translation. Scales are continuous from 1 (Negative end) to 100 (Positive end). Participants were provided with a definition of soundscape which can be translated into: “The soundscape is the collection of all the sounds and noises that you hear around you.”*

### 2.3.5. Follow-up interviews

The experiment was followed by semi-structured interviews based on six questions (Table 4). The goal of the interviews was to obtain interpretative guidance on the results obtained with the scales, but also to identify participants’ opinions on the added sounds and their relationship with the forecourt of the Judicial Court. Quotes reported in the results were translated from French by the first author.

Question (translation EN)	Question (original FR)
<i>Generally speaking, how do you feel about these listening sessions?</i>	<i>De manière générale, quel est votre ressenti par rapport à ces écoutes ?</i>
<i>Were there any remarkable, out of the ordinary soundscapes during your listening? If so, which ones? Would they be desirable in the forecourt of the Judicial Court?</i>	<i>Y'a-t-il eu des environnements sonores remarquables durant vos écoutes, qui sortent de l'ordinaire ? Si oui, lesquels ? Seraient-ils désirables sur le parvis du Tribunal Judiciaire ?</i>
<i>What would you like to hear in this space that was missing in this experiment?</i>	<i>Qu'aimeriez-vous entendre dans cet espace, et qui manquait dans cette expérience ?</i>
<i>What brings you to the forecourt of the Judicial Court?</i>	<i>Qu'est-ce qui vous amène sur le parvis du Tribunal Judiciaire ?</i>
<i>What do you think about the forecourt of the Judicial Court?</i>	<i>Que pensez-vous du parvis du Tribunal Judiciaire ?</i>
<i>Do you have any comments, anything to add?</i>	<i>Avez-vous des remarques, quelque chose à ajouter ?</i>

Table 4. Interview guide for the follow-up semi-structured interviews.

## 2.4. Data analysis

Statistical analyses were computed in R 4.0.3 with RStudio 2022.12.0+353 for Windows, with a statistical significance level of 0.05. Prior to the analysis, ratings were collapsed for each participant across duplicate conditions with the mean value, including the two conditions with no added sounds. The data was highly non-normal, whether univariate or multivariate. For this reason and because of the relatively small sample size, we decided to conduct semi-parametric and non-parametric analyses when relevant. To investigate the two research questions, we conducted two types of statistical analysis.

To validate the questionnaire instrument and to determine components underlying soundscape judgements in presence of sound art while increasing interpretability of the results [RQ1], we ran a Principal Components Analysis (PCA) on the 9 items with oblique rotation (*oblimin*) using the psych package version 2.0.9 (Revelle, 2022). Prior to the PCA, the Kaiser-Meyer-Olkin verified the sampling adequacy  $KMO = .76$  ('middling', according to Kaiser, 1974), and all KMO values for individual items were above .6, which is above the acceptable limit of .5. Subsequent analyses were made from the resulting components of the PCA, shown in italics.

To investigate the effect of the added sounds on soundscape evaluation and to compare composition strategies [RQ2], we conducted two semi-parametric repeated measures MANOVAs with the components from the PCA as dependent variables and the composition strategy as independent variables using the multRM function from the MANOVA.RM package, version 0.5.3 (Friedrich et al., 2018). The first MANOVA was conducted with the composition strategy excluding mixes (Baseline; Referential; Resonated; Synthesized) as a within-subject factor to compare the influence of added sounds along the referential/abstract paradigm. The second MANOVA was conducted on all composition strategies (Referential; Synthesized; Ref/Res Fluctuating; Ref/Syn Fluctuating; Ref/Syn Steady) in the within-subject factor to evaluate the influence of the combination of abstract and referential sounds on soundscape evaluation. Since the covariance matrix was singular in some cases and because of the small sample size, we used the Modified ANOVA-type statistic (MATS) and wild bootstrap resampling method for p-values, with 10,000 iterations (Friedrich et al., 2017). For both tests, follow-up semi-parametric repeated measures ANOVA were conducted with the same independent variables using the ANOVA-type statistics (ATS) and wild bootstrap resampling also with 10,000 iterations from the RM function in the MANOVA.RM package. Finally, we ran *post-hoc* Wilcoxon signed rank exact tests to compare each condition, with Holm p-value correction using the R package stats (*Stats Package - RDocumentation*, 2023). For each Wilcoxon test, we report on p-values in addition to the *r* effect size estimated using the package rstatix (Rosenthal, 1991; *Wilcoxon Effect Size — Wilcox\_effsize*, n.d.). For the MANOVAs and subsequent analyses, data was collapsed for each participant with the mean value corresponding to each condition.

For interpretative guidance on the quantitative results, follow-up interviews were transcribed and analyzed using NVivo 1.7.1 for Windows (NVivo, 2024), using Open coding to identify emerging themes (Allsop et al., 2022).



### 3. Results

#### 3.1. Baseline evaluation and methodological validation

The 20 participants rated the Baseline soundscape as mildly pleasant (Mdn = 57.0) and neither soothing nor arousing (Mdn = 50.2). The reproduction of the forecourt's soundscape was perceived as representative of the forecourt of the Judicial Court as participants rated the Baseline soundscape as appropriate with the forecourt (Mdn = 71.5), familiar (Mdn = 84.7) and reflecting the character of the space (Mdn = 77.2). Six participants stated in the follow-up interviews that the experiment was realistic and representative of the forecourt (e.g. *"I closed my eyes and I really had the sensation that I was on the forecourt"*), while only one participant questioned its realism (*"I don't know whether car noises were artificial or not"*). The systematic exclusion of salient or disruptive sounds from the Baseline's concatenated excerpts is reflected in participants' ratings, as they rated it as being stable over time (Mdn = 35.7) and with an average emergence (Mdn = 49.5). Conversely and despite the Baseline's perceived Sound Level being mildly low (Mdn = 61.2), six participants described the listening experiment as globally loud, while one participant stated that it was quieter than in situ. Table 5 shows the full list of values for the Baseline condition.

Pleasant	Soothing	Sound Level	Character	Appropriate
57.0(14)	50.2(19)	61.2(22)	77.2(31)	71.5(14)
Familiar	Coherent	Varied	Emergence	
84.7(25)	78.7(29)	35.7(28)	49.5(30)	

*Table 5. Scales for the baseline condition: median and inter-quartile range*

To assess the test-retest reliability of the participants' ratings, the values obtained for the 6 excerpts that appeared twice were correlated using Pearson's coefficient of correlation. The test-retest reliability was found to be poor. The mean correlation across the 9 items was 0.5 with a range of 0.41-0.60. Results were similar when comparing the two baseline conditions with a mean correlation of 0.56 across all scales, with the exception of the scales Varied ( $r = 0.21$ ) and Coherent ( $r = 0.84$ ). However, Cronbach's  $\alpha$  values for internal consistency suggested that the scales were reliable to some extent (Table 6).

### 3.2. Principal components analysis

An initial analysis was done to obtain eigenvalues for each component in the data. Based on the scree plot and in accordance with Kaiser’s criterion (eigenvalues > 1.0), three components were retained that explained 74% of the variance.

The items that cluster on the same components suggest that component 1 (*Pleasant*) represents the soundscape’s appreciation (29%), component 2 (*Familiar*) is associated with the character, familiarity and appropriateness of the soundscape (28%), while component 3 (*Varied*) is linked to the variety and emergence of the soundscape (16%). See Table 6 for component loadings. Both the soundscape’s appreciation and character had high reliabilities (Cronbach’s  $\alpha = .84$  and  $.83$ , respectively). However, the soundscape’s variety had relatively low reliability (Cronbach’s  $\alpha = .60$ ). These values suggest that the participants’ ratings were reliable despite the poor test-retest scores. All items mostly load on only one component with a complexity ranging from 1.0 to 1.3, except for Coherent, which loaded both on soundscape’s appreciation and character with a complexity of 2.

Item	<i>Pleasant</i>	<i>Familiar</i>	<i>Varied</i>
Pleasant	<b>.90</b>	.09	.03
Soothing	<b>.90</b>	-.08	-.02
Sound Level	<b>.76</b>	-.06	-.16
Character	-.02	<b>.89</b>	-.03
Appropriate	.22	<b>.84</b>	.11
Familiar	-.28	<b>.83</b>	-.12
Coherent	<b>.50</b>	<b>.56</b>	-.05
Varied	-.03	.04	<b>.84</b>
Emergence	-.04	-.05	<b>.83</b>
Eigenvalue	2.63	2.56	1.48
Variance explained (%)	29	28	16
Cronbach’s $\alpha$	.84	.83	.60

Table 6. Oblimin rotated component loadings of the PCA (N=540; RMSR = .07; fit = .96). Loadings above .3 appear in bold in greyed cells.

The three components emerging from the data show similarities with some of the components first identified by Axelsson et al. (Axelsson et al., 2010) and later confirmed by Tarlao et al. (Tarlao et al., 2021). See the discussion for further comparisons. These components will be used in the next sections to compare the composition sketches.

### 3.3. Abstract and referential composition strategies

In this section, we compare the three composition strategies (Referential, Resonated and Synthesized excerpts) with the Baseline condition. The overall repeated-measure MANOVA on these four conditions shows a significant effect of composition strategy on the three components (MATS  $\approx$  98.16,  $p < 0.001$ ). Follow-up repeated measures ANOVAs show a significant effect of composition strategy on all components (*Pleasant*: ATS  $\approx$  4.5,  $p \approx 0.009$ ; *Familiar*: ATS  $\approx$  29.5,  $p < 0.001$ ; *Varied*: ATS  $\approx$  16.7,  $p < 0.001$ ).

Descriptive statistics are shown in Figure 7 and in Table 9, while results of the *post hoc* tests are shown in Table 7. Together, they reveal that:

- For the *Pleasant* component, the Synthesized excerpts were significantly less appreciated than the Referential condition. However, there were no significant differences between the other conditions, despite moderate effect sizes suggesting that the Synthesized excerpts may be less appreciated than the Referential excerpts ( $r = .49$ ) and the Resonated excerpts ( $r = .40$ ).
- For the *Familiar* component, all conditions were significantly different from one another except for the Resonated and Synthesized excerpts. Specifically, all excerpts were perceived as being strongly less *familiar* than the Baseline. In addition, both Resonated and Synthesized excerpts were perceived as being less *familiar* than Referential excerpts.
- For the *Varied* component, the Baseline condition was perceived as being less *varied* than any other condition. Despite being significant, effect sizes suggest that Resonated ( $r = .49$ ) and Synthesized excerpts ( $r = .43$ ) were perceived as being more *varied* than Referential excerpts.

	<i>Pleasant</i>		<i>Familiar</i>		<i>Varied</i>	
	r	p	r	p	r	p
Baseline – Referential	.14	.996	.86	<.001	.88	<.001
Baseline – Resonated	.16	.996	.88	<.001	.85	<.001
Baseline – Synthesized	.49	.133	.87	<.001	.81	<.001
Referential – Resonated	.23	.935	.60	.011	.49	.080
Referential – Synthesized	.61	.029	.63	.011	.43	.106
Resonated – Synthesized	.40	.303	.18	.430	.22	.330

Table 7. Statistical significance in the change of the soundscape components with the composition strategy excluding mixes: Holm post-hoc Wilcoxon signed-rank exact tests and *r* effect size estimate.

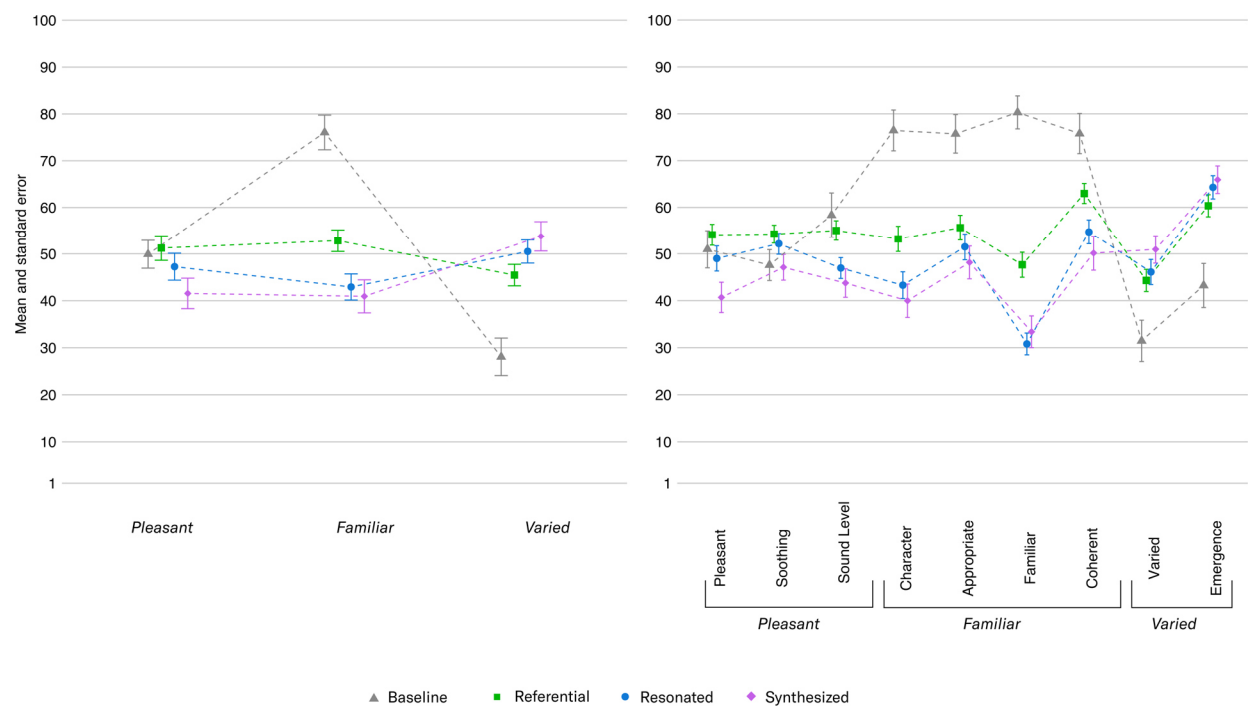


Figure 7. Mean ratings and standard error for the PCA components (left) and for all scales (right), collapsed over all participants, by condition excluding mixes ( $N=260$ ). Post-hoc tests reveal that Synthesized excerpts were significantly less pleasant than Referential excerpts and all three composition strategies were significantly less familiar and more varied than the Baseline. In addition, Resonated and Synthesized excerpts were significantly less familiar than Referential excerpts.

If we did not observe the impact of composition strategies on soundscape appreciation except for Synthesized excerpts which were less appreciated than Referential excerpts, results suggest that all composition strategies substantially affected soundscape *familiarity* and *variety*. Specifically, the Resonated and Synthesized excerpts more strongly affected the *familiarity* compared to the Referential excerpts, while effect sizes suggest that they also more strongly affected the perceived *variety*.

### 3.4. Hybrid composition strategies

In this section, we only report on results relative to hybrid composition strategies (i.e. mixes between referential and abstract compositions) as the Referential, Resonated and Synthesized excerpts have been discussed before. The overall repeated-measure MANOVA on the conditions excluding the Baseline (Concrete; Referential; Synthesized; Ref/Res Fluctuating; Ref/Syn Fluctuating; Ref/Syn Steady) shows a significant effect of composition strategy on the three components (MATS  $\approx 41.65$ ,  $p < 0.001$ ). Follow-up repeated measures ANOVAs show a significant effect of excerpt on all components (*Pleasant*: ATS  $\approx 3.8$ ,  $p = 0.007$ ; *Familiar*: ATS  $\approx 5.4$ ,  $p = 0.005$ ; *Varied*: ATS  $\approx 6.6$ ,  $p = 0.002$ ).

Descriptive statistics are shown in Figure 8 and Table 9, while results of the post hoc tests are shown in Table 8. Together, they reveal that:

- For the *Pleasant* component, there were no significant differences between conditions, despite moderate effect sizes suggesting that Ref/Syn Fluctuating and Ref/Syn Steady excerpts were less *pleasant* than Referential excerpts ( $r = .61$  and  $r = .49$ , resp.) and that Ref/Res Fluctuating and Ref/Syn Steady excerpts were more *pleasant* than Synthesized excerpts ( $r = .45$  and  $r = .47$ , resp.).
- For the *Familiar* component, Ref/Syn Fluctuating and Ref/Syn Steady excerpts were significantly less *familiar* than Referential excerpts. Despite being significant, moderate effect sizes suggest that the other mix strategy (Ref/Res Fluctuating) was also being perceived as less *familiar* than Referential excerpts ( $r = .48$ ). Effect sizes also suggest that the Ref/Res Fluctuating excerpts were

perceived as more *familiar* than Resonated excerpts ( $r=.44$ ), that the Ref/Syn Steady and Ref/Res Fluctuating excerpts were more *familiar* than the Synthesized excerpts ( $r = .47$  and  $r = .43$ , resp.), and finally that Ref/Res Fluctuating excerpts were more *familiar* than the Ref/Syn Fluctuating excerpts ( $r=.48$ ).

- For the *Varied* component, all three mix strategies (Ref/Res Fluctuating, Ref/Syn Fluctuating and Ref/Syn Steady) were significantly more *varied* than Referential excerpts. Despite being significant, moderate effect sizes suggest that all three mix strategies were also perceived as being more *varied* than Resonated excerpts ( $r=.54$ ,  $r=.55$  and  $r=.42$ , resp.).

	<i>Pleasant</i>		<i>Familiar</i>		<i>Varied</i>	
	r	p	r	p	r	p
Referential – Resonated	.23	1.00	.60	.067	.49	.266
Referential – Synthesized	.61	.073	.63	<b>.047</b>	.43	.479
Referential – Ref/Res F.	.34	1.00	.48	.360	.83	<b>&lt;.001</b>
Referential – Ref/Syn F.	.61	.073	.72	<b>.009</b>	.74	<b>.005</b>
Referential – Ref/Syn S.	.49	.346	.68	<b>.020</b>	.63	<b>.048</b>
Resonated – Synthesized	.40	.759	.18	1.00	.22	1.00
Resonated – Ref/Res F.	.07	1.00	.44	.387	.54	.150
Resonated – Ref/Syn F.	.28	1.00	.18	1.00	.55	.145
Resonated – Ref/Syn S.	.05	1.00	.28	1.00	.42	.510
Synthesized – Ref/Res F.	.45	.485	.43	.408	.23	1.00
Synthesized – Ref/Syn F.	.31	1.00	.33	.857	.31	1.00
Synthesized – Ref/Syn S.	.47	.435	.47	.360	.11	1.00
Ref/Res F. – Ref/Syn F.	.39	.759	.48	.360	.09	1.00
Ref/Res F. – Ref/Syn S.	.14	1.00	.27	1.00	.32	1.00
Ref/Syn F. – Ref/Syn S.	.23	1.00	.19	1.00	.29	1.00

Table 8. Statistical significance in change of the soundscape components with the composition strategy excluding the baseline: Holm post-hoc Wilcoxon signed rank exact tests and effect size estimate.

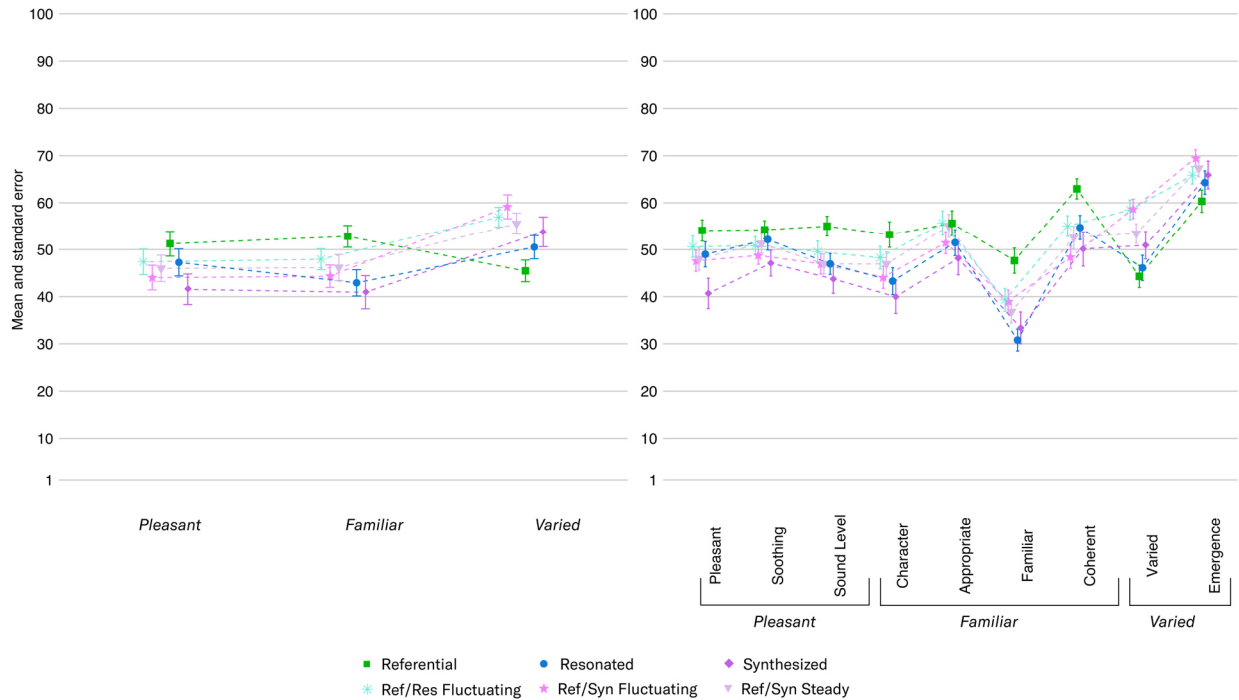


Figure 8. Mean ratings and standard error for the PCA components (left) and for all scales (right), collapsed over all participants, by condition excluding the baseline (N=440). Post-hoc tests reveal that Referential excerpts were significantly more familiar than Ref/Syn Steady and Ref/Syn Fluctuating excerpts and less varied than all three mix strategies (Ref/Res Fluctuating, Ref/Syn Fluctuating and Ref/Syn Steady).

	<i>Pleasant</i>		<i>Familiar</i>		<i>Varied</i>	
	Median	IQR	Median	IQR	Median	IQR
Baseline	54.4	8.31	76.1	32.2	31.8	26.5
Referential	51.4	13.5	52.8	10.5	45.1	11.3
Resonated	50.0	13.8	41.7	10.3	49.3	16.4
Synthesized	43.7	16.9	42.4	17.8	56.0	16.0
Ref/Res Fluctuating	48.0	7.98	50.1	8.52	56.9	10.4
Ref/Syn Fluctuating	46.4	12.5	45.2	10.8	56.8	16.0
Ref/Syn Steady	45.4	12.6	46.5	13.6	53.7	11.7

Table 9. PCA Components for all conditions (previously collapsed across composition strategies, N=140).

Results indicate that soundscapes with mixed excerpts might be more *pleasant* than those with Synthesized excerpts and less *pleasant* than those with Referential excerpts, although we could not identify significant differences. Mixed excerpts were also less *familiar* and more *varied* than those with Referential excerpts, while effect sizes suggest that they tended to be more *familiar* than those with Synthesized and Resonated excerpts, as well as more *varied* than those with Resonated excerpts. Otherwise, we did not detect significant differences between the ratings of the three hybrid composition strategies across all components, although effect sizes suggest that Ref/Res Fluctuating excerpts might have been perceived as more *familiar* than Ref/Syn Fluctuating excerpts. Overall, results suggest that soundscapes with hybrid compositions fall in between purely referential and purely abstract compositions in terms of *pleasantness* and *variety*, while they were perceived as being more *varied* than Referential excerpts, and potentially than Resonated excerpts.

### 3.5. Synthesis and qualitative exploration

During the interviews, all twenty participants referred to at least one referential sound such as birdsong (N=17), wind/rain (N=9), kids playing (N=14) or water (N=13) while sixteen participants mentioned abstract sounds through diverse associations (e.g. “*some kind of music*”, “*electroacoustic music*”, “*electronic sounds*”, “*metallic noise*”, “*crystal sounds*”). These mentions provide interpretative guidance on the quantitative results. Since it is unclear as to which specific condition the participants actually referred to, the qualitative exploration that follows is only associated with Referential and Abstract composition strategies when relevant. It should be noted that Referential sounds are more often mentioned than Abstract sounds, likely because it is easier to describe identifiable sounds (in terms of sound source or action producing sound) than unidentifiable sounds as the latter cannot be ascribed to a specific cause (Lemaitre et al., 2010).



### 3.5.1. Opinion and appreciation of composition sketches

Interviews reveal that all participants had a positive opinion of at least one of the referential sounds, most often referring to nature sounds such as birdsong (N=13, e.g. “*I liked the sound of the birds. It struck me, yeah, it struck me.*”), or wind/rain (N=12, e.g. “*the rustling leaves, I enjoyed them*”), while nine participants also had a negative opinion of at least one of the referential sounds, most often water (N=6, e.g. “*the sounds from the water, they were a little unpleasant*”). Opinion on Abstract sounds was given by only thirteen participants and was positive for four participants (e.g. “*there were tones that pleased the ear*”), mixed for five participants (e.g. “*for the electronic sounds[...], they were aggressive. [...] Some other were more balanced, I could consider them.*”), and negative for four participants (“*the metallic noise would be unpleasant*”). Overall, Referential composition strategies were more often described positively than negatively during the interviews, and participants particularly enjoyed natural sounds such as birdsongs and wind or rain. However, the difference in *Pleasant* ratings between Referential excerpts and the Baseline did not reach statistical significance. Conversely, Abstract strategies were described equally often positively and negatively, but among them, Synthesized excerpts were rated significantly lower than the Baseline and than most of the other conditions on the *Pleasant* component. These results illustrate that interviews can provide more nuanced evaluations than scales alone. They also suggest that people agree more easily on what they do not like than on what they like when describing sound art interventions.

### 3.5.2. Familiarity and appropriateness

To the question: “*Were there any remarkable, out of the ordinary soundscapes during your listening?*”, all participants mentioned at least one of the Referential sounds and half of them mentioned at least one of the Abstract sounds. Fourteen participants stated that at least one of the added sounds was unfamiliar or surprising. Among them, five participants reflected on the potential of added sounds to transport them elsewhere (e.g. “*there was one that was completely different, that took us completely elsewhere*”) or to remind them of nearby parks (e.g. “*the fact that we could hear [birds], it reminded me of*

*the park next door*”), highlighting the restorative potential of added sounds. Conversely, nine participants were concerned about the added sounds’ appropriateness. Among those that explained why, some felt that the purpose of site was incompatible with sound art (e.g. *“I had some trouble imagining how you could hear music next to a judicial court. I don’t know, maybe it’s a misconception because it would be very pleasant.”*; *“I don’t find [the added sounds] appropriate for the place, which is majestic, it’s the judicial court. [...] It represents Justice.”*), while others thought it might be disruptive (e.g. *“they may not be adapted for someone who wants to read or sit next to it”*).

The data from the interviews was consistent with participants’ ratings, where both Referential and Abstract composition strategies had a strong impact on soundscape *familiarity* when compared to the Baseline. The interviews also confirm the close relationship between *familiarity* and *appropriateness* found in the PCA and illustrate the challenge of proposing a sound installation that gives people the impression of being away while still being appropriate for the site. As a participant pointed out: *“On the one hand, it is totally inappropriate because unfortunately it is uncommon to hear sound art in public spaces [...]. On the other hand, it would be appropriate because it would allow us to disconnect from the soundscapes we are used to hearing”*.

### 3.5.3. Emergence, variety and masking

The propensity of added sounds to emerge from the soundscape or to bring variety was not directly discussed in the interviews, except for a few rare mentions (e.g. a participant when talking about the added sounds: *“it’s pretty varied”*). However, eight participants stated that the added sounds had a masking effect on the existing sound environment, referring to either Referential sounds (e.g. *“there was some kind of a rain sound that soothed everything and was very enveloping”*), Abstract sounds (e.g. *“sometimes the electroacoustic music masks the traffic noise”*), mixed excerpts (e.g. *“The water sounds with the birds and the gong-like sound [...]; the mix between them covers the annoying background noise, we almost don’t hear it anymore”*) or as a whole (e.g. *“I was hearing the sounds and I thought: well, that’s good, it compensates well, it envelops well the sounds from the cars”*).

These direct references provide evidence that sound art has the potential to provide a form of non-energetic masking from unwanted noise in the existing environment, as is often discussed by sound artists (e.g., Anderson, 2008; Rudi, 2005; Tittel, 2009; Vogel, 2013) and was recently observed in a few studies (Cerwén, 2016; Oberman et al., 2020; Van Renterghem et al., 2020). Though non-energetic masking was not directly measured, it is likely related to the rise in soundscape *variety* and *emergence* caused by both Referential and Abstract composition strategies during the listening test.

#### 3.5.4. Hybrid composition strategies

Participants did not refer to the mixes between Abstract and Referential excerpts, except for the one above-quoted mention. Rather, their description of the soundscapes was either general or focused on a specific sound. It suggests that the combination of composition strategies did not raise specific concerns or strong opinions, explaining why the evaluation of hybrid composition strategies fell in between that of Abstract and Referential compositions regarding *pleasantness* and *familiarity*.

## 4. Discussion

### 4.1. Components underlying soundscape evaluation in presence of sound art

In answer to the first research question [RQ1], our results suggest that the evaluation of everyday city soundscape modified by the presence of sound art can be described in terms of three components: *Pleasant*, *Familiar* and *Varied*. The first component, *Pleasant*, was found to explain 29% of the variance in soundscape measures and is analogous to the *pleasantness* component used in the model presented in the ISO 12913-2:2018, proposed by Axelsson et al. and validated by Tarlao et al. (Axelsson et al., 2010; ISO TS 12913-3, 2019; Tarlao et al., 2021). This component allowed to measure the impact of sound art interventions on soundscape appreciation. If *appropriateness* was loaded on a factor associated with *pleasantness* in Tarlao and colleagues' model (Tarlao et al., 2021), we found it associated with a different component, *Familiar*, that explains 28% of the

variance. Similar to the *familiarity* identified by Axelsson et al. (Axelsson et al., 2010) while explaining a greater amount of variance, it played a significant role in the comparison of composition strategies. Our study suggests that assessing soundscape's *familiarity* is necessary when evaluating and comparing sound art interventions as it allows to gauge how their inclusion can evoke novelty in a familiar soundscape, specifically how they can lead to less *familiar* soundscapes by disrupting the rhythms that dominate the urban experience, without a positive or negative connotation (Lacey, 2016). This also corroborates Oberman and colleagues' observation that sound art interventions could influence the *appropriateness* of the sound environment (Oberman et al., 2020). The third component, *Varied*, was found to explain 16% of the variance, and seems to be inversely related with *monotonous* observed by Tarlao et al. (Tarlao et al., 2019). *Varied* was related with the variety and number of sources but was believed to be less related to the presence of sources denoting human activities than *eventfulness* (Tarlao, Aumond, et al., 2023). This component provided information on the propensity of sound art interventions to rise above the existing soundscape and can be meaningful to position sound art within an *integrated/oppositional* dichotomy (Livingston, 2016). Further research is required to assess the comparative performance of scales relative to *variety* and *eventfulness* to describe variation in soundscape, and their relationship with sounds from human activity.

Together, these results suggest that a model for soundscape evaluation solely based on *pleasantness* and *eventfulness* as proposed in the ISOs 12913-2:2018 and 12913-3:2019 may be incomplete to assess sound art installations and/or unconventional soundscape interventions and situations. Although it provides adequate characterizations of soundscapes (Tarlao et al., 2021), this two-dimensional model does not allow to evaluate how soundscape interventions can (positively) reshape or reconfigure urban soundscapes, i.e. their impact on *familiarity* or on *variety*, even though these aspects are often critical to sound artists (e.g., see Lacey, 2016).

## 4.2. Impact of composition strategies on soundscape measurement

To answer the second research question [RQ2], we compared the impact of different sound art composition strategies on quantitative and qualitative soundscape measurement. The sound design methodology proposed by the second author allowed to gather sketches of the sound installation in the form of excerpts into six composition strategies that we positioned within an Abstract (sounds that can't be ascribed to any real or imagined provenance) / Referential (recorded sounds that suggest or at least do not hide the source to which they belong) dichotomy (Landy, 2007). If all added sounds led to less *familiar* and more *varied* soundscapes, results show that Abstract sounds more affected soundscape *familiarity* and were perceived as more *varied* than Referential sounds. These effects were similar for Synthesized excerpts (note-to-midi abstractions of the Referential excerpts, see section 2.2) than Resonated effects (filtering of the Referential excerpts), while the evaluation of hybrid composition strategies (mixes between Referential and Synthesized or Resonated excerpts) fell in between that of purely Abstract and purely Referential composition strategies regarding *familiarity*, but were overall perceived as being more *varied*. This suggests that the impact of the added sounds on *familiarity* was more pronounced with deeper sonic abstractions and was somehow proportional to the ratio of Abstract/Referential sounds within the compositions, while hybrid composition strategies were overall perceived as more *varied*, likely due to a greater diversity of sound sources. Together with the qualitative feedback, this confirms our prior intuition that more processed, artificial sounds can be considered more *oppositional* as they were perceived as more *varied* and less *familiar* than recorded sounds, hinting to a non-energetic masking that is stronger when sounds are least expected. Still, hybrid compositions received the highest scores on the *varied* components, highlighting the role of soundscapes' diversity on perceived *variety*. Some of the participants also reflected on the ability of the added sounds to transport them elsewhere, evidencing the potential for sound art interventions to improve the restorativeness of a space by allowing its users to experience a sense of being-away (Payne, 2013). Otherwise, we couldn't observe the impact of the composition strategies on soundscape appreciation except for Synthesized excerpts that were rated significantly lower than Referential excerpts on the *Pleasant* component. Incidentally, we

acknowledge that person-related factors—specifically whether participants were local residents or workers, but also variables such as age or sensitivity (Tarlao et al., 2021)—may influence people’s evaluation of the forecourt’s soundscape in presence of added sounds. Further analysis is required to investigate the relationship between these person-related factors and the impact of sound installations.

Follow-up interviews provided more nuanced feedback and showed that participants’ opinion on Referential excerpts was generally positive especially when they referred to natural sounds (in line with recent works; see for instance Hong et al., 2020; Jeon et al., 2010; Lugten et al., 2018; Ong et al., 2019) while it was more nuanced regarding Abstract sounds. This suggests that participants more easily reached a consensus when evaluating least liked excerpts than preferred ones. Incidentally, we could not observe significant results in situations where the effect size was small to moderate. This indicates a probable lack of statistical power due to the small sample size, constrained because of the inclusion criterion requiring that participants are familiar with the forecourt of the Judicial Court. This could explain why we did not detect significant differences between conditions on the *Pleasant* component when qualitative results suggested otherwise. This advocates for further research on the impact of sound art interventions on soundscape appreciation.

### 4.3. Methodological outcomes

The proposed methodology was the result of shared reflections between the scientific team and the sound artist (the second author) to help inform the composition of a public space sound installation prior to its deployment while investigating our research questions [RQ1] and [RQ2]. This research-creation methodology was fruitful both for the sound artist by providing perceptual feedback on sketches of the sound installation and for the scientific team in generating theoretical knowledge on the relationship between sound art composition strategies and their impact on soundscape evaluation.

In this study, we validated the soundscape simulation tool (Fraisse, Schütz, et al., 2022) in a context of comparison between sound art interventions: participants recognized the Baseline sound environment as familiar and realistic and we observed significant

differences between composition strategies across all components. However, the sound environment was only representative of the forecourt's average level of activity, and the removal of disruptive sounds and especially of sirens during the edition of HOA recordings tempered its validity, as those sounds are part of the identity of the Judicial Court: for instance, five participants mentioned that sirens were missing from the soundscape during the follow-up interviews (e.g. "*I expected to hear a lot more sirens*"). Further work is required to evaluate the impact of the *Niche Acoustiques* sound installation over different scenarios representative of the diversity of sound environments that can be heard within the forecourt. Conversely, the sound installation sketches were made up of elementary building blocks to allow the comparison of well-delineated composition strategies. Another study is required to evaluate compositions that will be closer to the final installation and consider different soundscape scenarios related to different times and days of the week. Otherwise, we could not evaluate the influence of prolonged or repeated exposure of public space users to the sound installation, a key feature as it will be permanently integrated into the public space. This was also a constraint for the second author in their creation process as the final composition is intended to evolve over long periods of time. It should also be noted that although our participants were seated in a fixed location, users will experience the installation on-site while moving through space, which will modulate their exposure to added sounds and create variations across space. Other sensory modalities, including visual cues (Li & Lau, 2020) may also influence the reception of the sound installation.

Regarding the questionnaire itself, the three components not only helped understand how public space users evaluate familiar soundscapes in the presence of sound art [RQ1] but facilitated the comparison of the sonic contents [RQ2] and provided useful, easy to understand feedback to the second author in their creative process: reduced into these three components, the results helped assess how the different composition strategies affected soundscapes in relation to the installation's design goals. In addition, follow-up interviews provided interpretative guidance by revealing the multifaceted nature of the components and evidencing the presence of non-energetic masking, advocating the use of methodological triangulation (Botteldooren et al., 2023; ISO TS 12913-3, 2019). To the sound artist, these interviews were considered insightful as they provided an in-depth

understanding of participants' perceptual and emotional feedback and a contextualization of the quantitative results. Moreover, outputs from the interviews allowed the sound artist to better identify compositional outcomes pointed out with the quantitative results. Open-ended responses from participants in relation to *familiarity* and *appropriateness* also highlighted the importance of previous experience of a specific site and of their relationship to the site. It is therefore important to collect participants' experience in their own words and beyond closed-ended questions, which is an oft-ignored recommendation from the ISO 12913 series.

#### 4.4. Practical contributions

This experiment was part of a greater art-science collaboration to inform the composition of the *Niches Acoustiques* sound installation with soundscape evaluations. Future work includes the laboratory evaluation of more elaborate composition sketches in different usage scenarios of the forecourt, and a comparison between laboratory results and the *in situ* evaluation of the sound installation once it is deployed.

Overall, this study showed the potential and feasibility for soundscape simulation to inform the composition of public space sound art prior to its deployment *in situ*. If it is possible to adjust the content of a sound installation once it is deployed or during its prototyping, the changes must be done under strong constraints (see for instance Anderson, 2008). In contrast, a laboratory setting provides the sound artist the opportunity to freely explore and anticipate the impact of composition strategies relevant to their artistic intention so that they can implement modifications before deployment, although the laboratory situation considerably restrains the compositional aspects to be evaluated (absence of characteristic multimodal and kinesthetic aspects that come with *in situ* outdoors experience, time constraints, etc.). To find an answer to our research questions, we reported here on relations between broad composition strategies and their impact on soundscape measurement.



In the context of the composition of the sound installation *Niches Acoustiques*, the experiment yielded valuable perceptual feedback on the effect of elementary compositional materials on soundscape evaluation, a first step towards their combination into finite compositions and their mapping with data collected by the future installation using environmental sensors. On this matter, an excerpt-to-excerpt analysis was also useful as it provided detailed feedback on the sound installation sketches. Ultimately, the experiment showed that the sound installation could provide novelty and variety in the forecourt's soundscape and advocated the use of hybrid compositions to achieve such a goal without reducing soundscape appreciation. Furthermore, participants' feedback implicitly indicated a potential that the present composition samples haven't explored yet with regard to such a hybrid composition strategy; the combination of the two different referential sound types (narrative scenes and natural tones) as a composition/sound production basis, with their different temporal and spectral implications.

In terms of design and planning, this experiment highlights the potential of sound installation to affect soundscape *familiarity* and *variety* and the relationship between the Abstract/Referential nature of added sounds and their impact on these components. While we believe that some of these outcomes might transfer to other sound installations, sound art in public spaces is closely related to site-specific characteristics, which should be accounted for. We advocate for the use of similar methodologies for the design and evaluation of sound installations throughout the creation process, to better understand the complex and crucial role of sound in everyday experiences of public spaces.

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## **Author declarations**

Conflict of Interest: The authors have no conflict to disclose.

Ethics Approval: This research has been approved by McGill research ethics board (REB #22-01-033) and by Sorbonne University Research Ethics Committee (CER-2021-109). Informed consent was obtained from all participants.

## **Data availability**

Due to the nature of consent obtained from participants, data cannot be made available outside of the research team, as per the ethics approval obtained from the McGill Research Ethics Board and the Sorbonne University Research Ethics Committee. For future data requests, please contact the McGill Ethics Officer at [lynda.mcneil@mcgill.ca](mailto:lynda.mcneil@mcgill.ca) or the Sorbonne University Research Ethics Committee at [CER@sorbonne-universite.fr](mailto:CER@sorbonne-universite.fr). However, the analysis code as well as the python script used to generate the randomized baseline audio are available here:

[https://github.com/valerianF/analysis\\_codes/blob/main/JASA\\_Using\\_Soundscape\\_Simulation](https://github.com/valerianF/analysis_codes/blob/main/JASA_Using_Soundscape_Simulation).

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