Soundscapes in context: investigating *in situ* experiences and proposing a simulator for urban professionals

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Contents

Abstract

The sound of our urban environments, framed as urban noise, is an increasing concern as cities develop, diversify, and densify, impacting both well-being and quality of life for a majority of the urban population. But, in many environments, reducing sound levels has proven insufficient to improve the quality of the urban auditory experience. The *soundscape* approach considers sound as a resource in sonically complex urban environments, rather than only a pollutant to be eliminated. Accordingly, soundscape research has demonstrated the potential for positive and restorative qualities of sound environments. Additionally, an approach that views sound as a resource allows for a more proactive and holistic management of sound environments. This is why the soundscape approach, and its integration in the processes of urban design from an early stage, can be of special interest to cities.

Urban planners are regularly confronted with the complexity of managing urban sound and understand that available noise guidelines fall wholly short in their reduction of such a complex experience. However, urban professionals involved in the decisions shaping the built environment of the city rarely have the resources and knowledge to deal with urban sound in such a resource-centered manner. Curriculum and policy are long-range goals requiring a global change in approach from many different stakeholders, but tools can be implemented and impact practice in a more immediate manner.

The present research is an effort to address some of these sound-related urban planning concerns by prototyping a soundscape simulation tool for urban professionals to

integrate in their workflow. To this end, we first need to understand how the soundscape experience of city users is shaped and the ecological validity of reproducing urban soundscapes over loudspeakers in a laboratory setting. Finally, based on those theoretical and methodological results, we can proceed with the development and testing of a soundscape simulator tool with urban professionals. The present research contributes to advancing theoretical knowledge of contextual influences on the urban soundscape experience, methodological knowledge regarding soundscape assessment and laboratory reproduction, and practical applications through the investigation of the needs and requirements of urban professionals regarding the development of a simulation tool.

Résumé

L’aspect sonore de nos environnements urbains, souvent présenté comme du bruit, est une préoccupation grandissante à mesure que les villes se développent, se diversifient et se densifient, avec un impact à la fois sur le bien-être et sur la qualité de vie de la majorité de la population urbaine. Mais, dans de nombreux environnements, la réduction des niveaux sonores n’a pas eu l’effet d’amélioration de la qualité de l’expérience auditive urbaine escompté. L’approche de *paysage sonore* considère le sonore comme une ressource plutôt qu’une pollution à éliminer, dans les environnements urbains complexes sur le plan sonore. Dans cette optique, les chercheurs en paysage sonore ont démontré le potentiel positif et ressourçant des environnements sonores. De plus, une approche qui considère le sonore comme ressource permet de prendre une position de gestion des environnements sonores plus proactive et holistique. De ce fait, l’approche du paysage sonore, et son intégration en amont dans les processus de design urbain, devrait être d’un intérêt particulier pour les villes.

Les planificateurs urbains se trouvent régulièrement confronté à la complexité de gestion du sonore dans la ville et savent pertinemment que les directives sur le bruit ne sont pas en mesure de prendre en compte une telle complexité d’expérience. Cependant, les professionnels en urbanisme qui façonnent l’environnement bâti de la ville ne possèdent que rarement les ressources et les connaissances pour prendre en compte le sonore comme une ressource. Il sera possible de faire évoluer les politiques et les cursus d’apprentissage en impliquant les nombreuses parties prenantes dans le long terme, mais il est possible dès à présent d’implémenter des outils technologiques qui pourront être intégrés à la pratique de design de manière beaucoup plus immédiate.

La présente recherche vise à offrir des solutions à ces préoccupations sonores de planification urbaine, notamment via un prototype d'outil de simulation des paysages sonores qui s'intègrerait dans le processus de travail des professionnels en urbanisme. Dans cette optique, il est d'abord nécessaire de comprendre comment les expériences sonores des usagers de la ville sont formées et façonnées, puis d'examiner la validité écologique de la reproduction des paysages sonores par haut-parleurs en laboratoire. Enfin, sur la base de ces résultats théoriques et méthodologiques, il est possible de procéder au développement et à l'évaluation du simulateur avec des professionnels en urbanisme. La présente recherche contribue ainsi à faire avancer le savoir théorique des influences contextuelles sur l'expérience sonore urbaine, les connaissances méthodologiques quant à l'évaluation du paysage sonore et sa reproduction en laboratoire et les applications pratiques en examinant les besoins et attentes des professionnels en urbanisme quant au développement d'un outil de simulation.

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Contribution of authors and acknowledgements

This dissertation has been prepared as a manuscript-based thesis and includes the following publications. The research and results are my own original work carried out under the guidance of my supervisor Prof. Catherine Guastavino, with contributions from others as described below.

Chapter 2:

Tarlao, C., Steffens, J., & Guastavino, C. (2021). Investigating contextual influences on urban soundscape evaluations with structural equation modeling. Building and Environment, 188, 107490. https://doi.org/10.1016/j.buildenv.2020.107490

Dr. Jochen Steffens contributed statistical and writing guidance. Additionally, Dr. Steffen Lepa (Audio Communication Group, Technical University of Berlin) was consulted for statistical guidance and Dr. Daniel Steele (Sounds in the City, McGill University) for proofreading. Finally, the Arrondissement du Plateau-Mont-Royal was a repeated collaborator for all of the presented sub-projects, allowing our team to conduct research in multiple public spaces.

The studies in this paper were funded by grants from Canada's SSHRC [Social Sciences and Humanities Research Council, #430-2016-01198 and #890-2017-0065 to CG, Sounds in the City]. Ethical approval for this project was given by the Research Ethics Board II of McGill University [REB #55-0615].

Preliminary reports of the results were first published in:

- Tarlao, C., Steele, D., Fernandez, P., & Guastavino, C. (2016). Comparing soundscape evaluations in French and English across three studies in Montreal. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. INTERNOISE 2016, Hamburg.
- Tarlao, C., Steele, D., & Guastavino, C. (2019, June). Investigating Factors Influencing Soundscape Evaluations Across Multiple Urban Spaces In Montreal. *INTER-NOISE and NOISE-CON Congress and Conference Proceedings*. INTERNOISE 2019, Madrid, Spain.

Chapter 3:

Tarlao, C., Steele, D., & Guastavino, C. (2021). Assessing the ecological validity of soundscape reproduction in different laboratory settings. *Manuscript Submitted for Publication*.

This study is the logical continuation of previous studies conducted by the Sounds in the City team. Postdoctoral fellow Daniel Steele contributed to the experimental design and by establishing a working relationship with the city leading to data collection opportunities.

Mariana Mejía Ahrens (McGill University) carried out the field recordings with equipment provided by the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT). Christopher Trudeau (McGill University) and Valérian Fraisse (Institut de Recherche et de Coordination Acoustique/Musique, Sorbonne Université) contributed to data collection, on site and in the laboratory, respectively. Grégoire Blanc (Institut de Recherche et de Coordination Acoustique/Musique, Sorbonne Université) assisted me in data collection and software design at CIRMMT. The Arrondissement du Plateau-Mont-Royal was also a repeated collaborator for all of the presented sub-projects, allowing our team to conduct research in multiple public spaces.

The studies in this paper were funded by grants from Canada's SSHRC [Social Sciences and Humanities Research Council, #430-2016-01198 and #890-2017-0065 to CG, Sounds in the City]. Ethical approval for this project was given by the Research Ethics Board II of McGill University [REB #686-0606 and #55-0615].

Chapter 4:

Tarlao, C., Blanc, G., Steele, D., & Guastavino, C. (2021). Evaluating interactive soundscape simulation as a co-design tool for urban professionals. *Manuscript in Preparation*.

Grégoire Blanc assisted in the development and the running of the software used in this study. Dr. Daniel Steele led the preparation of and moderated the workshop activity.

Mariana Mejía Arhens contributed to field recordings with CIRMMT and personal equipment. Romain Dumoulin provided sound recordings and Audiotopie a sound art composition used in the software. Dr. Josée Laplace was in charge of note-taking during the workshop activity.

The studies in this paper were funded by a grant from Canada’s SSHRC [Social Sciences and Humanities Research Council, #890-2017-0065 to CG, Sounds in the City]. Ethical approval for this project was given by the Research Ethics Board II of McGill University [REB #450-0413].

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Chapter 1 – Introduction

1.1 Motivation

Sound is increasingly considered as a concern in cities, particularly in the context of densification, which results in increased noise exposure (European Environment Agency, 2010). Decades of research have documented the negative impact of noise on people's health and well-being. Noise exposure can lead to detrimental outcomes on a human's physical and psychological health by inducing stress, annoyance, sleep disturbance, poor task performance, attentional problems, and heart issues (Bronzaft et al., 1998; Evans et al., 1995; Stansfeld & Matheson, 2003; van Kempen et al., 2017).

The traditional approach to respond to these detrimental effects has been to mitigate noise that exceeds harmful levels. However, approaches that focus on reducing exposure levels have proven insufficient in addressing the detrimental effects of noise outside of specific contexts, such as around airports (Bijsterveld, 2008). Additionally, sound levels do not necessarily correlate to perceptions (Cain et al., 2013) and noise reduction approaches cannot apply to the multiplicity of factors involved in improving the quality of the urban auditory experience (Aletta et al., 2016; Payne et al., 2009; Raimbault et al., 2003). Noise reduction can even create or reveal other problems (Raimbault & Dubois, 2005) (e.g., lower traffic noise revealing persistent HVAC noise in Montreal during the COVID-19 pandemic (Steele & Guastavino, 2021)). Thus, by considering urban sound only as noise to be kept under set sound pressure levels, the aforementioned approaches obscure other types of noise issues, such as neighborhood noise, which are less readily measured but more common than sources like aircraft noise, which are more localized and louder (Bijsterveld, 2008).

The case of neighborhood noise exemplifies the importance of considering the meaning attributed to sound sources to understand how sounds are experienced by people. For example, human sources are expected and desired in urban contexts (Guastavino, 2006), and even traffic noise can be considered to contribute to a city's vibrancy (Brown & Muhar, 2004). One approach to urban sound environments that emphasizes the importance of meaning and context is the *soundscape* approach. The concept of soundscape was introduced through the pioneering work by Schafer in the 1970s (Schafer, 1977) and led to the development of a soundscape research field in the 1990s. The soundscape approach aims to address sound from the perspective of human experiences in context (International Organization for Standardization, 2014) and, as such, 1) focuses on the perceptions and experiences of the listeners in understanding sound environments and 2) does not consider environmental sounds as inherently good or bad. In other words, whether a sound has a positive or negative outcome is influenced by both listener and context. In this view, sound, especially in sonically complex urban environments, is not a pollutant to be eliminated but a resource that can be managed (Schulte-Fortkamp et al., 2007). As such, the soundscape approach seeks to offer a flexible and broad range of tools to enhance the quality of urban sound experiences.

Soundscape research has demonstrated the potential for positive and restorative qualities of sound environments: sounds can also lead to an improvement in ones state of mind (Axelsson et al., 2010), an increased sense of safety (Andringa & Lanser, 2013), and faster recovery from stress (Alvarsson et al., 2010; Annerstedt et al., 2013) to name but a few (see Aletta et al., 2018 for a recent systematic review of positive outcomes). More specifically in urban environments, sound has been shown to have the potential to foster pro-social behavior (Lavia et al., 2016). Additionally, an approach that views sound as a resource rather than a nuisance allows for a proactive and holistic management of sound environments. This is why the soundscape approach, and its integration in the processes of urban design from an early stage, can be of particular interest to cities and the breadth of practitioners involved in shaping their built environment (including urban designers, planners, architects). We will refer to these professions throughout the manuscript using the umbrella term of *urban professionals*.

1.2 Research-practice gap

This growing body of soundscape literature on the role of sound in urban spaces offers considerable potential to inform urban design and practice and to shape the sound environments of our cities. Both sound(scape) researchers and urban professionals recognize the limitations of traditional noise mitigation strategies, although through different lenses and using different vocabularies. On the one hand, soundscape researchers are advocating for incorporating soundscape into the urban planning process from an early stage, offering a flexible framework to preempt costly noise remediation and to preserve urban sound identities (e.g., De Coensel et al., 2010). On the other hand, urban professionals have long been confronted with the complexity and multiplicity of urban sound experiences and the shortcomings of available noise policy frameworks (Raimbault & Dubois, 2005). For these reasons, urban professionals who know about the soundscape approach are enthusiastic about its potential for their work (Raimbault & Dubois, 2005).

However, despite the work of soundscape researchers and the difficulties urban professionals encounter in their work in relation to urban sound, sound considerations are rarely a priority in the planning and design process of urban development projects (Bild et al., 2016; Steele, 2018; Steele et al., in press), only entering the process once major decisions have already been made (Defrance et al., 2016). Urban professionals are rarely equipped to engage with urban sound as a resource, and they find soundscape research too abstract to be used in practice, so that they generally approach sound only as noise and decibel levels to be enforced (Steele, 2018). Some of the reasons highlighted in the literature include 1) lack of training, 2) lack of a regulatory framework, and 3) lack of resources, including tools (Bild et al., 2016; Laplace et al., in press; Yanaky et al., 2020).

First, curricula for urban professionals rarely include sound in any other capacity than as a pollutant to be mitigated (Steele, 2018). Additionally, when urban professionals do recognize the complexity of the urban sound environment – generally through field experience (Chalas, 1998; Raimbault & Dubois, 2005), the lack of a shared vocabulary between the different fields involved is an obstacle to knowledge sharing and intervention (Steele, 2018). To start bridging this training gap, soundscape researchers have put in place workshops (Maffei & Kang, 2013; Steele et al., 2020) and training schools (Maffei & Kang, 2013) aimed at urban professionals, and published toolboxes for urban sound planning (Estévez Mauriz et al., 2016).

Second, policy has historically focused on noise levels and noise mitigation, and change is slow to come due to a number of obstacles, including the complexity of alleviating the health and social harms of noise (Kang, 2010) and the associated higher financial and temporal costs of qualitative studies, in comparison to quantitative assessments (M. Adams et al., 2006). Indeed, this historical trend to increasingly seek to control noise through noise measurements has led to the neglect of noise issues that cannot be easily measured, such as neighborhood noise (Bijsterveld, 2008). While policy makers are increasingly recognizing the importance of integrating user-centered considerations in noise management (e.g., Europe's Environmental Noise Directive (*Assessment and Management of Environmental Noise*, Directive 2002/49/EC)), soundscape researchers are involved in policy projects pushing for a more holistic approach to urban sound (e.g., Laplace et al., in press).

Lastly, resources encompass a breadth of indicators, guides, and tools as sound design aids at different stages of the urban design process. There is an acute need for the development of such sound design aids to help bridge the gap between abstract academic research output and concrete design and planning projects (Steele, 2018). The development of such aids requires less of an in-depth culture change in the different urban professions and can more easily prove their worth through the outcome of their implementation by even a few professionals, especially knowing that urban professionals would welcome new tools to help them work with sound (Raimbault & Dubois, 2005; Steele et al., in press).

Curriculum and policy are long-range goals requiring a global change in approach from many different stakeholders, but tools can be implemented and impact practice in a more immediate manner. For these reasons, the present dissertation focuses on the development of a technological tool to facilitate sound design for urban professionals.

Furthermore, while professionals lend high credibility to academic research, they often find it too abstract and rarely applicable to their daily practice (Steele, 2018). To address this gap between credibility and applicability, it is critical to better understand how the specific context of an urban project influences the urban sound experience so that abstract principles of soundscape research can be tailored to specific contexts for a wide range of urban projects. Contextual influences include a breadth of factors – from person-related factors (e.g., demographics, culture) to environmental factors (e.g., visual environment), and including situational factors (e.g., user activity) – and need to be investigated in a variety of urban settings.

1.3 Conceptual framework

1.3.1 Soundscape in context

Context is a concept central to soundscape – and increasingly recognized as such (Axelsson et al., 2019). Indeed, the importance of contextual influences on sound experience is acknowledged in the ISO conceptual framework, which defines context as “includ[ing] the interrelationships between person and activity and place, in space and time” (International Organization for Standardization, 2014). Based on this definition, context includes all non-acoustic components of a space, such as prior experience of the space, that can play a role in the perception of the acoustic environment of a space (Brown et al., 2016). Yet, Bild et al., (2016) found that soundscape studies still generally fail to take into account contextual influences, such as user characteristics and activity.

This limited attention paid to context in soundscape research until recently (Axelsson et al., 2019) might be partially explained by methodological challenges to the investigation of the complex contextual effects influencing soundscapes. Soundscape research has historically rested on two parallel methodological schools (Axelsson et al., 2019), making it difficult to compare or reconcile results from different studies: on-site assessment in the actual soundscape (e.g., Engel et al., 2018), and laboratory-based assessment with reproduced soundscapes (e.g., Guastavino, 2007). On-site and laboratory-based studies offer different, and often complementary, benefits and limitations. Site studies, by virtue of being conducted in the context of interest, can lead to highly representative and generalizable insights as a result of often complex analyses and interpretations. In comparison, laboratory studies allow more control over context, variables, and participants, which can simplify the analyses and interpretation of results, while limiting their generalizability and representativeness and leaving out a breadth of potentially relevant factors. Thus, laboratory-based soundscape assessment studies are often limited in scope, both in terms of variables tested/measured and sites investigated. For example, laboratory studies cannot reproduce important contextual influences such as people's expectations about the urban space or their choice of activity to conduct in said space (International Organization for Standardization, 2014)

Therefore, for further contextual investigation, it is essential to both systematically review the existing literature and gather new evidence in a systematic manner on multiple sites at a time. As such, systematic reviewing efforts have recently been undertaken, for example looking at soundscape health outcomes (Aletta et al., 2018) or soundscape methodologies (Aletta et al., 2016). In addition, beyond the characterization of specific spaces, the question of generalizability of the results across studies has recently received increased interest as a major challenge limiting theory development for the soundscape community (Axelsson et al., 2019). Accordingly, the first study of the present research examines the outcomes of the deployment of the same questionnaire over multiple sites in Montreal to investigate the influence of contextual factors on soundscape assessments.

1.3.2 Ecological validity

Following the assessment of city users' sound experience on site, we can compare it to the sound experience elicited by reproducing urban soundscapes in the laboratory. Indeed, as laboratory settings differ from everyday life situations, specifically in terms of contextual influences (e.g., weather, expectations), they may elicit different perceptions. This is captured in an important tenet of experimental psychology: the notion of the *ecological validity* of an experiment. The concept of ecological validity was first introduced by Egon Brunswik (1943, 1956) and later developed by James Gibson (1979) into the concept we understand today. **Chapter 3** will present a detailed literature review of *ecological validity* but simply put, any experiment can be said to be *ecologically valid*, i.e., to represent, and therefore allow inferences and generalizations to, what happens in everyday life situations if the following three conditions are met:

(1) the participants are representative of the studied population;
(2) the experimental setup and stimuli are representative of the studied environments;
(3) the experimental task and procedure are representative of the studied processes.

Previous studies have revealed relationships between: 1) individual experience and ecological validity of soundscape reproduction (Guastavino, 2003), 2) reproduction technique/system and spatial features of urban sound environments (Guastavino et al., 2005), and 3) data collection instruments and task results (Hart & Staveland, 1988). For example, sound expertise influences the way listeners attend to a sound scene, whether holistically or analytically (Guastavino, 2003). Additionally, soundscapes with sounds coming from above, or with more diffuse sources, are judged more realistic when reproduced over a three-dimensional setup (Guastavino et al., 2005). Guastavino et al. (2005) found that the *Ambisonic* 3D-audio reproduction technique was ecologically valid for source identification and yielded similar verbal descriptions of urban soundscape to field studies. For these reasons, the present work makes use of Ambisonics and tests its ecological validity for soundscape reproduction in the case of questionnaire-based soundscape evaluations.

1.3.3 Participatory design

Once the ecological validity of laboratory-based soundscape reproduction has been assessed, we can proceed with the development and evaluation of said soundscape simulation tool to help urban professionals integrate sound considerations into their design practices. To do so, we need to bridge the urban sound considerations and the practice needs of urban professionals, and the explicit requirements and analytical knowledge of our soundscape research team. This knowledge bridging is at the core of participatory design (PD) methodologies from the field of user experience (UX) (Spinuzzi, 2005). PD adds values of “broadened participation and skill development” (Suchman, 1993, p. viii) to the existing values of technology development processes, both of which are central to our approach in the present research.

PD emerged in Scandinavia in the 1970s from a specific political motivation – Marxism – and aimed to break down the workplace power structures between workers and their management in the implementation of new technologies (e.g., Ehn, 1988). Specifically, PD focused on empowering the workers, as users of technologies, by considering them as experts on their work and including them in the design process for the tools they will be using (Schuler & Namioka, 1993). Due to the expansion of PD and technologies to other fields and contexts, the theoretical approach of participatory designers does not always incorporate the original political motivations but still revolves around constructivism and opposing the notion that there is only "one best way to perform any activity" (Spinuzzi, 2005, p. 165). In this manner, works from the American PD legacy have focused primarily on solving problems and ensuring functionality for the users of a technology through the creation of mutual learning, knowledge, and language between them and the designers (Béguin, 2003; Muller & Druin, 2012) – with the aim of fitting technologies into the existing workflow and knowledge of users (Spinuzzi, 2005).

However, workers/users involved in PD, being deeply rooted in their own paradigm and knowledge processes, may struggle to imagine how to implement their needs for new technologies in support of their work (Spinuzzi, 2005). Indeed, previous research (Raimbault & Dubois, 2005; Steele, 2018) has revealed that urban professionals could not express specific expectations towards new tools for soundscape practice, despite showing the necessity of understanding their needs to help them integrate sound in their practice.

However, resources for urban professionals on urban sound, and especially regarding perception and design, are scant and usually limited to academic publications, which are rarely meant to be accessible to professionals (Steele, 2018). Our team has been working with urban professionals to try to bridge that knowledge gap and understand their needs via a range of research approaches (Yanaky et al., 2020), in an iterative process to develop resources and tools to support their practice (in the context of the Sounds in the City partnership funded by SSHRC since 2016). The present research is an integral part of this iterative process, aiming specifically at assessing the potential of a soundscape simulator for co-design with urban professionals.

1.4 Research objectives and questions

The research reported in this thesis addresses some of the aforementioned sound-related urban planning concerns through two major avenues. The first one is an investigation of the contextual factors influencing soundscape evaluations by city users. The second avenue is the development and evaluation of a soundscape simulator as a co-design tool for urban professionals.

1.4.1 Contextual influences on soundscape evaluation

The **first research objective** of this work is to add to the growing pool of research aiming at understanding and modeling soundscape evaluations by investigating contextual influences. Based on the literature reviewed in **Chapter 2**, the person-related factors of age, gender, noise sensitivity, and extraversion, and the situational factor of social interaction were identified for further investigation in a multi-site field study. Additional contextual factors are explored through a follow-up laboratory-based study leveraging the insights of one of the sites investigated in the multi-site field study. This follow-up study focuses on time of day, day of the week, and location on site as factors of interest identified through a review of the limited soundscape literature presented in **Chapter 3**. Both of these studies will explore the following research question:

- **RQ1**: How do the identified contextual factors influence soundscape evaluations?

1.4.2 A soundscape simulator for urban professionals

The **second research objective** of this work is to develop a soundscape simulator to study soundscape evaluation in controlled laboratory environments. To be useful, such a tool should elicit a representative experience of *in situ* soundscapes. For that, two conditions need to be met: that the reproduction technique is *ecologically valid*, and that the needs and requirements of prospective users are met. In this instance, urban professionals are the targeted user group, and their needs and requirements are paramount to the acceptance and use of the tool. But even before this step, the representational validity of the chosen audio technique needs to be assessed.

Gibson (1957) pointed out that it is often not possible to know if an experiment will be representative or not only based on theory. It is therefore necessary to investigate the ecological validity of our soundscape reproduction empirically through listening tests in the laboratory. To this end and based on the modeling of the *in situ* urban soundscape experience from the first research objective, we can study the ecological validity of the reproduction of urban soundscapes over loudspeakers in a laboratory setting:

- **RQ2:** Are laboratory-based 3D-audio soundscape reproduction and evaluation ecologically valid?

Beyond reproducing soundscapes in the laboratory, the envisaged tool is aimed at offering ways to manipulate soundscapes so as to simulate urban interventions (e.g., pedestrianization, installation of a fountain). To this end, the tool cannot support only reproduction and play back of soundscape recordings but simulation and manipulation of sources and environments as well. In this manner, such a tool would be an equivalent to visual sketching and prototyping in support of sound design, allowing urban professionals to hear the sound consequences of design choices.

In order to ensure our soundscape simulation tool will be accepted and integrated by urban professionals into their workflow, designing a quality user experience based on their feedback and collaboration is essential. At this point in the development of the tool, we would be looking for intermediate evaluations to guide the following steps and iterations, which calls for formative evaluation. Formative evaluation is a concept historically coming from the field of education evaluation (Scriven, 1966), and later integrated into design evaluation (Carroll et al., 1992), which aims to identify potential design issues as the product is being developed, rather than using testing as a last step. Based both on the previous results of the present research and that of our team and on a literature review of the viewpoint of urban professionals – presented in **Chapter 4**, the last step seeks feedback via a formative UX evaluation with from urban professionals about the potential of our soundscape simulation prototype for co-design practice:

- **RQ3:** What are urban professionals' expectations for, and evaluation of, the use of the simulator in the context of soundscape co-design?

1.5 Thesis structure

Following are the publications corresponding to each study of the present research: **chapters 2 to 4** of this thesis by manuscript will provide a literature review relevant to each publication or manuscript's research objective.

Chapter 2 (publication 1) presents the results of the multi-site soundscape study in four Montreal urban public spaces. This study answers **RQ1** by building a model of personal factors – specifically age, gender, noise sensitivity, and extraversion – and the situational factor of social interaction as contextual influences on soundscape evaluations.

In **Chapter 3 (publication 2)**, we investigate the ecological validity of laboratory soundscape studies [**RQ2**]. Specifically, Ambisonic reproduction over loudspeakers, stimuli selection, and mode of questionnaire administration are tested. Furthermore, this study adds to **RQ1** by exploring the influence of the contextual factors of time of day, day of the week, and location on site on soundscape evaluations *in situ* and in the laboratory.

Chapter 4 (publication 3) presents the formative evaluation of the soundscape simulator prototype with urban professionals [**RQ3**]. Through a series of codesign exercises during a workshop with a range of stakeholders involved in urban sound, this study invites knowledge mobilization and sharing between urban professionals and soundscape experts. The aim is two-fold: for urban professionals to integrate soundscape principles and tools in their practice and for soundscape researchers to ensure the future tool can be integrated in the workflow of urban professionals.

Finally, **Chapter 5** will tie up the different conclusions of each publication, and discuss the theoretical, methodological, and practical contributions of my thesis, as they relate to the research gaps and topics put forward in this chapter.

1.6 Preliminary results

- Tarlao, C., Steele, D., Fernandez, P., Guastavino, C., 2016. Comparing soundscape evaluations in French and English across three studies in Montreal, in: Proceedings of INTERNOISE 2016. Presented at the INTERNOISE 2016, Hamburg.

- Tarlao, C., Steele, D., & Guastavino, C. (2019). Investigating Factors Influencing Soundscape Evaluations Across Multiple Urban Spaces In Montreal. Proceedings of INTER-NOISE 2019. Presented at the INTER-NOISE 2019, Madrid.

- Yanaky, R., Tarlao, C., Guastavino, C., 2020. An Interactive Soundscape Simulator for Professionals of the Built Environment. Proceedings of HAID 2020. Presented at the HAID 2020, Montreal.

Chapter 2[1] – Investigating contextual influences on urban soundscape evaluations with structural equation modeling

Cynthia Tarlao, Jochen Steffens, Catherine Guastavino

Abstract

Previous soundscape research has shown a complex relationship between soundscapes, public space usage and contexts of users' visits to the space. Yet many of these findings are restricted to one study site at a time and may not generalize to a global understanding of urban sound environments. The present study is a comparative analysis of in situ questionnaires collected over four study sites in Montreal (N = 1429) in both French and English. At each site, the questionnaire included items from the Swedish Soundscape Quality Protocol and other soundscape variables, as well as person-related (age, gender, extraversion, noise sensitivity) and situation-related (social interaction) variables. We first tested measurement invariance between the French and English versions of the used soundscape questionnaire. We then investigated the influence of contextual factors (combining person-related and situation-related variables) on soundscape evaluations. The analyses confirmed the underlying conceptualizations of proposed soundscape assessment questionnaires, confirmed metric invariance between French and English questionnaires,

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[1] This chapter is based on an article published as Tarlao, C., Steffens, J., & Guastavino, C. (2021). Investigating contextual influences on urban soundscape evaluations with structural equation modeling. *Building and Environment*, 188, 107490.

and revealed significant influences of contextual factors on soundscape dimensions. Our analysis further suggests that younger people, women, and extraverted people occupy the public space more in groups, and that people in groups rate the soundscape as more pleasant and less eventful. Older people and women were found to be more sensitive to noise, and more sensitive people tended to perceive the soundscape as less pleasant and less monotonous. This research represents a critical step in rigorously assessing soundscape evaluation methods and establishes solid groundwork to build more complex models of contextual influences on soundscape evaluation.

2.1 Introduction

2.1.1 Soundscape

Urban public spaces play an essential role in the everyday life of city users. The use of such spaces and the benefits for users is contingent on an array of factors, including the experience of the sound environment. Soundscape research investigates the “acoustic environment as perceived or experienced and/or understood by a person or people, in context” (International Organization for Standardization, 2014), often using interdisciplinary and mixed-methods approaches to characterize sound environments, with an emphasis on measures of human perception (in addition to purely physical measurements, such as sound level measurements). One of the essential tools when researching everyday life auditory experiences is questionnaires – which can include both scale ratings and open- and close-ended questions.

In the last decade, several soundscape scales have been developed and refined to measure the human perception of acoustic environments (see Engel et al., 2018 for a methodological review). Axelsson and colleagues (Axelsson et al., 2010) created and validated the Swedish Soundscape Quality Protocol (SSQP) – one of the most widely used soundscape questionnaires, comprised of eight unipolar scales, in Swedish and English – and which led in part to the ISO standard on soundscape procedures (International Organization for Standardization, 2018). The SSQP measures soundscape evaluations along three dimensions underlining people’s perception of the sound environment: *pleasantness*, *eventfulness*, and *familiarity*; with *pleasantness* and *eventfulness* constituting an orthogonal space, along the four complementary unipolar scales of “pleasant” and “unpleasant”, and "eventful" and "uneventful" with the four other scales forming their diagonals ("monotonous" to "vibrant" and "calm" to "chaotic"). Translations of the SSPQ have been used in other languages. In our own work, we proposed and tested a translation of the SSQP (Tarlao et al., 2016) in Québec French, with the same first and second dimensions of *pleasantness* and *eventfulness* (the dimensions of *agréable* and *animé*, respectively, in French), but that does not follow the exact proposed orthogonality in both French and English (Tarlao et al., 2016, 2019) (see sections 2.4.1 and 2.4.2 for a short discussion). Other French translations have been developed in France (Jeon et al., 2018), confirming the same first and second dimensions of *pleasantness* and *eventfulness.* However, no statistical confirmation of those translations has been undertaken yet.

In subsequent work and in response to comments by researchers from urban studies (e.g., Brown, 2012), Axelsson (2015) recommended adding the assessment of the *appropriateness* of the soundscape to the space as an orthogonal dimension to the *pleasantness* and *eventfulness* dimensions previously established. *Appropriateness* of the soundscape for the space can cover multiple aspects, for instance the *harmony* between the visual and sound environments (Hong & Jeon, 2015), the *consistency* between soundscape and physical environment (Acun & Yilmazer, 2019), or the soundscape *appropriateness* for specific activities (Nielbo et al., 2013). In our own work, we have explored the *appropriateness* of the soundscape for the activity conducted in the surveyed space (Steele et al., 2016).

At the same time, since the soundscape approach also entails a shift from sound as a pollutant to sound as a resource (Schulte-Fortkamp et al., 2007), soundscape researchers have started investigating the potential for restoration (Kaplan, 1995) of urban soundscapes (Payne, 2008). According to the literature, restorative soundscapes provide opportunities to recover from the negative effect of noise exposure, and reflect upon daily or life issues (Kaplan, 1995), resulting in lower stress levels.

Both the recognition that a soundscape needs to be *appropriate* and that it can be *restorative* signal a more complex relation between listener and sound environment including contextual factors, such as personality traits and expectations.

2.1.2 Context

As the aforementioned ISO definition suggests, soundscape research is interested in – and has recently been producing an increasing body of work focusing on – identifying the contextual factors in urban soundscapes (see Lionello et al., 2020 for a systematic review of prediction models). Although the notion of complex and diverse influences on the way people understand and apprehend their sound environment is not new (e.g., Thibaud, 2003, p. 331), systematic studies on the influence of contextual factors on the relationship between users and their sound environment has remained scarce until the last few years (Bild et al., 2016). The relationships included in the ISO definition of context as "the interrelationships between person and activity and place, in space and time" (International Organization for Standardization, 2014) have seen models and frameworks emerge in the last decade (Bild et al., 2016; Brown et al., 2011; Herranz-Pascual et al., 2010), and specific interest even more recently, using a diversity of methods both *in situ* and in laboratory settings (Axelsson et al., 2019). Yet, a majority of soundscape studies, including those exploring more holistic soundscape models, are restricted to one study site and may not generalize to a global understanding of urban sound environments. For example, Lionello et al. (Lionello et al., 2020) found only 22 studies, out of 185, investigating soundscape prediction models with more than one study site.

There is no consensus, however, on the precise categorization and nomenclature for contextual factors yet, but the ISO definition points out the three main facets: personal factors (e.g., demographics), situational factors (e.g., activity), and environmental factors (e.g., visual environment). Bild et al. (Bild et al., 2016) consider "user characteristics" – including demographics but also cognitive aspects, such as needs and expectations – on a different level to "contextual factors," which refer to any factor, such as weather or day and time, that influences the relationship between users and their auditory environment, while "activity" is the main mediator of this relationship (see Figure 2.1). In this study, we refer to "contextual factors" as including all of the above; that is person-related ("user characteristics" for Bild (Bild et al., 2016)) and situational factors ("contextual factors" for Bild (Bild et al., 2016)).

The notion of activity is therefore central to the ISO definition (International Organization for Standardization, 2014) and to the models of contextual influences theorized around it (Bild et al., 2016; Herranz-Pascual et al., 2010). Activity serves both as a moderator of people's perceptions of their sound environment (e.g., appropriateness of the soundscape for the desired activity (Nielbo, 2015; Steele et al., 2015)) and as an active modifier of the sound environment (e.g., sounds of activities are part of and reinforce the soundscape).

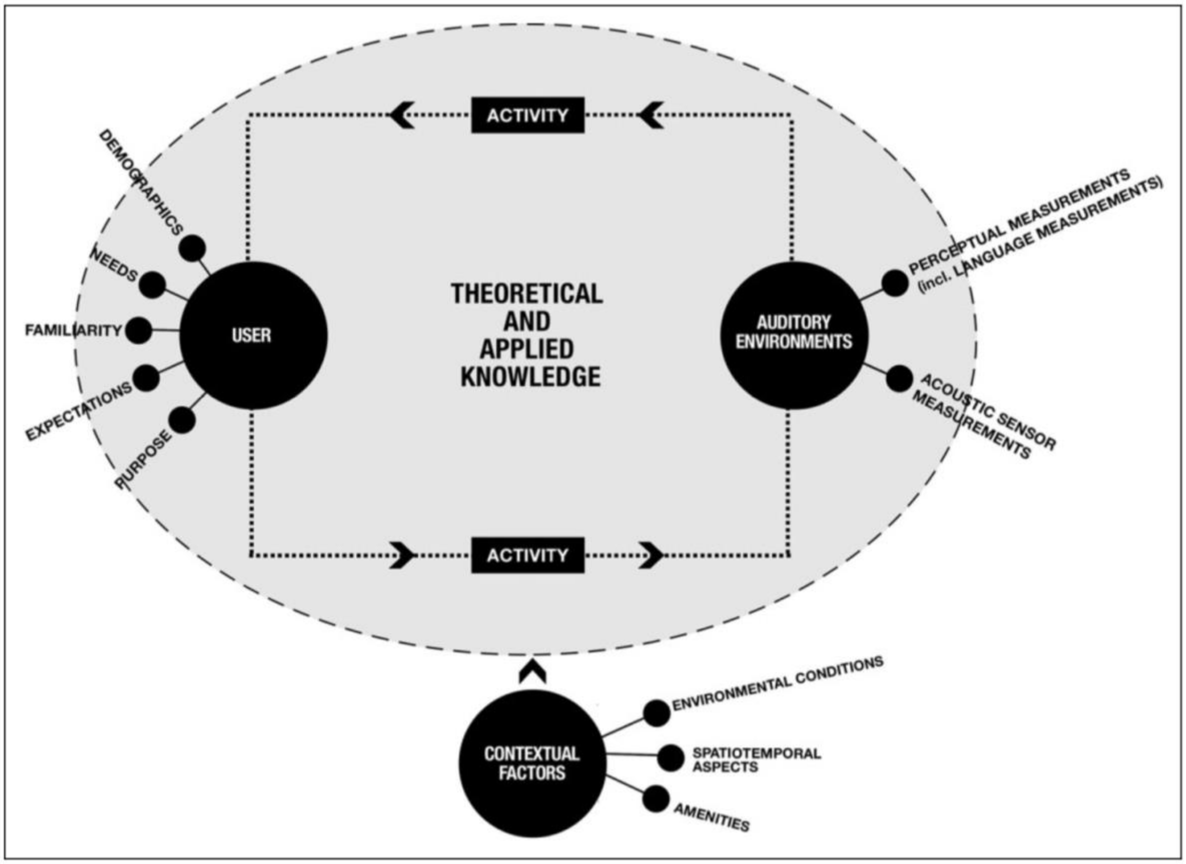

Figure 2.1. Activity-centered framework for the integration of sound research and practice. Reproduced from Bild et al. (2016) with permission.

In this study, we chose to operationalize the broad and complex concept of activity in terms of level of social interaction – i.e. whether they used the space alone or in a group. In this, we follow previous studies conducted in different urban spaces from various countries, which show that socially interactive people found the soundscape more suitable and less disruptive to their activity (Bild, Pfeffer, et al., 2018), more appropriate and more pleasant (Bild, Steele, et al., 2018), and less unpleasant (Steele et al., 2016) than solitary respondents. Additionally, Steffens et al. (Steffens et al., 2017) conducted an experience sampling study in which participants repeatedly performed soundscape ratings over one week – prompted by their cell phones, which sent questionnaires at random times. The authors observed an effect of the company of and interaction with others on pleasantness and eventfulness judgments. For instance, those who were around, but not interacting with, others found soundscapes less pleasant than those alone or interacting with others.

The "interrelationships between people and activity and place" (International Organization for Standardization, 2014) also include the aforementioned "user characteristics," as mediators of both environment perception and activity choice. Historically, sound studies have been more interested in the direct influence of personal characteristics on auditory perception. For example, noise sensitivity has been shown to be a crucial factor in explaining reactions to noise and noise annoyance (Ellermeier et al., 2001). Ellermeier (Ellermeier et al., 2001) found significant positive relationships between noise sensitivity and loudness and unpleasantness ratings. There is also a wealth of studies suggesting that noise sensitivity is correlated positively with age (e.g., Schreckenberg et al., 2010), and negatively with extraversion (e.g., Dornic & Ekehammar, 1990), and that women are more noise-sensitive than men (e.g., Aniansson et al., 1983). Interactions between extraversion, age, and gender were also found regarding their influence on noise sensitivity (Shepherd et al., 2015).

More recently, as the field of soundscape studies has been developing, researchers have investigated the relationships between personality traits and soundscape assessments. For example, people with higher extraversion scores rated soundscapes during shopping and recreation/entertainment activities as more pleasant than less extroverted peers (Steffens et al., 2017). Extraversion was also found to be a significant predictor of soundscape eventfulness, positive for urban soundscapes and negative for restaurant soundscapes (Lindborg & Friberg, 2016). Our team also found age important to consider in how people assess soundscapes (Bockstael et al., 2019), with increased noise sensitivity, louder, more chaotic, less calm, and less appropriate soundscape assessments with increasing age.

2.1.3 Research hypotheses

We situate our research within this debate to address questions on the effect of social interaction and personal factors on soundscape evaluations using a relatively large dataset, collected in two languages – French and English – in multiple public spaces in the bilingual context of Montreal. As a first step to justify the collapsing of both languages, we explored the measurement invariance between the existing English translation of the SSQP and other soundscape assessment scales, and our local French translation – hypothesizing two underlying factors (see section2.3.1 and Figure 2.3 for the original model): a *pleasantness* ("PL") factor, constituted of the measured variable "pleasantness" and other related variables, and an *eventfulness* ("EV") factor, constituted of "eventfulness" and related variables.

We then tested a model of influences (see Figure 2.5) built on our previous work (Tarlao et al., 2019) and past literature, with "social interaction" and "noise sensitivity" directly influencing the underlying factors ("PL," "EV"), with the addition of the SSQP item of "monotony," and a second level of indirect influence of "age," "gender," and "extraversion" on "PL," "EV," and "monotonous" through "social interaction" and "noise sensitivity." We chose the Structural Equation Modeling (SEM) approach because it allows for the use of both latent variables (for underlying factors) and mediation analyses that other methods like multi-level regressions cannot offer (see section 2.2.4 for more details).

2.2 Methods

2.2.1 Sites

Questionnaires were collected over four study sites in Montreal during the summer months from 2015 to 2019 (N = 1429). We capitalized on our team's collection of a large dataset over multiple sites of varied types in the same dual linguistic context and using the same questionnaire methodology. The different sites, all located in downtown Montreal in the trendy Plateau neighbourhood, were selected to represent a variety of morphologies and sound environments. Specifically:

1. **Public Square (PS)**, a small (about 1,800 m^2) public square right next to one of the main commercial streets of that area, with shops and restaurants along with two traffic lanes also used by bus lines operating regularly (every 10 minutes or less in both directions) during the day (Place Fleurs-de-Macadam, N = 1130),

2. **Pocket Park (PP)**, a slightly larger (almost 2,000 m^2) pocket park in a lively, musical area that has become one of the centers of Montreal nightlife. On one side, it borders a commercial artery, active almost 24/7, with shops, cafes, bars, and companies along with heavy one-way traffic, and a bus line. On the other side, it borders a quieter residential area with low buildings – 2 to 3 floors high (Parc du Portugal, N = 155),

3. **Green Park (GP)**, a big (340,000 m^2) green park located at the hearth of the neighborhood and bordered by major arteries one all four sides. It is surrounded by restaurants and bars and offers mixed functions for residents and non-residents, with a very quiet center and more lively edges (Parc LaFontaine, N = 41),

4. **Pedestrian Zone (PZ)**, the pedestrianization project (almost 1,000 m^2) of a semi-commercial, semi-residential street with addition of furniture and greenery. It is surrounded by small shops, some restaurants and residential apartments. The streets are mostly one-way streets and relatively quiet, one of the main routes with more dense traffic is a block away, behind a row of buildings (Roy street, N = 103).

2.2.2 Questionnaires

The questionnaire was offered in French or English (see Appendix Figure A 1), entirely in one language or the other, as preferred by each respondent. Common questions (see Table 2.1) between all sites in the questionnaire were soundscape-related (Sound sources heard, Swedish Soundscape Quality Protocol [SSQP], Appropriateness, Loudness, Restorativeness), personality- and person-related (Age, Gender, Extraversion, Noise Sensitivity), and situation-related (Activity conducted, Social Interaction). This paper focuses on the quantitative analysis of the 15 common close-ended questions, the qualitative analysis of the free-format responses is beyond the scope of this paper. Note that *restorativeness* has been operationalized in various ways in previous research (Payne, 2013; Payne & Guastavino, 2018), but in this study, we focus on the ability of the soundscape to offer a break from the daily routine, which measures the Being-away component of Attention

Restoration Theory) as part of the Perceived Restorativess Soundscape Scale (proposed by (Payne, 2013) and validated by (Payne & Guastavino, 2018)). Additionally, as the data collected in the Pocket Park (PP) and Green Park (GP) was rated on 7-point Likert scales, we standardized all Likert scale data with Z-scores. Z-scores are measures of how many standard deviations a data point is away from the mean. They are obtained by subtracting the mean from each data point and dividing the result by the standard deviation.

Table 2.1. Variables in common between the four sites' questionnaires (5-letter abbreviations used in model figures for legibility).

Section	Variable	Abbr.	Type
Soundscape-related	Sound sources (Pleasant, Unpleasant, Neutral)	–	Free response
	Pleasantness	plsnt	Likert scale
	Monotony	mntns	Likert scale
	Vibrancy	vbrnt	Likert scale
	Chaoticness	chatc	Likert scale
	Calmness	calm	Likert scale
	Eventfulness	evntf	Likert scale
	Appropriateness	apprp	Likert scale
	Loudness	loud	Likert scale
	Restorativeness (Being-away)	rstrt	Likert scale
Person-related	Extraversion	extrv	Likert scale
	Noise Sensitivity	snstv	Likert scale
	Age	age	Free response
	Gender	gendr	Binary
Situation-related	Activity	–	Free response
	Social Interaction (alone or in a group)	alone	Binary

2.2.3 Respondents

Of the 1429 respondents, 74.2% chose to fill the questionnaire in French, and 25.8% in English. They were 52.2% women, and 44.9% men (2.9% others or unspecified), ranging in age from 19 to 98 (mean age: 34.7, SD: 14.0 years).

2.2.4 Statistical analysis

We conducted Confirmatory Factor Analyses (CFA) and Structural Equation Modeling (SEM) in R 3.5.3 for Mac OS X and RStudio® 1.2.1335 with the *lavaan* (Rosseel, 2012) package, respectively. Figures were created using the package *semPlot* (Epskamp, 2015). A CFA attempts to determine if the researcher's hypotheses, about the constructs (i.e. factors, or latent variables) underlying the data, fit the dataset, and considers that the total variance is the sum of the variance in common between the measured variables (i.e. indicators) and of the variance unique to each indicator[2]. SEM builds on CFA models and allows for the use of mediation analyses involving both latent and measured variables.

Missing values for Likert scales were replaced by the mean for each site, as proportions of missing values were 6.1% or less (1.3-6.1% – see Appendix Table A 1). Because of this, we considered the Likert variables as continuous in the following analyses. Our data was non-normal, both for univariate and multivariate normality. For this reason, and

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[2] By contrast to Principal Component Analysis (PCA), which attempts to reduce the dimensionality of the data with no prior hypothesis from the researcher and considers the entirety of the variance of all the variables as common to (i.e. shared by) all measured variables (Jolliffe & Cadima, 2016).

due to our large sample size, we used a robust estimation method, namely Maximum Likelihood with Satorra-Bentler correction (MLM) (Satorra & Bentler, 1994) for both parameter estimates and goodness-of-fit statistics.

Note that, due to their nature, missing values (total NA = 85) for the variables "age" (NA = 32 – 2.2%), which can hardly be imputed, and "gender" (NA = 41 – 2.9%) and "social interaction" (NA = 16 – 1.1%), which constituted binary variables in our study, were not imputed and were automatically removed (listwise) from the analyses.

Additionally, we removed all case data for univariate outliers (total N = 52 – 3.6%), as detected with boxplots over all data (see Figure 2.2), that is values > 1.5 * IQR (interquartile range). After the removal of those univariate outliers, the total number of participants included in the subsequent analyses was 1377.

Based on the results from previous works and the literature, we hypothesized three underlying factors in our soundscape assessment data (see Figure 2.3 for the original CFA model): a pleasantness ("PL") factor and an eventfulness ("EV") factor. The subsequent iterations of the model, including the final model, retain this 2-factor structure. In order to freely estimate the direct effects of factors on their indicators, we standardized the factors to constrain them. Note that Site was entered in the model as a clustering variable, to account for potential differences in the environment due to site location and layout.

Different types of fit were estimated with different indices (Kline, 2016):

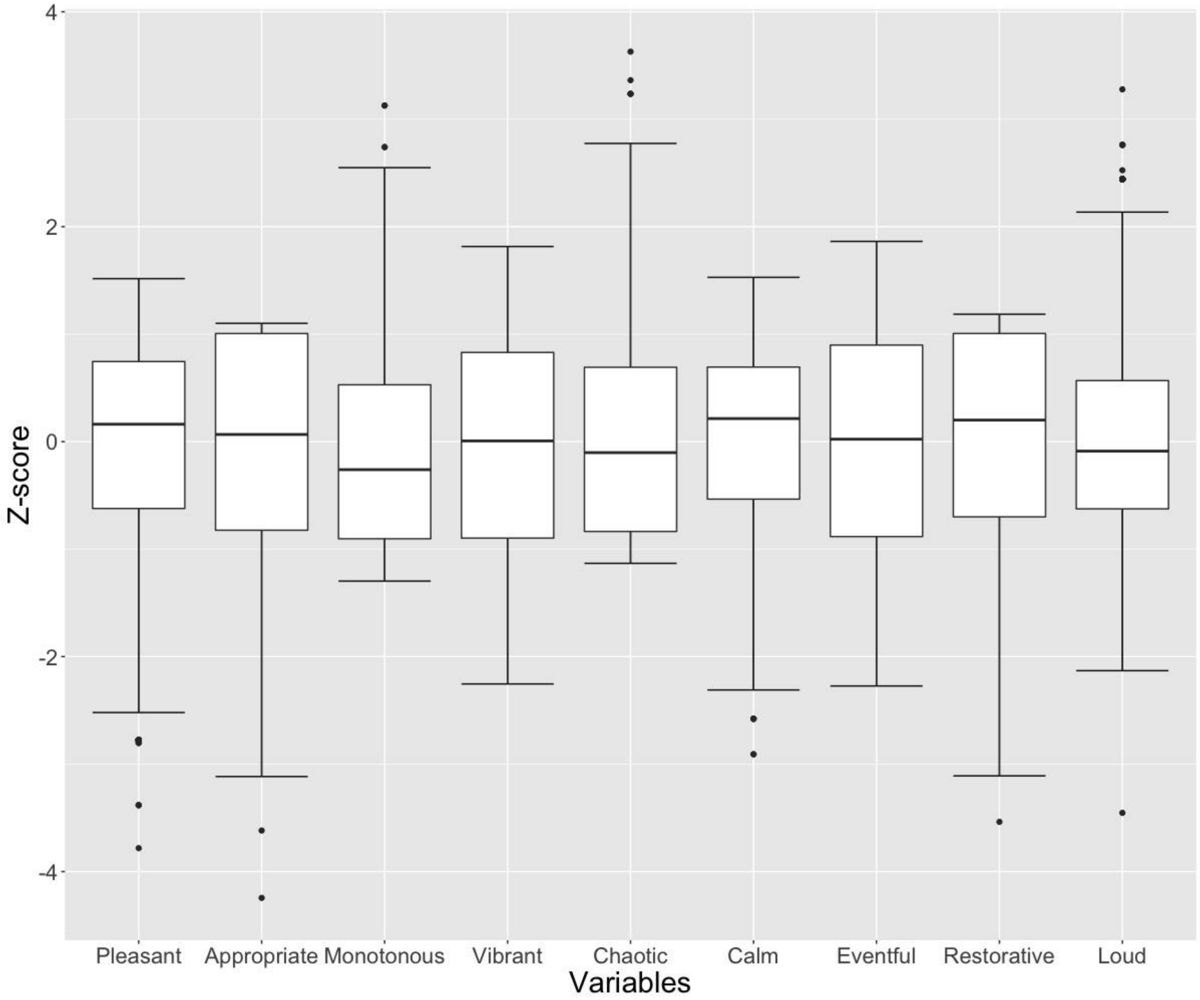

Figure 2.2. Distribution of each Likert variable over all sites (outliers shown with black dots).

- the original chi-square (χ^2) statistic[3] measures departure from perfect fit and is overly sensitive to large sample size (n > 200) and non-normal data – a fitting model should not, but models with large sample sizes often do, have a significant χ^2;

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[3] Because we used the Maximum Likelihood estimation method with Satorra-Bentler correction, we reported the Satorra-Bentler scaled chi-square values (χ^2_{SB}) when appropriate.

- the comparative fit index (CFI) compares the departure from close fit of the tested model versus of the corresponding "null" model – a CFI ≥ 0.90 is considered acceptable, but a CFI ≥ 0.95 is needed for good fit;
- the Root Mean Square Error Approximation (RMSEA) measures departure from approximate fit and favors models with more degrees of freedom and larger sample sizes – should be ≤ 0.05;
- the Standardized Root Mean Square Residual (SRMR) measures differences between implied and observed covariance matrices – should be ≤ 0.08;

Once the CFA fit was ascertained over the entire dataset, we tested the measurement invariance between the French and English versions (see Appendix Table A 2 for translations). In short, measurement invariance examines if the operationalization of a construct holds the same meaning under the different conditions of interest (Kline, 2016), French and English versions in our case.

Finally, based on the CFA model obtained, we conducted an SEM to estimate the influence of measured contextual variables on the CFA factors: four person-related variables ("age", "gender", "extraversion", "noise sensitivity") and one situation-related variable ("social interaction"). Based on the literature, "age", "gender", and "extraversion" were hypothesized to affect "noise sensitivity" and "social interaction", which in turn were assumed to influence the two factors of "PL" and "EV", and the variable "monotonous" (see Figure 2.5).

2.3 Results

The results are structured in three parts: (1) the CFA to validate the latent constructs to be entered in the subsequent measurement invariance and structural models; (2) the measurement invariance testing between French and English; (3) and the SEM to explore contextual influences on soundscape ratings.

2.3.1 Analysis of the hypothesized latent structure of soundscape assessment

The CFA model of the soundscape assessment scales measured on-site that we initially hypothesized, based on the literature and our PCA results from previous years (Tarlao et al., 2019), was as follows (see Figure 2.3):

- "PL" factor measured by the variables "pleasant", "appropriate", "calm", "restorative", "chaotic", and "loud";
- "EV" factor measured by the variables "eventful", "vibrant", "chaotic", and "loud".

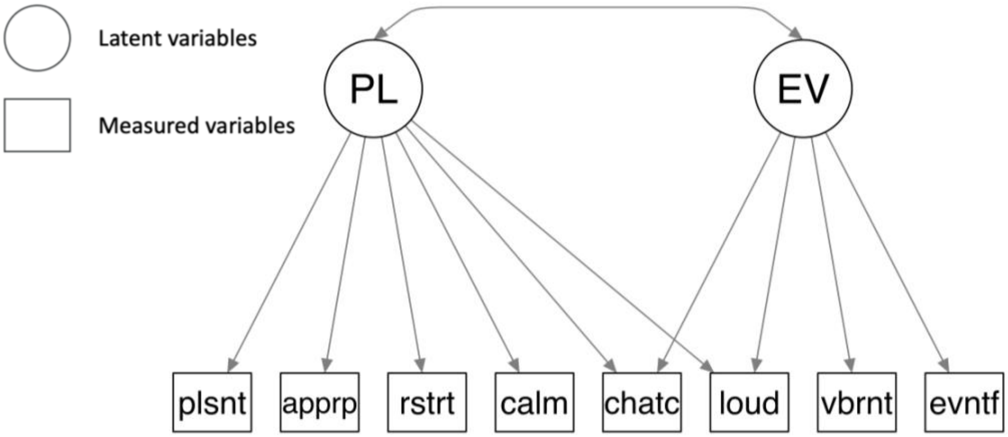

Figure 2.3. Theoretical structure of the originally-hypothesized CFA model of soundscape ratings, before improvement.

The model fit was acceptable but not excellent, with $\chi^2_{SB} = 372.96$, df = 17, $p < 0.001$; robust CFI = 0.930; robust RMSEA = 0.087, 90% CI[4] [0.079, 0.095]; and SRMR = 0.050. In consequence, we looked at modification indices to explore how to improve the model, which suggested adding the "calm" measured variable to the "EV" factor definition (mi = 100.77). This is supported by the theory behind the SSQP scales, wherein "calm" is expected to correlate partially to both the *Pleasantness* and the *Eventfulness* dimensions (Axelsson et al., 2010). This new model (see Figure 2.4) yielded a good fit, with $\chi^2_{SB} = 186.33$, df = 16, $p < 0.001$; robust CFI = 0.971; robust RMSEA = 0.057, 90% CI [0.050, 0.065]; and SRMR = 0.028, and was therefore retained.

The estimates of the factor loadings in the improved model (see Table 2.2 and Figure 2.4) were middling to large (0.28 – 0.75) and statistically significant ($p < 0.001$). The "pleasant" (0.75), "appropriate" (0.60), "restorative" (0.53) and "calm" (0.65) variables loaded positively, while the "chaotic" (-0.50) and "loud" (-0.48) variables loaded negatively on the latent factor called "PL" to represent the *pleasantness* axis from previous PCA works. In parallel, "calm" (-0.28) loaded negatively, and "chaotic" (0.35) and "loud" (0.35), as well as the additional variables of "eventful" (0.68) and "vibrant" (0.58), loaded positively on the latent factor "EV", representing the *eventfulness* axis from previous PCA works.

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[4] CI = confidence interval.

Additionally, the two latent variables “PL” and EV” are not strictly independent, showing a significant ($p < 0.001$) but weak positive covariance (cov = 0.235, SE[5] = 0.023), which is expected, as they share some measured variables.

Table 2.2. Factor loadings and standard errors (SE) for the retained CFA model.

	PL		EV	
	Loadings	SE	Loadings	SE
Pleasant	0.754	0.024		
Appropriate	0.603	0.008		
Restorative	0.531	0.017		
Calm	0.645	0.031	-0.283	0.027
Chaotic	-0.495	0.022	0.347	0.046
Loud	-0.475	0.020	0.353	0.012
Eventful			0.675	0.018
Vibrant			0.576	0.018

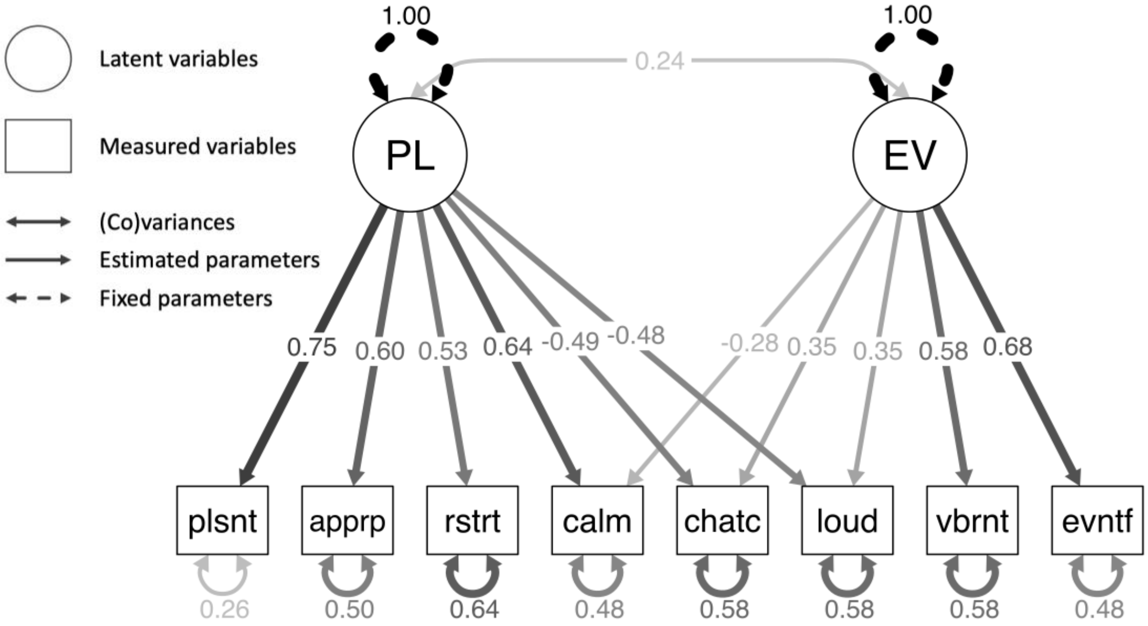

Figure 2.4. Retained CFA model with estimates of pattern coefficients (straight arrows), and variances and covariances (curved arrows). The width and color of the arrows are proportional to the unstandardized parameter estimates.

2.3.2 Measurement invariance between French and English language versions

Based on the retained CFA model, we tested the language invariance of our measurement tool (see Appendix Table A 2 for English and French items). Previously, our PCAs have shown a high similarity between French and English results with the SSQP (Tarlao et al., 2016), but language invariance of soundscape questionnaires has not been tested yet to our knowledge.

Measurement invariance testing consists of four steps, each more restrictive than the previous one: configural invariance, metrical invariance, scalar invariance, and strict invariance (strict invariance is rarely needed and therefore rarely tested (Kline, 2016, pp. 396–399)). Validating each subsequent step is carried out by comparing fit indices for each model to the last step, implying that each step's model depends on the validation of the previous step's model. This validation relies on testing the change in overall fit between two subsequent models, by conducting a chi-square difference ($\Delta\chi^2$) test. For our non-normal data, the robust $\Delta\chi^2$ test was conducted on the non-corrected χ2 using the Satorra-Bentler correction method (see $\Delta\chi^2_{SB}$ in Table 2.3). This test is, however, susceptible to sample size and, in our case, was highly significant (see Table 2.3) for each model comparison, because we have large samples (French, n = 1016, and English n = 361). In consequence, we needed to investigate the difference between other model fit values: CFI, RMSEA, and SRMR. A difference in CFI (ΔCFI) ≤ 0.010 (Chen, 2007; Cheung & Rensvold, 2002) and a difference in RMSEA (ΔRMSEA) ≤ 0.015 (Chen, 2007) are considered reasonably accurate to detect invariance for large samples.

The first step is configural invariance, wherein all parameters are freely estimated. Using Language as the grouping variable, the model fit was judged acceptable to accept configural invariance (see Table 2.3). This level of invariance indicates that the same indicators load on the same factors between the two groups. This procedure allows for a “visual” comparison of English- and French-speaking participants, much like what has been done previously with PCAs in the soundscape assessment literature (e.g., Davies et al., 2014; Jeon et al., 2018; Sudarsono et al., 2017; Sun et al., 2019; Tarlao et al., 2016, 2019).

The second step is metric invariance, wherein the pattern coefficients (or factor loadings) of the indicators on their respective factors are constrained; that is, the model forces identical coefficients across groups. In our case, the model fit was not appreciably worse; that is, the CFI was acceptable, while the differences in CFI and RMSEA are within bounds (see Table 2.3). Thus retaining the metric invariance hypothesis allowed us to conclude that the regression coefficients of each indicator on their respective factors are the same across groups, and we are allowed to compare estimated factor variances and covariances. Validating the metric invariance of our two language versions allowed us to conduct the subsequent steps of our study, that is to conduct regressions as part of the SEM.

The third step is scalar invariance, wherein the intercepts are added to the list of constrained parameters. The intercept of an indicator is the score it takes when its factors are zero; that is, scalar invariance tests the hypothesis that the measurement scales are used in the same way across groups. In our case, the model yielded a ΔCFI too large to justify its retention (see Table 2.3). To understand which indicator(s) were potentially not invariant, we ran a Lagrange Multiplier test, which approximates the improvement in fit from freeing the equality constraints. The multivariate test was significant (χ^2 = 84.36, df = 19, $p < 0.001$), indicating the need to look at univariate tests. Univariate tests suggested that releasing the intercept of the item “vibrant” (χ^2 = 25.22, df = 1, $p < 0.001$) would improve the fit. This model (model M3a in Table 2.3) was still just outside the range of acceptable values, so we reiterated the Lagrange Multiplier test, which was significant (χ^2 = 57.77, df = 18, $p < 0.001$) and indicated the need to release the intercept of “chaotic” (χ^2 = 19.66, df = 1, $p < 0.001$). However, we decided the latter did not make theoretical sense (MacCallum et al., 1992), both because our previous work never highlighted the translation of this item as problematic and because the words are very close in both languages (“*chaotic*” and “*chaotique*”). For this reason, we decided to reject scalar invariance entirely (see Table 2.3).

Table 2.3. Tests of measurement invariance between French (n = 1016) and English (n = 361). All $\Delta\chi^2_{SB}$ are highly significant ($p < 0.001$).

Model	χ^2_{SB} (df)	CFI	RMSEA (90% CI)	SRMR	Comparison	$\Delta\chi^2_{SB}$ (Δdf)	ΔCFI	ΔRMSEA	ΔSRMR	Retain
M1: Configural	242.04 (32)	0.959	0.069 (0.061-0.077)	0.033	–	–	–	–	–	Y
M2: Metric	275.54 (41)	0.950	0.067 (0.060-0.074)	0.040	M2 vs. M1	40.91 (9)	-0.009	-0.002	0.007	Y
M3: Scalar	400.07 (47)	0.929	0.075 (0.068-0.082)	0.046	M3 vs. M2	164.62 (6)	-0.021	0.008	0.006	N
M3a: Partial Scalar	342.42 (46)	0.939	0.070 (0.063-0.077)	0.043	M3a vs. M2	65.92 (5)	-0.011	0.003	0.003	N
M3b: Partial Scalar	298.10 (45)	0.947	0.066 (0.059-0.073)	0.041	M3b vs. M2	22.32 (4)	-0.003	-0.001	0.001	N

Note: Partial models have the intercepts of Vibrant (M3a, M3b) and Chaotic (M3b) released from the equality constraints across groups.

The fourth step and most restrictive level of invariance is strict invariance. It assumes, on top of the equality constraints of the scalar invariance model, that error variances and covariances are equal across groups. Constraining the amount of variance assumed to be due to error hypothesizes that indicators precision of measurement is the same across groups. In our case, we could not test for strict invariance since we did not obtain partial scalar invariance.

Ultimately, our data showed metric invariance between French and English; that is, with loadings comparable between languages, allowing the use of metric statistical methods like regressions, as used in the SEM.

2.3.3 Analysis of contextual influences on soundscape assessment

This section covers the investigation of the influence of the person-related variables "age", "gender", "extraversion", and "noise sensitivity", and the situational variable "social interaction" on soundscape assessment, with SEM. The hypothesized SEM model of contextual influences on soundscape assessment was based on the retained CFA model (see Figure 2.4), presented in section 2.3.1.

The covariance matrix for the SEM model is reported in Appendix Table A 3. The model fit was acceptable but not excellent, with $\chi^2_{SB} = 559.84$, df = 62, $p < 0.001$; robust CFI = 0.923; robust RMSEA = 0.054, 90% CI [0.050, 0.059]; and SRMR = 0.036. Consequently, we looked at how to improve the model with modification indices, which indicated the possibility to add three correlations to the model: monotonous with chaotic, loud with sensitive, and pleasant with appropriate (see Figure 2.5). We considered those suggestions theoretically sound, based on our previous work with PCAs, which showed associations between chaotic and monotonous and between pleasant and appropriate (Tarlao et al., 2019), and based on the literature showing that people who report a higher noise sensitivity tend to judge sounds as louder (Ellermeier et al., 2001). The final model (see Table 2.4 and

Figure 2.6) had a good fit, with $\chi^2_{SB} = 397.88$, df = 59, $p < 0.001$; robust CFI = 0.948; robust RMSEA = 0.046, 90% CI [0.042, 0.050]; and SRMR = 0.033.

However, not all regressions were significant (see Table 2.4). The factor loadings and covariances estimates being very similar to the ones obtained in the CFA reported in section 2.3.1, on which this SEM is based, we will only refer the reader to Table 2.4 for further details.

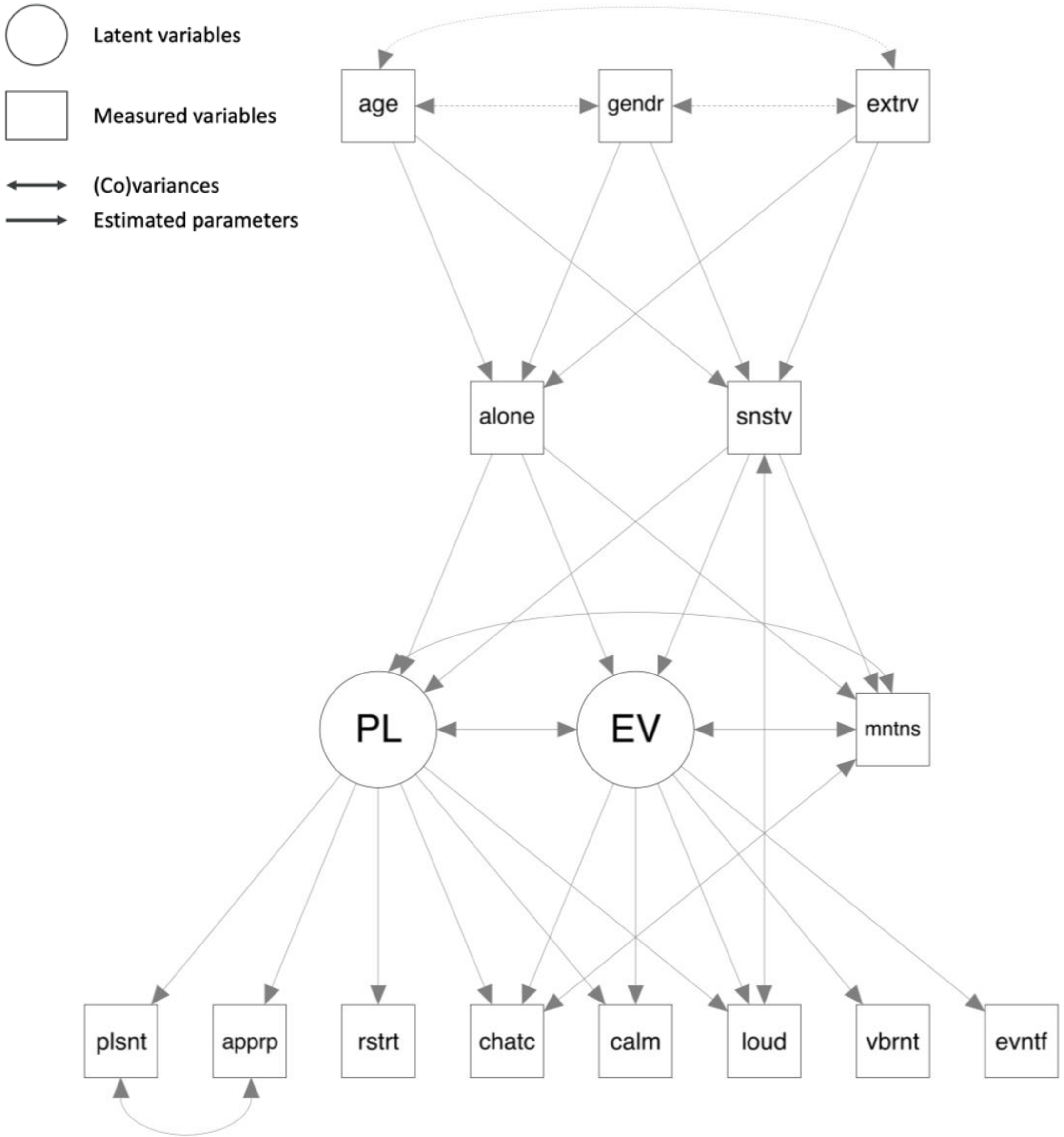

Figure 2.5. Theoretical structure of the retained SEM model.

The regression results from the SEM model support the hypotheses that “PL” (i.e. *pleasantness*) increased with “social interaction” (B = 0.146, SE = 0.069, β[6] = 0.078) and decreased with “noise sensitivity” (b = -0.117, SE = 0.042, β = -0.114), while “EV” (i.e. *eventfulness*) only decreased with “social interaction” (b = -0.077, SE = 0.006, β = -0.036) and “monotonous” only decreased with “noise sensitivity” (b = -0.101, SE = 0.028, β = -0.104). In other words, an increase in “social interaction” was associated with an increase in “PL” and a decrease in “EV,” while an increase in “noise sensitivity” was associated with a decrease in both “PL” and “monotonous.”

Additionally, “social interaction” decreased with “age” (b = -0.008, SE = 0.001, β = -0.241) and “gender” (b = -0.036, SE = 0.010, β = -0.038), and increased with “extraversion” (b = 0.019, SE = 0.004, β = 0.041). Moreover, “noise sensitivity” increased with “age” (b = 0.017, SE = 0.001, β = 0.227) and was associated with “gender” (b = -0.217, SE = 0.068, β = -0.110). Because of the coding of the gender variable (0 = women, 1 = men), this finding implies that women were more likely to occupy a public space in groups and to report being sensitive to noise. As for the other factors, an increase in “age” correlated to a decrease in “social interaction” and an increase in “noise sensitivity,” while an increase in “extraversion” was correlated to an increase in “social interaction.”

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[6] Standardized regression coefficients (labeled β) are reported to provide an indication of the effect size.

Table 2.4. Parameter estimates of SEM model: $\chi^2_{SB} = 559.84$, df = 88, $p < 0.001$; CFI = 0.923; RMSEA = 0.054, 90% CI [0.050, 0.059]; SRMR = 0.036; N = 1296. Grey text indicates non-significant estimates.

Regression path	Estimate	SE	P-value	Standardized estimate
PL =~ Pleasant	0.774	0.023	< 0.001	0.805
PL =~ Appropriate	0.620	0.008	< 0.001	0.641
PL =~ Chaotic	-0.558	0.027	< 0.001	-0.587
PL =~ Calm	0.706	0.021	< 0.001	0.727
PL =~ Restorative	0.574	0.016	< 0.001	0.588
PL =~ Loud	-0.537	0.018	< 0.001	-0.554
EV =~ Vibrant	0.622	0.017	< 0.001	0.642
EV =~ Eventful	0.647	0.019	< 0.001	0.668
EV =~ Chaotic	0.380	0.049	< 0.001	0.397
EV =~ Loud	0.379	0.005	< 0.001	0.387
EV =~ Calm	-0.319	0.017	< 0.001	-0.327
PL ~ Social Interaction	0.146	0.069	0.035	0.068
PL ~ Noise Sensitivity	-0.117	0.042	0.005	-0.114
EV ~ Social Interaction	-0.077	0.006	< 0.001	-0.036
EV ~ Noise Sensitivity	0.012	0.016	0.452	0.012
Monotonous ~ Social Interaction	-0.011	0.030	0.710	-0.006
Monotonous ~ Noise Sensitivity	-0.101	0.028	< 0.001	-0.104
Social Interaction ~ Age	-0.008	0.001	< 0.001	-0.241
Social Interaction ~ Gender	-0.036	0.010	< 0.001	-0.038
Social Interaction ~ Extraversion	0.019	0.004	< 0.001	0.041
Noise Sensitivity ~ Age	0.016	0.001	< 0.001	0.227
Noise Sensitivity ~ Gender	-0.217	0.068	0.001	-0.110
Noise Sensitivity ~ Extraversion	-0.040	0.031	0.198	-0.041
PL ~~ EV	0.284	0.024	< 0.001	0.284
PL ~~ Monotonous	-0.194	0.008	< 0.001	-0.204
EV ~~ Monotonous	-0.220	0.009	< 0.001	-0.232
Chaotic ~~ Monotonous	0.114	0.013	< 0.001	0.158
Loud ~~ Noise Sensitivity	0.121	0.017	< 0.001	0.161
Pleasant ~~ Appropriate	0.093	0.023	< 0.001	0.215

Note: table uses *lavaan* notation (=~: factor loadings; ~: regression paths; ~~: covariances)

We also tested the indirect effects of “age”, “gender”, and “extraversion”, as mediated through “social interaction”, or “noise sensitivity” (see Table 2.5), with an online Sobel test (Preacher & Leonardelli, 2001). We found a significant indirect effect of “age” on “PL” ($b_1 * b_2$

= -0.001, SE = 0.001) and “EV” (b_1*b_2 = 0.001, SE = 0.000) through “social interaction.” In other words, since an increase in “age” was associated with a decrease in “social interaction”, and the latter implies a decrease in “PL”, older people rated the soundscape lower on the “PL” latent variable due to occupying the public space on their own more than younger people. For the same reason, older people rated the soundscape as higher on the “EV” variable, since a decrease in “social interaction” is associated with an increase in “EV”.

Table 2.5. Mediation (indirect) effects of the SEM model, as calculated with Sobel tests. Grey text indicates non-significant effects.

	b_1*b_2	Test statistic	SE	*p*
Age → Social Interaction →PL	-0.001	-2.046	0.001	0.041
Age → Social Interaction → EV	0.001	6.789	0.000	0.000
Age → Social Interaction → Monotonous	0.000	0.366	0.000	0.714
Age → Noise Sensitivity → PL	-0.002	-2.744	0.001	0.006
Age → Noise Sensitivity → EV	0.000	0.749	0.000	0.454
Age → Noise Sensitivity → Monotonous	-0.002	-3.519	0.000	0.000
Gender → Social Interaction → PL	-0.005	-1.824	0.003	0.068
Gender → Social Interaction → EV	0.003	3.466	0.001	0.001
Gender → Social Interaction → Monotonous	0.000	0.365	0.001	0.715
Gender → Noise Sensitivity → PL	0.025	2.099	0.012	0.036
Gender → Noise Sensitivity → EV	-0.003	-0.730	0.004	0.465
Gender → Noise Sensitivity → Monotonous	0.022	2.390	0.009	0.017
Extraversion → Social Interaction → PL	0.003	1.933	0.001	0.053
Extraversion → Social Interaction → EV	-0.001	-4.455	0.000	0.000
Extraversion → Social Interaction → Monotonous	-0.000	-0.366	0.001	0.715
Extraversion → Noise Sensitivity → PL	0.005	1.171	0.004	0.242
Extraversion → Noise Sensitivity → EV	-0.000	-0.648	0.001	0.517
Extraversion → Noise Sensitivity → Monotonous	0.004	1.215	0.003	0.224

“Age” also showed negative indirect effects on “PL” ($b_1*b_2 = -0.002$, SE = 0.001) and “monotonous” ($b_1*b_2 = -0.002$, SE = 0.000) mediated by "noise sensitivity." Following the same logic as above, these results indicate that older people rated the soundscape lower on the “PL” and “monotonous” variables due to being more sensitive to noise.

There were also positive indirect effects of “gender” on “EV” mediated by “social interaction” ($b_1*b_2 = 0.003$, SE = 0.001) and on “PL” ($b_1*b_2 = 0.025$, SE = 0.012) and “monotonous” ($b_1*b_2 = 0.022$, SE = 0.009) through “noise sensitivity.” That is, as women occupied the public space more in groups than men, which was associated with a decrease in “EV,” women rated the soundscape lower on the “EV” variable due to being more in groups. Moreover, as women tend to be more sensitive to noise, which was associated with a decrease in “PL” and “monotonous,” they rated the soundscape lower on the “PL” and “monotonous” variables due to being more sensitive to noise.

Finally, “extraversion” showed a negative effect on “EV” ($b_1*b_2 = -0.001$, SE = 0.000) mediated by “social interaction.” This finding suggests that, as extraverted people were more likely to engage in social interaction, they consequently rated the soundscape lower in “EV.”

Note that two variables tended ($p < 0.01$) to have an effect through “social interaction” on “PL”: “gender” ($b_1*b_2 = -0.005$, SE = 0.003) and “extraversion” ($b_1*b_2 = 0.003$, SE = 0.001). As both women and extraverted people occupy the public space more in groups, they, consequently, tended to rate the soundscape as higher in “PL.”

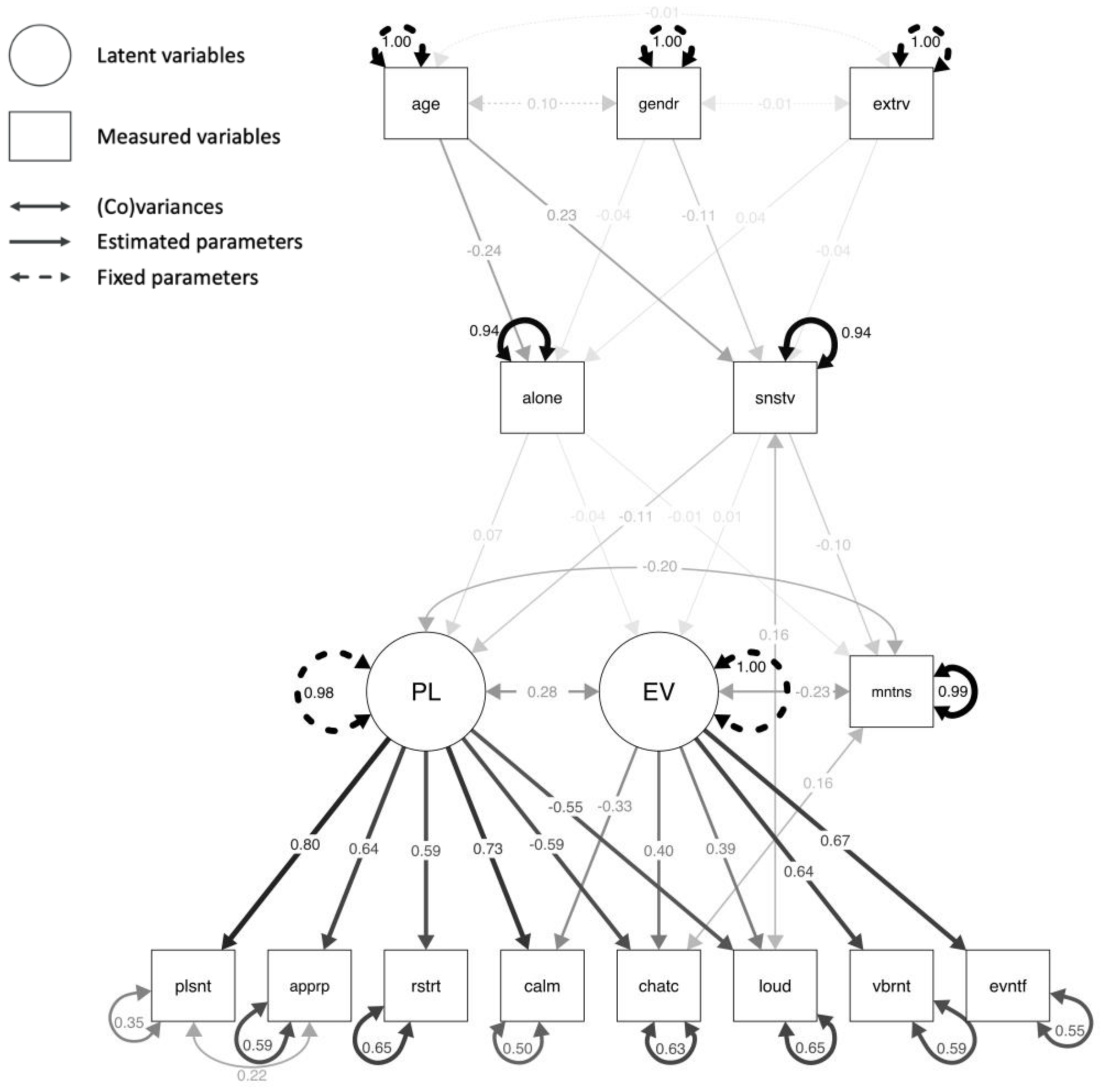

Figure 2.6. Tested SEM model with standardized parameter estimates. The width and color of the arrows is proportional to the unstandardized parameter estimates.

2.4 Discussion

This meta-analysis using over 1400 questionnaires collected on four sites in Montreal in English and French provides new insights on the influence of contextual factors influencing soundscape evaluation. Our contributions are both theoretical and methodological. We first tested for language invariance of soundscape evaluation scales, then confirmed the two-dimensional underlying conceptualizations of soundscape evaluation in terms of *pleasantness* and *eventfulness*, and finally propose a Structural Equation Model to account for the role of contextual factors in soundscape evaluation. We now explore these contributions in light of previous research.

2.4.1 Validation of SSQP underlying conceptualizations

To the best of our knowledge, this paper is the first to present a statistical evaluation of the underlying structure of some commonly-used soundscape assessment tools, including the SSQP (Axelsson et al., 2010), as well as of the comparability of French and English versions of such tools. This paper also contributes to the growing literature exploring contextual influences on soundscape (e.g., Herranz-Pascual et al., 2017, 2010).

In a first step, we found that the underlying structure of two factors, *pleasantness* and *eventfulness,* for soundscape judgments we previously found with PCAs (Tarlao et al., 2019), led to a decent fit to the data we collected in multiple public spaces in the same city. That is not to say that other models would not explain our data just as well, but it offers support for theories of soundscape judgments developed in the past decade (e.g., Axelsson et al., 2010). It should, however, be noted that our model does not fit the exact orthogonality of the proposed SSQP and ISO two-dimensional models (Axelsson et al., 2010; International Organization for Standardization, 2019). First, our data has consistently (Tarlao et al., 2016, 2019) shown closer relationships between certain variables (e.g., “pleasant” and “calm” or “vibrant” and “eventful”). Second, “monotonous” has shown more complexity than those aforementioned models may suggest (also see section 2.4.2 below), both as a separate dimension in both languages (Tarlao et al., 2016, 2019) and with nuances of meaning in each language (Tarlao et al., 2016).

2.4.2 French translation of SSQP

Subsequently, we show that the way our participants in both French and English understand the soundscape items is similar, but not how they use the measurement scale. Specifically, the “vibrant” (“*dynamique*”) item was significantly different between French and English translations, which is theoretically plausible. Here, an explanation could lie within its more positive use in English than in French. The validation of similar variable associations between languages (metric invariance) led us to conclude we could combine our data in both languages for our subsequent analyses, which required the use of metric statistical methods like regressions. However, since we failed to reach scalar invariance, we do not recommend the use of scalar statistical methods relying on mean comparisons like ANOVAs. We decided to stop our invariance analyses when the “chaotic” item was deemed the most mathematically significant to release, as we did not have theoretical justification to do so. But further investigation could help us understand if this item is indeed understood differently between languages and if we can improve on it. Additionally, the context of this study is specific to a predominantly bilingual city (Montreal, Canada), and further investigation in singular language contexts should be conducted for confirmation. Nevertheless, the results are promising, as all but two items remain invariant between French and English at the scalar level.

It should also be noted that we could not include the "monotonous" item in the CFA due to identification constraints, and this item would almost certainly influence the invariance results, as our previous PCA results suggest (Tarlao et al., 2016, 2019). We have previously observed differences in the conceptualization of this item between French and English, "monotonous" ("*monotone*") being also associated with "calm" ("*calme*") in the French version, as opposed to being on its own in English (Tarlao et al., 2016). Generally, we found "monotonous" to load on a separate axis, sometimes associated with "chaotic" or "calm" (Tarlao et al., 2019). Additionally, a preliminary exploration of Quebecers' understanding of this item suggests that it may not be understood clearly or in the same way by all respondents, sometimes associated with "annoying / boring", other times with "constant / repetitive". This is in line with differences in translations reported by other teams in France, concerning different modes of listening (e.g., holistic vs. listening process (Raimbault, 2006)) or comparisons with the original scales in Swedish (e.g., Jeon et al. (2018) translated monotonous as "ennuyeux", which can be translated as "boring" or "annoying" depending on the context).

This line of research has recently been expanded to other languages as part of an international collaborative effort to compare translation of soundscape scales across languages (Aletta et al., 2020).

2.4.3 Personal and situational influences on soundscape evaluations

Finally, for the core of this paper, we explored and tested the first-of-its-kind Structural Equation Model of personal and contextual influences on soundscape evaluation, using this confirmed latent structure (see model diagram in Figure 2.5). SEM has been previously used in soundscape research to model influences of the visual environment (Hong & Jeon, 2015), as well as of expectations and preferences (Acun & Yilmazer, 2019), on soundscape, as well as influences of soundscape on visiting experience (Liu et al., 2019). However, to the best of our knowledge, this is the first soundscape study conducting SEM to examine a model of influences on soundscape ratings collected over multiple urban public spaces.

This model included two levels of influences: first, directly influencing the soundscape assessments were the contextual factor of "social interaction" (using the space alone vs. in a group) and the personal factor of "noise sensitivity"; second, indirectly influencing the soundscape assessments through those aforementioned two factors were the person-related factors of "age", "gender", and "extraversion."

We found that people in groups rated soundscapes significantly higher on the *pleasantness* dimension (which includes ratings of pleasantness, appropriateness for their activity, restorativeness by allowing for a break in their day, calmness, as well as chaoticness and loudness negatively loaded), and significantly lower on the *eventfulness* dimension (which includes eventfulness, vibrancy, loudness, and chaoticness, as well as calmness negatively loaded). It may be seen as surprising that people in groups find the soundscape less eventful than solitary users, but a plausible explanation could be that people pay less attention to the events in the soundscape when they are in groups, as their attention is drawn to their partners. Steffens et al. (Steffens et al., 2017) found that the effect of social interaction on *pleasantness* was related to information processing style and personality traits. Similarly, we found that extraverted people, who occupy the space significantly more in groups, rated the soundscape as significantly less eventful than introverted people, who were more solitary. However, the indirect effect suggesting that extroverted people find the soundscape more pleasant because they go out more in groups than introverted people was only marginally significant.

We also observed that women and younger people are significantly more likely than men and older people to visit a public space in groups, and a higher social interaction is associated with significantly higher pleasantness and lower eventfulness. For women, only the indirect effect on eventfulness is significant, while it is marginally significant for pleasantness. For younger people, both of these indirect effects are significant.

Additionally, in line with the literature, we found that women are significantly more likely than men to be more sensitive to noise (Aniansson et al., 1983), and younger people report being less sensitive to noise than older people (Schreckenberg et al., 2010). People who reported a higher sensitivity to noise rated their soundscape lower in *pleasantness* and *monotony* (that is, the “monotonous” item). This means that women and older people rate the soundscape as less pleasant and less monotonous than men and younger people because they are more sensitive to noise. The first result, of more noise sensitive participants judging their soundscape lower in *pleasantness,* perhaps easily anticipated based on intuition and the literature showing an increase in perceived unpleasantness of sounds in relation to higher noise sensitivity (Ellermeier et al., 2001), nevertheless is an interesting confirmation in more complex sound environments. Multiple explanations could contribute to the result of more sensitive people finding their soundscapes less monotonous: it could be that they pay more attention to their surroundings, or that they actively choose better soundscapes to spend time in, or a combination of the two.

2.4.4 Limitations and future directions

As was shown, the scalar invariance, needed to conduct statistical methods relying on mean or variance comparison (e.g., ANOVA), was not validated in this study, but results look promising, as only two variables were visibly problematic. It should also be noted that the "monotonous" variable could not be investigated with this method, as it was conceptually isolated from the rest of the variables. Further study, involving more in-depth discussion of participants' understanding of the scales, should permit improvements on the translation of the problematic scales to refine our French version.

Additionally, Sobel tests are generally recommended only if no better alternative can be implemented (such as due to no access to raw data – (Hayes, 2018, p. 97; Preacher & Leonardelli, 2001)). The focus of this paper was to explore our French translation and a more parsimonious model of contextual influences on soundscape evaluations as a first step, and future research will investigate more comprehensive models, including more rigorous approaches to indirect effects, such as bootstrap approaches, and involving additional contextual factors. These next steps will also include exploring potential direct effects, such as a direct effect of "age" on "monotonous," amongst others (Bockstael et al., 2019), as well as potential moderated mediation effects of contextual factors.

Finally, the tested SEM model did not yield excellent performances, which points to the need to improve the questionnaire; although it should be noted that this study did not test the validity and reliability of the theorized underlying factors as we had already done so in previous work (Tarlao et al., 2019). As mentioned, further study in improving the questionnaire will be conducted, which should improve the performance of the entire model. In general, more work is needed from the field to refine and validate the commonly-used soundscape questionnaires (Axelsson et al., 2019), including the collection methods recommended by the ISO (International Organization for Standardization, 2018).

2.4.5 Conclusions

To sum up, we confirmed the underlying two-dimensional structure of soundscape assessment that has emerged from the field (Axelsson et al., 2010; Jeon et al., 2018), by which people evaluate their sound environment in terms of, first, *pleasantness* and, second, *eventfulness*. However, areas of uncertainty remain (e.g., regarding "monotonous"), and improvements are still to be expected in the future.

We further validated our French translation as invariant from the English version to the level of metric invariance, thus allowing to compare or combine them for any statistical method relying on the distance and relations between variables (e.g., regressions). Results are also promising for scalar invariance, with only two potentially problematic scales.

We proposed a Structural Equation Model to account for the influence of contextual factors on soundscape evaluations in our pursuit of understanding city user experience. We observed direct influences of "social interaction" (using the space alone vs. in a group) and "noise sensitivity"; as well as indirect influences of "age", "gender", and "extraversion." Although, the influence of context on soundscape is a broad and diverse question, this work provides some answers regarding a subset of contextual factors. Our findings provide a better understand of the complex role person-related and situation-related factors play in soundscape evaluation. In short summary, people occupying the public space in groups find the soundscape more pleasant and less eventful than solitary users, and an increased sensitivity to noise is associated with decreased pleasantness and monotony.

This model addresses the recurring challenge of individual variation in soundscape evaluation across individuals and situations (Bild et al., 2016). On theoretical grounds, this model represents a critical step for the soundscape research field to develop further and build unified theories. It also calls for further research investigating how other person-related (e.g., vulnerability to stress, information processing styles) and situation-related (e.g., activity conducted, time of the day/year) factors affect the way people experience urban environments. On practical grounds, the findings could inform the design of more inclusive public spaces that accommodate the differing needs of diverse groups of city users.

2.4.6 Transition

This chapter investigated the soundscape experience of city users to understand how soundscape is shaped by context. Through the analysis of hundreds of questionnaires collected over a range of public spaces, this study revealed a complex pattern of contextual influences on *in situ* soundscape evaluations, which points to the need for researchers to investigate further both on site and in the laboratory, and for urban professionals to take this into account in their practice. Laboratory experiments need first to be validated as *ecologically valid* – that is, as eliciting similar perceptions as on-site experiences. The following chapters aim to accomplish this: first, **Chapter 3** will examine the ecological validity of soundscape reproduction in the laboratory; second, **Chapter 4** will explore the potential of a soundscape simulation prototype as a design aid for urban professionals.

Chapter 3 [7] – Assessing the ecological validity of soundscape reproduction in different laboratory settings

Cynthia Tarlao, Daniel Steele, Catherine Guastavino

Abstract

The ever-growing body of soundscape research includes studies conducted both in everyday life environments and in laboratory settings. Yet, laboratory settings differ from in-situ and therefore may elicit different perceptions. The present study explores the *ecological validity* of soundscape reproduction in the laboratory using first-order Ambisonics and of different modes of questionnaire administration. Furthermore, it investigates the influence of the contextual factors of time of day, day of the week, and location on site on soundscape evaluations *in situ* and in the laboratory, based on the Swedish Soundscape Quality Protocol. We first tested measurement invariance between the computer-based and pen-and-paper administration of the soundscape questionnaire. We then investigated the influence of the above-mentioned contextual factors on soundscape evaluations, as well as the effect of stimuli selection in the laboratory. The analyses confirmed the underlying dimensions of proposed soundscape assessment questionnaires, confirmed metric invariance between computer and pen-and-paper, and revealed significant influences of time, day, and location

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[7] This chapter is a version of Tarlao, C., Steele, D., & Guastavino, C. (2021). Assessing the ecological validity of soundscape reproduction in different laboratory settings. *Manuscript Submitted for Publication.*

on soundscape scales. This research represents a critical step in rigorously assessing soundscape evaluations in the laboratory and establishes solid evidence for the use of both *in situ* and laboratory soundscape studies.

3.1 Introduction

3.1.1 State-of-the-art in soundscape research

A growing body of literature on urban soundscape has emerged to contrast urban noise mitigation (Bild et al., 2016). Soundscape, defined as the “acoustic environment as perceived or experienced and/or understood by a person or people, in context” (International Organization for Standardization, 2014), affords new strategies for urban sound management by focusing on human experience and considering sound as a resource rather than a nuisance. In this way, the soundscape approach offers opportunities for cities, both to improve urban experiences from the earliest stages of urban design, and to work on the development of new overarching policies (Bild et al., 2016).

As the ISO definition (International Organization for Standardization, 2014) suggests, soundscape research takes context into account as a critical factor in how humans perceive acoustic environments. As such, models and frameworks of the contextually-mediated relationships between soundscape and listener have started to emerge in the field (Bild et al., 2016; Brown et al., 2011; Herranz-Pascual et al., 2010), with increased interest in the last few years (Axelsson et al., 2019). Specifically of interest to us here are the spatiotemporal factors mentioned in the ISO: “The context includes the interrelationships between person and activity and place, *in space and time*” (International Organization for Standardization, 2014), based on their theorization as important influences in activity-centric soundscape frameworks (Bild et al., 2016; Brown et al., 2011; Jennings & Cain, 2013).

Urban soundscapes have been shown to vary in loudness and dominant sources as a function of time of day (Hong & Jeon, 2017; Liu et al., 2013), day of the week (weekday vs. weekend), and location within the studied space (Fraisse, 2019). However, most spatiotemporal factors examined in the literature revolve around city- or neighborhood-level location (i.e., functions of spaces) (Hong & Jeon, 2017; Liu et al., 2013), spatial characteristics of the studied space and user behavior (frequency, duration, preference) (Aburawis & Dokmeci Yorukoglu, 2018), or short-term temporality (Botteldooren et al., 2006). In this paper, we will be focusing on the spatial factor of location within the studied space, and the temporal factors of day of the week and time of day.

3.1.2 Soundscape assessment instruments

In the last decade, several soundscape measurement scales have been developed and refined to elicit human evaluations of acoustic environments (see Engel, Fiebig, Pfaffenbach, & Fels, 2018 for a methodological review). The Swedish Soundscape Quality Protocol (SSQP), developed in Swedish and English in lab-based experiments (Axelsson et al., 2010), measures soundscape evaluations along the two main dimensions of *pleasantness* and *eventfulness* and formed an important basis for the ISO standard on soundscape methodologies (International Organization for Standardization, 2018). In response to urban studies considerations (Brown, 2012), Axelsson (Axelsson, 2015) proposed adding the dimension of soundscape *appropriateness* to the SSQP, which is understood as soundscape *appropriateness* for specific activities (Steele et al., 2019) in this study. In addition, the soundscape approach considers sound as a resource, most notably in terms of the potential for restoration (Kaplan, 1995) provided by urban soundscapes

(Payne, 2008), with the recent development of the Perceived Restorativeness Soundscape Scale (Payne & Guastavino, 2018).

In parallel to the growing interest in the soundscape approach to improve urban experiences and policies (Bild et al., 2016), researchers are exploring the potential of soundscape simulation and manipulation in the laboratory. Laboratory experiments reproducing soundscapes in virtual acoustics allow for more control than *in situ* studies, especially regarding the ability to manipulate variables and explore causal relationships between them. Such increased control can come with other costs, such as artefacts introduced by the recording and reproduction techniques, an altered sensory and cognitive experience, or a lack of certain contextual factors like time of day or weather, which all contribute to limiting the transferability of findings to other contexts. Nevertheless, virtual soundscapes offer flexibility in posing new research questions for the academic community and could, in the longer term, provide opportunities for the urban design and planning communities to “visualize”, understand, manipulate, or communicate soundscapes.

3.1.3 Soundscape reproduction

Soundscape researchers are conscious of the gap between academic progress and urban practice. One important aspect of this gap is a lack of tools that are easy to use and useful for integrating sound considerations in the practice of urban professionals. Soundscape researchers therefore understand that a major avenue to bridge the research-practice gap lies in the development of soundscape simulation tools (Aletta & Xiao, 2018). Such simulation tools would offer technological support for urban professionals to understand and imagine (“sketch out”) soundscapes. However, urban professionals have not benefitted from this research up until now, because of both the lack of accessible content for non-experts (Steele, 2018) and the complexity of use of most audio manipulation technologies (Bild et al., 2016). Nevertheless, urban professionals have shown interest in 3D-reproduction of soundscapes for knowledge mobilization, for the purpose of learning from sound experts and researchers, for its immersive benefits, including “emphasiz[ing] the importance of human experience” and “show[ing] tangible design potential” (Steele et al., 2020). In the same spirit, it is no leap of the imagination to consider the potential applications to support the integration of soundscape in the design process, from design to communication of designs to stakeholders (Bild et al., 2016).

There already exists a number of commercial tools for acoustically accurate 3D simulation of soundscapes by environmental acoustics experts hired by urban professionals, such as MithraSound (Geomod & CSTB, n.d.). Such tools make use of the technical specifications of existing and envisaged urban designs to produce accurate modeling of sound sources and sound propagation but require a high degree of expertise to wield. In contrast, different soundscape simulator tools have been developed by researchers, most often for experimental testing both with research purposes and with applied goals of defining city users’ preferences in the context of specific development projects. However, most of those technologies have not been developed with the urban professional in mind, and this lack of tools to help urban professionals understand the quality of soundscapes limits their ability to consider sound beyond the required acoustic measures (Bild et al., 2016), even when they readily understand sound can be a resource for their own practice (Steele, 2018).

The premise at the root of this study stems from the idea that research-oriented spatial soundscape simulation tools, which generally aim less for physical accuracy than to center perception and experience, could offer a foundation for the development of practical applications for urban professionals with moderate changes to account for their needs. Note that these tools are not intended to displace acoustics expertise, but to complement it. In the visual analog, designers will often provide models and collages that lead to more precise CAD drawings done in collaboration with engineers.

3.1.3.1 Existing tools for soundscape reproduction

Two main uses can be distinguished for soundscape reproduction applications: first, as-is reproduction and databases, which rely directly on existing recording and reproduction techniques; and second, what can be called *simulators*, which include some level of interactive manipulation of the reproduced soundscape and sound sources. Soundscape composition has also been used for more artistic purposes (e.g., Truax, 2002), but we will not explore this aspect here. This paper makes use of the former and what follows will be a quick non-exhaustive overview of some of those direct reproduction tools in research.

Soundscape researchers have shown increasing interest in using spatial sound reproduction to study soundscape ratings in the laboratory in the last decade, starting with Brambilla and Maffei (2010), who created visual and audio design scenarios for two Neapolitan public squares to explore the potential of laboratory simulation of design changes. Interestingly, they found that the sound component always had more influence than the visuals on the overall assessment. More recently, in the same vein of designing scenarios, a

French team (Misdariis et al., 2019) composed immersive sound scenes, from recordings of outdoor spaces' backgrounds and isolated vehicles, to study noise annoyance, for which they obtained high realism ratings, although no "real life" comparisons could understandably be conducted.

For research using soundscape reproduction as is, a recent example is a study comparing soundscape ratings *in situ* and in the laboratory in order to establish a model of the factors influencing soundscape ratings (Skoda et al., 2019), which showed no differences of the overall pleasantness between the *in situ* soundwalk and the laboratory immersive reproduction. This team also found a higher correlation of overall pleasantness with soundscape pleasantness than visual pleasantness. In the same vein, a Croatian study was conducted to test the influence of sound art installations in public spaces with a "virtual soundwalk" in the laboratory (Oberman et al., 2020). This "virtual soundwalk" methodology (Oberman et al., 2018) uses 3D sound recordings and 2D panoramic pictures at fixed locations, defined by the researchers, reproduced sequentially in the laboratory, for participants to evaluate. Through comparisons of participant mean ratings of the SSQP between *in situ* and laboratory settings, the authors concluded that the "virtual soundwalk" yielded ratings similar to those collected *in situ*, thus validating the methodology. However, the authors did not provide any statistical analysis to substantiate this claim.

With both research goals and urban design applications in mind, the Urban Soundscapes of the World project compiled a comprehensive database of audio-visual recordings of systematically-selected urban sites from cities all over the world (De Coensel et al., 2017) to offer a wide range of urban soundscapes for perceptual experiments. In the same spirit of supporting research and creative practice, CityTones is a repository of soundscapes captured using 360º audio and video or photo, with both recording and labelling partially crowdsourced (Roginska et al., 2019). For an application with a more popular goal, *I Hear NY3D*, a project for capturing and reproducing 3D soundscapes in New York City, collected 3D recordings of various locations in Manhattan (Boren et al., 2013) to offer an interactive interface to experience the soundscapes of Manhattan virtually. Those awareness-raising efforts are essential to archive urban soundscapes for use in research and creative practice. The question remains open, however, as to how the use of such systems could facilitate the work of professionals of the built environment, such as urban designers, architects, etc.

In this work, the chosen method of reproduction will be Ambisonics. The Ambisonic technique (Gerzon, 1973, 1975) is most commonly used in research and now also being implemented in widespread commercial-consumer applications such as Youtube 360°. This technique can be presented on any playback configuration and prioritizes envelopment and immersion over precise localization of sound sources (Guastavino et al., 2007), elicit similar cognitive processes to *in situ* results especially in relation to urban background noise (Guastavino et al., 2005).

When conducting laboratory experiments, one should be aware of their limitations in terms of the perceptual and cognitive processes being studied. Laboratory settings differ from everyday life situations and therefore may elicit different judgments, whether through different perceptions, experiences, expectations, or biases, specifically in terms of contextual factors (for example, the reason for choosing to visit a particular space at a particular time).

This is an important tenet of experimental psychology, known as *ecological validity*. The ecological validity of data collected with spatial audio in laboratory settings has become a common matter of interest and concern for soundscape researchers (Aletta & Xiao, 2018).

3.1.4 Ecological approach

The concept of ecological validity was first introduced by Egon Brunswik (1943, 1956) and later developed into the concept we understand today by James Gibson (1979), both psychologists investigating visual perception. As Brunswik (1943) first stated, perception of our environment is ambiguous, with multiple “probable partial causes” (p. 257), and requires compromises between informative environmental cues to determine a “best bet” (p. 259) on the perception of an object. This “intrinsic lack of perfection” (p. 258) in everyday life should not be eschewed by the experimenter and the experiment should be designed to present “conditions representative of actual life” (p. 261).

Gibson is possibly better known than Brunswik for having developed the *ecological approach to visual perception* (Gibson, 1979) which is now the more common understanding of ecological validity and has been accepted by psychology textbooks: “Studies are high in ecological validity if the conditions in which the research is conducted are similar to the natural setting where the results will be applied” (Matlin, 2013, p. 12).

The ecological validity of an experimental design rests on three elements: 1) the participants being representative of the population the results are intended to be generalized to; 2) the experimental conditions being representative of the actual conditions the results are meant to apply to; and 3) the task (including instructions and data collection instruments) eliciting similar cognitive processes than in the everyday life situations (Brunswik, 1943; Guastavino, 2009). Only then can the experimenter ensure that the research design is ecologically valid, that is, that it truly allows to explore the cognitive processes of the everyday-life conditions it purports studying. This also means that it is often not possible to know in advance the extent to which a research design will be ecologically valid or not (Gibson, 1957). Even with sound theory based on previously accepted arguments and experiments, new designs need to be validated for the population, conditions, and cognitive processes they intend to represent.

3.1.4.1 Ecological approach to soundscape

The ecological approach was first applied to auditory perception with VanDerveer's (VanDerveer, 1979) work exploring the perception of environmental sounds. Gaver's work is also significant for defining the notion of *everyday listening*, in contrast to musical listening (Gaver, 1993a, 1993b) however much of it was embedded in the perception of *physical dimensions*, in relation to materials (i.e., liquids, solids, gasses) and simple events (e.g., impact, scraping, gust). This approach did not take into account higher cognitive processes of socially-constructed meaning and memory (Dubois et al., 2006) which play a critical role for complex everyday sounds. Indeed, Dubois (Dubois, 2000) showed that sounds are also perceived and identified holistically by listeners who integrate everyday situations in which the sounds are experienced into complex mental representations (Guastavino, 2018). Dubois further discusses the methodological consequences for investigating everyday cognition in laboratory settings, including reconsidering the opposition of subjective and objective (Dubois et al., 2021), recalling the arguments put forth by Brunswik (1943, 1956) and Gibson (1979).

More recently, Guastavino (Guastavino, 2009) reviewed studies that explored the three aspects of ecological validity of auditory perception of reproduced urban soundscapes. Regarding participants, sound experts (sound engineers) and non-experts (city users) focused on different aspects of the soundscape reproduction, highlighting the relationship between individual experience and ecological validity (Guastavino, 2003). Non-experts attended to the scene holistically, preferring the feeling of immersion over precision of the reproduced scene, whereas experts prioritize precision and stability in a more analytical listening strategy. Regarding condition representativeness, they found that different reproduction methods and systems were preferred depending on the soundscape reproduced (Guastavino et al., 2005; Guastavino & Katz, 2004). For example, speaker configurations including a subwoofer were found more realistic only for recordings of traffic noise. Another example is that soundscapes where sounds were expected to come from above were judged as more realistic when reproduced over a 3D[8] configuration, while 1D[8] and 2D[8] configurations were found more realistic for soundscapes where sounds needed to be clear and localizable. These results highlight the importance of choosing a reproduction system valid for the specific sounds and soundscapes (conditions) studied (Guastavino & Katz, 2004), as well as for who is evaluating them. The principle here is to make sure the

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[8] Examples of 1D, 2D, and 3D loudspeaker configurations include, respectively, a stereo setup for sounds positioned in the left-right dimension, a ring of loudspeakers around the listener with sounds spatialized on the horizontal plane, and a sphere of loudspeakers presenting sound spatialized horizontally and vertically.

information reproduced generates perceptual judgments as close to the everyday-life soundscape would (Guastavino, 2009). A more recent study combining spatial audio and video recordings found no significant differences between *in situ* and 2D Ambisonic reproduction in terms of SSQP ratings and dominant sound sources (Hong et al., 2019).

Finally, in terms of the experimental process, Guastavino showed that different reproduction systems prompted different cognitive representations (Guastavino et al., 2005). In the case of soundscape reproduction, source identification and spatial immersion, especially as it contributes to the cognitive representation of city background noise, might be most important. 3D multichannel configurations were found to offer the best spatial immersion, while source identification remained close to everyday-life situations. Hong et al. (Hong et al., 2019) also found a 2D Ambisonic reproduction method to elicit significantly higher immersion, realism, externalization, and listening experience ratings than Ambisonics-based binaural reproduction methods.

Another aspect of the experimental process is the procedure. Among several decisions, the experimenter must choose how the data collection instruments (e.g., questionnaire) will be administered. For instance, a NASA study (Hart & Staveland, 1988) found that the mode of administration of their task load index scales (NASA-TLX) influenced the results. On average, results obtained on computer were significantly higher than those obtained with a paper-and-pen method, although the patterns of responses were similar. In general, soundscape questionnaires are administered *in situ* with pen and paper, while laboratory studies are more conducive to computer-based tasks. It is therefore fundamental to explore the transferability of results from one mode of administration to the other in the context of soundscape studies.

3.1.5 Research questions

There are two bases for the present study on the ecological validity of soundscape reproduction. The first is that differences between soundscape ratings collected *in situ* and in laboratory settings is a relatively understudied domain considering its importance in the context of emerging audio technologies. It is important to establish if laboratory reproduction can elicit similar cognitive processes and reveal similar effects of contextual factors (such as time of day, day of week) on soundscape ratings. The second basis is the fact that the mode of administration (pen-and-paper vs. computer-based) has been found to influence ratings in other contexts, so one might wonder if it could also influence soundscape ratings.

As discussed above, a research setting can be considered *ecologically valid* only when three elements are present:

- the participants are representative of the studied population;
- the experimental setup and stimuli are representative of the studied environments;
- the experimental task and procedure are representative of the studied cognitive processes.

To answer the first requirement, little can be done outside of the recruitment procedure, in this case, by selecting participants familiar with the site of interest. The other two requirements are the focus of this paper addressing the research questions below.

At a theoretical level, comparing in situ and laboratory conditions:

1. Can similar effects of contextual factors (time of day, day of week, and location on site) on soundscape ratings be observed in situ and in the laboratory?
2. Can similar underlying soundscape dimensions be observed in situ and in the laboratory?

At a methodological level in laboratory settings:

3. Does the mode of administration influence soundscape ratings?
4. Does stimuli selection influence soundscape ratings?

3.2 Methods

To answer the research questions, this study was structured in two connected parts. First, data was collected in a public space through a) users' questionnaire-based soundscape evaluations and b) audio recordings taken during a representative portion of some of the data collection periods. Second, the audio recordings were reproduced in a laboratory experiment to collect participants' soundscape evaluations and compare those to the ones obtained on site. Ethical approval for this project was given by the Research Ethics Board II of McGill University [REB #686-0606 and #55-0615]. For the *in situ* study, participant consent was obtained verbally and participation details were reiterated and explained through a written (bilingual) description in the notebook containing the paper-based questionnaire – their written participation is taken as documentation of consent. For the laboratory experiments, participants signed a consent form and were compensated for their participation.

3.2.1 In situ study

3.2.1.1 Study site

The study site was a small (about 1,800 m^2) public square in Montreal on one of the main commercial streets of that area (Avenue Mont-Royal), with shops and restaurants along two opposing traffic lanes also used by frequent bus lines (<10 minutes) during the day. On the far side from the commercial artery, the space is bordered by residences and a footpath. The locations of the recordings are shown in Figure 3.1.

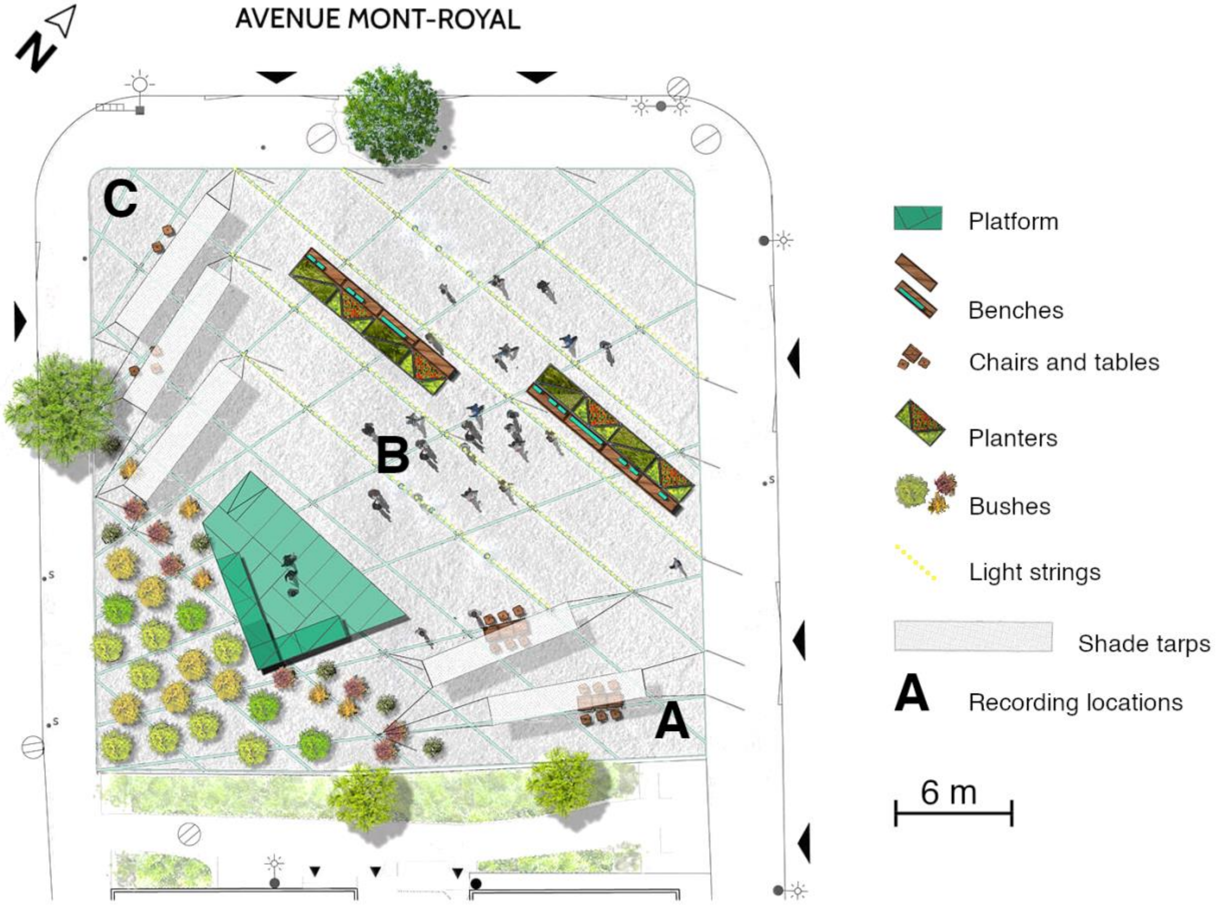

Figure 3.1. Simplified map of the study site, showing recording locations A, B, and C. Design layout provided by design firm Castor et Pollux and used and edited with permission.

3.2.1.2 Participants

In situ, participants were approached by a research team member while using the studied public space; generally, participants were only recruited if they had stopped in the space and spend at least a few minutes being exposed to the environment. They were asked to take a paper-based questionnaire, while the researcher noted the time of day and their location in the space while completing it.

Due to logistical constraints and evolving research considerations, the site study was not conducted with systematic factorial experimental design. Additionally, the location was not visited with the same frequency by users at all times of the day and week. Both of those factors led to highly unbalanced sample sizes in terms of weekday-weekend and afternoon-evening (Table 3.1). Despite variations in the visual design of the square, consistent with analyses conducted by Trudeau et al. (2020), we collapse respondent data across the visual design conditions.

Afternoon and evening periods consisted of the time slots of 2pm to 6pm and after 6pm, respectively. These choices, based on local working hours, and therefore activity levels, were confirmed by sound level trends on site (Fraisse, 2019). Additionally, due to differential sound levels (see *Ambisonic recordings* section below), participants were grouped based on their location on site. The space was divided in half with a quiet and a noisy side, closest to the residential side and to the commercial street, respectively. Sample sizes for each condition are presented in Table 3.1.

Table 3.1. Case counts [and sound levels in dBA (LAeq,10min)] for each condition of in-situ data collection, separated by weekday-weekend, afternoon-evening, and noisy-quiet side of the space.

	Time period				
	Weekday		Weekend		
Location	Afternoon	Evening	Afternoon	Evening	Total
Quiet	15 [57.33]	46 [61.45]	5 [57.92]	16 [58.69]	82
Noisy	9 [62.69]	53 [62.82]	13 [62.46]	28 [62.47]	103
Total	24	99	18	44	185

A total of 185 questionnaires (102 women, 76 men, age = 34.76 ± 14.82) were collected. See a summary of average age, noise sensitivity (from the NSS scale (Benfield et al., 2012)), and extraversion (from the BFI (Gosling et al., 2003) – both collected with demographic questions at the end) in Table 3.2.

Table 3.2. Participants' profile for both laboratory studies (N = 20 and 14, respectively) and in situ (N = 185).

	Computer-based		Pen-and-paper		*In situ*	
	Mean	SD	Mean	SD	Mean	SD
Age	44.60	16.61	45.93	17.09	34.76	14.82
Noise sensitivity	4.20	0.89	4.14	1.23	3.22	1.43
Extraversion	3.45	1.00	3.64	0.84	3.49	1.15

3.2.2 Ambisonic recordings

Ten-minute Ambisonic recordings were obtained with a Soundfield ST350 FOA (first-order Ambisonics) microphone and a Sound Devices 744T sound card at three locations on site (Figure 3.1). Sound levels were recorded simultaneously with a Brüel & Kjær type 2250 sound level meter. All recordings were obtained on the study site in September 2018.

Based on the 10-min average LAeq value for each recording, the two locations with the consistently lowest (range of 57.3-61.4 dBA) and highest (range of 61.9-66.5 dBA) sound levels were chosen for the laboratory experiments. The individual 10-min average

LAeq values (see Table 3.1) were used to calibrate the reproduction levels in the listening room.

An additional recording session was conducted late at night on site to obtain a naturalistic background noise floor between conditions for the experiment, referred to as the *baseline* below.

3.2.3 Laboratory study

3.2.3.1 Participants

For the laboratory studies, recruitment was conducted with the help of the Plateau borough in Montreal, to contact people who were familiar with the studied space, whether living or working nearby. An official email from the borough was sent to their mailing list and a Facebook post was posted on their page on two occasions. A total of 34 people (adults with self-reported normal hearing) participated in both studies (Table 3.2): 20 for the computer-based study (8 women, age = 44.6 ± 16.6, 2 English), and 14 for the pen-and-paper study (10 women, age = 45.9 ± 17.1, 0 English). They received a compensation of 15$ for 1h30 of experiment.

3.2.3.2 Conditions

Two-minute excerpts were isolated from a subset of 10-minute long Ambisonic recordings chosen based on location in the space (locations A and C in Figure 3.1) and day and time of recording. Additionally, to investigate internal consistency, two excerpts were selected from each 10-minute recording. Conditions were selected in a factorial design, with

2 locations (quiet vs. noisy) × 2 days of the week (weekday vs. weekend) × 2 times of day (afternoon vs. evening) × 2 excerpts (selected 2-minute excerpts within each recording), for a total of 16 excerpts.

3.2.3.3 Procedure

Participants were seated in the center of the listening room and loudspeaker array (Figure 3.2). Each trial lasted for 2 minutes, resulting in approximately 32 (2 minutes x 16 excerpts) minutes of testing with an optional break. They were first presented with two panoramic photographs of the studied site (the public space they were familiar with) from the two locations of recording facing the center of the space (Figure 3.3) for 30 seconds. They were then asked to listen to the 16 excerpts and fill out a shortened version of the questionnaire used *in situ* (Table 3.3). All excerpts were presented in a fully randomized order.

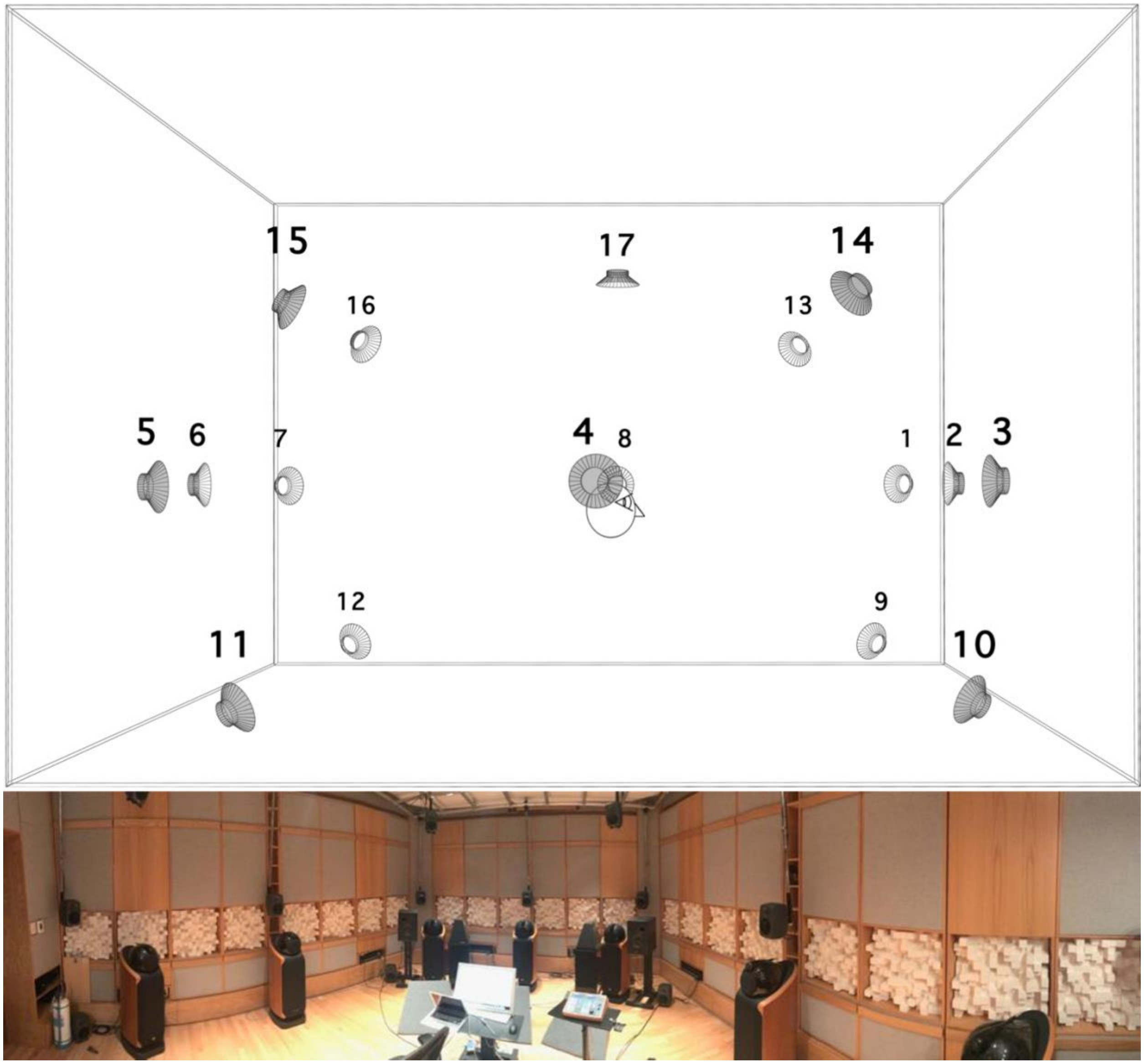

Figure 3.2. Listening room. Top: diagram of loudspeaker array from the side, simplified head for orientation; bottom: panoramic photograph of the room from the back right corner (original copyright: Grégoire Blanc [2019] under a CC BY 4.0 license).

Figure 3.3. Panoramic photographs of the space presented at the beginning of the laboratory experiments. Top: location A; bottom: location C (original copyright: Mariana Mejía Ahrens [2018] under a CC BY 4.0 license).

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. This was done to mirror the surveyed users of the studied site. They could answer the questionnaire for 1 min 40 s before the end of each excerpt. In the computer-based study, participants had no control over the timing of questionnaire presentation, all transitions were automated within the software. In the pen-and-paper study, participants were asked to respect this time, which appeared on screen, but the experimenter was not present to enforce it. However, all soundscape conditions (audio stimuli) were transitioned automatically for both studies. The last five seconds were used to fade into the baseline presented for 15 seconds between excerpts to avoid transitioning to silence.

Table 3.3. Questions for each of the 16 laboratory conditions.

Question	Type	Simplified name
I find this soundscape to be:		
Pleasant	Likert scale	pleasant
Appropriate for the activities I would conduct in this space	Likert scale	appropriate
Monotonous	Likert scale	monotonous
Vibrant	Likert scale	vibrant
Chaotic	Likert scale	chaotic
Calm	Likert scale	calm
Eventful	Likert scale	eventful
Spending time in this soundscape gives me a break from my day-to-day routine:	Likert scale	restorative

The experimenter ran a practice trial with the participant before starting the experiment, to help them familiarize themselves with the task and automated timing. A short break was automatically triggered at the halfway point (after the 8th excerpt).

3.2.3.4 Ambisonic reproduction

Stimuli were presented in an acoustically-treated listening room (5.9 x 4.9 x 3.3 m) conforming to the ITU-R BS.775-1 standard (International Telecommunication Union, 1994) over an array of 17 Genelec 8030A loudspeakers placed on four height levels and facing the listener (Figure 3.2):

- a square of four at floor level (#9-12 in Figure 3.2)
- a square of eight located at head level (1.2 m above the floor – #1-8)
- a square of four suspended from the ceiling (2.3 m above the floor – #13-16)
- a single speaker directly above the listener (2.6 m above the floor – #17)

Decoding was conducted in MaxMSP version 8.0.5 (Cycling ’74) using Heller’s Ambisonic Decoder Toolbox for MATLAB (Heller et al., 2012) compiled for MaxMSP with Faust (Heller & Benjamin, 2014).

3.2.4 Questionnaires

The full *in-situ* questionnaire used on site is the product of multiple iterations over the years and built on the literature presented in the *Soundscape assessment* section, using our Quebec French translation (see Tarlao et al., 2021). In this paper, we analyze the soundscape scales that were used in both in situ and laboratory conditions (Table 3.3). The question on *appropriateness* was rephrased to maintain equivalency between *in situ* and laboratory conditions, from: “I find this soundscape to be *appropriate for my activity*” (*in situ*) to: “I find this soundscape to be *appropriate for the activities I would conduct in this space*” (laboratory).

3.2.5 Statistical analyses

To investigate the four research questions, we conducted three types of analyses:

1. to validate the dimensions underlying soundscape judgments [RQ2], we conducted a CFA on each data set (site and laboratory) with a model based on previous work [61],

2. to explore the influence of the mode of administration on soundscape assessments [RQ3], we followed up the CFA with an analysis of measurement invariance on the laboratory data,

3. to investigate the ecological validity of Ambisonic reproduction [RQ1] and the influence of stimuli choice [RQ3], we conducted a MANOVA on each data set (site and laboratory) with day, time, and location as independent variables for the site data, and day, time, location, mode of administration, and excerpt as independent variables for the laboratory data.

Further details are given for each analysis below.

Statistical analyses were computed in R 4.0.2 for Mac OS X and Rstudio® 1.3.1073, with $\alpha = 0.05$. Both the laboratory and *in situ* data were highly non-normal, whether univariate or multivariate. The *in situ* data was additionally highly unbalanced with small groups (range of 5 to 53) when subdividing based on the three factors of interest: day (weekday-weekend), time (afternoon-evening), and location (quiet-noisy). For these reasons, we chose to conduct semi-parametric analyses when pertinent.

Furthermore, missing values for Likert scales were replaced by the mean (rounded to 2 decimals) for each dependent variable per mode of administration in the laboratory (computer-based, pen-and-paper) and per visual design on site, as proportions of missing values were 6.5% or less (0.6-2.2% in the laboratory and 1.6-6.5% *in situ*). Because of this, we considered the Likert variables as continuous in the following analyses.

We first ran a Confirmatory Factor Analysis (CFA) on the site data to ensure that the latent dimensions did not differ from previous results obtained with the same questionnaire (Tarlao et al., 2019, 2021). We also conducted a CFA on the laboratory data with the same model, followed by an analysis of measurement invariance (Kline, 2016) between pen-and-paper and computer-based responses. Both CFA and measurement invariance were run on the laboratory data by accounting for repeated measures, as allowed by the *lavaan* package (Rosseel, 2012) for R. Measurement invariance testing consists of four steps: configural invariance, metric invariance, scalar invariance, and strict invariance (the latter is almost never needed and tested) (Kline, 2016, pp. 396–399). Each step is more restrictive than, and relies on the validation of, the previous step. To validate a step, fit indices are compared to the ones from the previous, that is testing that the change in overall fit between two subsequent models falls under a certain threshold. A difference in Comparative Fit Index (ΔCFI) ≤ 0.010 and a difference in Root Mean Square Error of Approximation (ΔRMSEA) ≤ 0.015 are considered reasonably accurate to detect invariance for samples of more than 300 observations (Chen, 2007). All CFA were conducted before replacement of missing data, using the *lavaan* package (Rosseel, 2012), and with the robust estimation method of Maximum Likelihood with Satorra-Bentler correction (MLM) due to the non-normality of the data (Satorra & Bentler, 1994).

A semi-parametric repeated-measure MANOVA with four within-subject factors (day, time, location, and excerpt) and one between-subject factor (mode of administration) was conducted on the laboratory data using the *multRM* function from the *MANOVA.RM* package, version 0.4.2 (Friedrich et al., 2020). Due to the covariance matrix being singular and the relatively small sample size, we used the Modified ANOVA-type statistic (MATS) and wild bootstrap resampling method for p-values, as recommended by the package authors (Friedrich et al., 2017). The resampling was conducted with 1,000 iterations. Follow-up semi-parametric repeated-measure ANOVA with the same factors were conducted – with the *RM* function from the *MANOVA.RM* package looking at the ANOVA-type statistic (ATS) and wild bootstrap resampling – on each of the scales, with Šidák p-value corrections of $\alpha_{SID} = 0.0064$ for $\alpha = 0.05$.

Finally, a semi-parametric MANOVA, and follow-up semi-parametric ANOVA on each scale with Šidák p-value corrections of $\alpha_{SID} = 0.0064$ for $\alpha = 0.05$, with three factors (day, time, location) were conducted on the *in situ* data using the *MANOVA* function from the *MANOVA.RM* package. The ANOVA were not justified based on the MANOVA results but were conducted for comparison with the laboratory results.

3.3 Results

The results are organized in three parts following the four research questions:

- validating the dimensions underlying soundscape judgments [RQ2], with a CFA model based on previous work (Tarlao et al., 2021),
- verifying methodological aspects of mode of administration with measurement invariance [RQ3] and of stimuli choice as a factor in the MANOVA [RQ4],

- investigating the ecological validity of Ambisonic reproduction through the investigation of the effect of contextual factors in the MANOVA [RQ1].

3.3.1 Dimensions underlying soundscape judgments

To investigate if the dimensions underlying participant's soundscape judgments, both *in situ* and in the laboratory, correspond to the previously found model (Tarlao et al., 2019, 2021), we tested the same CFA model, which was as follows:

- "PL" factor measured by the variables "pleasant", "appropriate", "calm", "restorative", and "chaotic", representing the *pleasantness* dimension
- "EV" factor measured by the variables "eventful", "vibrant", "calm," and "chaotic", representing the *eventfulness* dimension.

3.3.1.1 In situ data

The model fit for site data, was acceptable but not excellent, with $\chi^2_{SB} = 18.53$, df = 11, p = 0.070; robust CFI = 0.970; robust RMSEA = 0.065, 90% CI [0.000, 0.121]; and SRMR = 0.054. In consequence, we looked at modification indices to explore how to improve the model, which suggested adding the correlation between "pleasant" and "appropriate" (mi = 11.035). This is supported by previous work (Tarlao et al., 2019, 2021), wherein "pleasant" is consistently found to be associated with "appropriate". This new model yielded an excellent fit, with $\chi^2_{SB} = 10.19$, df = 10, p = 0.424; robust CFI = 0.999; robust RMSEA = 0.011, 90% CI [0.000, 0.090]; and SRMR = 0.045, and was therefore retained.

The standardized estimates of the factor loadings in the improved model (Table 3.4) were middling to large (0.21–0.80) and statistically significant (all with $p < 0.001$ except "chaotic" on "EV" with $p = 0.024$). The "pleasant", "appropriate", "restorative", and "calm" variables loaded positively, while "chaotic" loaded negatively on the latent factor "PL". In parallel, "calm" loaded negatively, and "chaotic, "eventful", and "vibrant" loaded positively on the latent factor "EV".

Additionally, the two latent variables "PL" and "EV" are not strictly independent, showing a borderline significant ($p = 0.069$) but weak covariance (cov = 0.203, SE = 0.112), which is expected, as they share some measured variables. And finally, the added correlation between "pleasant" and "appropriate" is expectedly significant ($p = 0.010$) although moderate (cov = 0.363, SE = 0.079). Those results are very similar to those obtained in situ in previous studies (Tarlao et al., 2019, 2021).

Table 3.4. Standardized factor loadings and standard errors (SE) for the retained CFA model for in situ data (N = 185)

	PL		EV	
Item	Loadings	SE	Loadings	SE
Pleasant	0.746	0.085		
Appropriate	0.572	0.089		
Restorative	0.604	0.095		
Calm	0.795	0.096	-0.365	0.106
Chaotic	-0.563	0.101	0.210	0.111
Vibrant			0.637	0.128
Eventful			0.730	0.134

3.3.1.2 Laboratory data

In comparison to both the *in situ* data and previous results, we tested the same CFA model on the laboratory data. The model fit on the laboratory data was good, with χ^2_{SB} = 23.87, df = 11, $p < 0.05$; robust CFI = 0.987; robust RMSEA = 0.068, 90% CI [0.030, 0.105]; and SRMR = 0.031, and was therefore retained, thus confirming that laboratory reproduction elicits similar latent dimensions to *in situ* listening.

The standardized estimates of the factor loadings in this model (Table 3.5) were middling to large (0.19–0.90) and statistically significant ($p < 0.001$). The “pleasant”, “appropriate”, “restorative”, and “calm” variables loaded positively, while “chaotic” loaded negatively on the “PL” latent factor. In parallel, “calm” loaded negatively, and “chaotic”, “eventful”, and “vibrant” loaded positively on the “EV” latent factor.

Additionally, the two latent variables “PL” and “EV” are not strictly independent here as well, showing a significant ($p = 0.001$) but weak covariance (cov = -0.195, SE = 0.060).

Table 3.5. Factor Loadings and standard errors (SE) for the retained CFA model for laboratory data (N = 544)

	PL		EV	
Item	Loadings	SE	Loadings	SE
Pleasant	0.904	0.069		
Appropriate	0.869	0.087		
Restorative	0.855	0.082		
Calm	0.709	0.079	-0.193	0.056
Chaotic	-0.633	0.144	0.241	0.105
Vibrant			0.816	0.088
Eventful			0.794	0.104

3.3.1.3 Comparison of latent dimensions between in situ and laboratory results

Both CFA are validated, confirming that the previously developed model of factors underlying the soundscape ratings in our context is applicable for both *in situ* and laboratory data. The only difference between the two models is the addition of a correlation between pleasant and appropriate to the *in situ* model. This relation makes theoretical sense but we did not add it to the laboratory model in the interest of parsimony as it was already a good model. Comparing the two models' loadings, we see that the laboratory results are more salient, with higher absolute loading values and smaller standard errors.

3.3.2 Methodological verifications

3.3.2.1 Effect of mode of administration

Following the validation of the CFA model on laboratory results, we tested the measurement invariance between modes of administration (pen-and-paper vs. computer-based). The first step, configural invariance, merely compares parameter estimates and p-values for the two groups of interest – pen-and-paper and computer-based. The model fit was acceptable to accept configural invariance (M1 in Table 3.6). The next step, metric invariance, forces identical factor loadings across groups. The change in model fit compared to the previous step was within bound, so we retained it (M2 in Table 3.6). The third step, scalar invariance, additionally forces identical intercepts between groups. The change in model fit compared to metric invariance was within bound and the model was retained (M3 in Table 3.6). The fourth, and last, step is strict invariance and constrains residuals in addition to the previous constraints. This change in model fit was too large and the model was not retained (M4 in Table 3.6), but this last step is rarely needed and tested.

Table 3.6. Tests of measurement invariance between pen-and-paper (N = 224) and computer-based (N = 320).

Model	χ^2_{SB} (df)	CFI	RMSEA (90% CI)	SRMR	comparison	Δ χ^2_{SB} (Δ df)	p-value	Δ CFI	Δ RMSEA	Δ SRMR	Retain
M1: configural	38.431 (22)	0.985	0.072 (0.031-0.109)	0.037	–	–	–	–	–	–	Y
M2: metric	45.456 (29)	0.984	0.066 (0.023-0.101)	0.059	M2 vs. M1	8.1262 (7)	0.322	-0.006	-0.001	0.022	Y
M3: scalar	56.557 (34)	0.975	0.075 (0.038-0.108)	0.065	M3 vs. M2	9.9367 (5)	0.077	-0.013	0.011	0.006	Y
M4: strict	71.742 (41)	0.963	0.083 (0.049-0.115)	0.059	M4 vs M3	13.665 (7)	0.057	-0.012	-0.008	0.006	N

Ultimately, our laboratory data showed scalar invariance between pen-and-paper and computer-based administration, with the exception of the intercept for “appropriate,” which may necessitate more investigation to explain.

3.3.2.2 Effect of stimuli choice

The laboratory experiment relied on a factorial design that included the factor of excerpt selection. Within each recording of a specific combination of day, time, and location in the public space of interest, two distinct excerpts were selected to investigate the effect of excerpt selection. MANOVA results on laboratory data (see *Laboratory results* section below) showed no effect of excerpt. Excerpt was present in two significant interactions but they will not be detailed further since the main effect of excerpt was not significant and those interactions have no theoretical meaning.

3.3.3 Ecological validity of laboratory reproduction

The following section details semi-parametric (M)ANOVA results using (modified) ANOVA-type statistics ((M)ATS) – between-subjects for *in situ* data and within-subjects for laboratory data – to compare the extent to which the same factors significantly moderate the data.

3.3.3.1 In situ results

Overall MANOVA. The semi-parametric independent MANOVA with day, time, and location as factors on the site data shows no main effects and no interactions (Table A 4).

ANOVA per scale on site. Unsurprisingly, following the MANOVA results, the follow-up ANOVA on each scale are all highly non-significant (Table A 5). These were conducted for the purpose of comparison with the laboratory results.

3.3.3.2 Laboratory results

Overall MANOVA. The repeated-measure MANOVA (Table 3.7) shows significant main effects of day (MATS = 14.93, $p < 0.001$), time (MATS = 42.13, $p < 0.001$), and location (MATS = 424.79, $p < 0.001$). Significant interactions between day and time (MATS = 7.38, $p = 0.026$), day and location (MATS = 24.97, $p < 0.001$), and time and location (MATS = 47.05, $p < 0.001$) were also found. Additional interactions, involving the excerpt, were found: day and excerpt (MATS = 30.55, $p < 0.001$), and day and location and excerpt (MATS = 24.79, $p = 0.001$). These will not be detailed further for the aforementioned reasons.

What is immediately evident from Figure 3.4 is that the same profile is found when comparing on the basis of location – comparing the corner of the public space closest to the residential area ("quiet" side) and the corner on the commercial street ("noisy" side). Pleasant, appropriate, monotonous, calm, and restorative are always higher in the quieter location, while chaotic, vibrant, and eventful are always higher in the noisier location. The picture is less unequivocal for the effect of day of the week and time, so to understand those effects in a more granular manner, the next section describes post-hoc ANOVA with the same factors on each scale independently.

Table 3.7. Modified ANOVA-type statistics (MATS) and their resampled p-values (wild bootstrap – 1,000 iterations) for RM MANOVA over all scales (N = 544).

	Test statistic	p-value
Day	**14.926**	**<0.001**
Time	**42.132**	**<0.001**
Day x Time	**7.381**	**0.026**
Location	**424.786**	**<0.001**
Day x Location	**24.967**	**<0.001**
Time x Location	**47.05**	**<0.001**
Day x Time x Location	4.45	0.138
Excerpt	17.445	0.213
Day x Excerpt	**30.555**	**<0.001**
Time x Excerpt	2.415	0.723
Day x Time x Excerpt	2.735	0.487
Location x Excerpt	2.227	0.756
Day x Location x Excerpt	**24.79**	**0.001**
Time x Location x Excerpt	2.491	0.586
Day x Time x Location x Excerpt	2.474	0.58

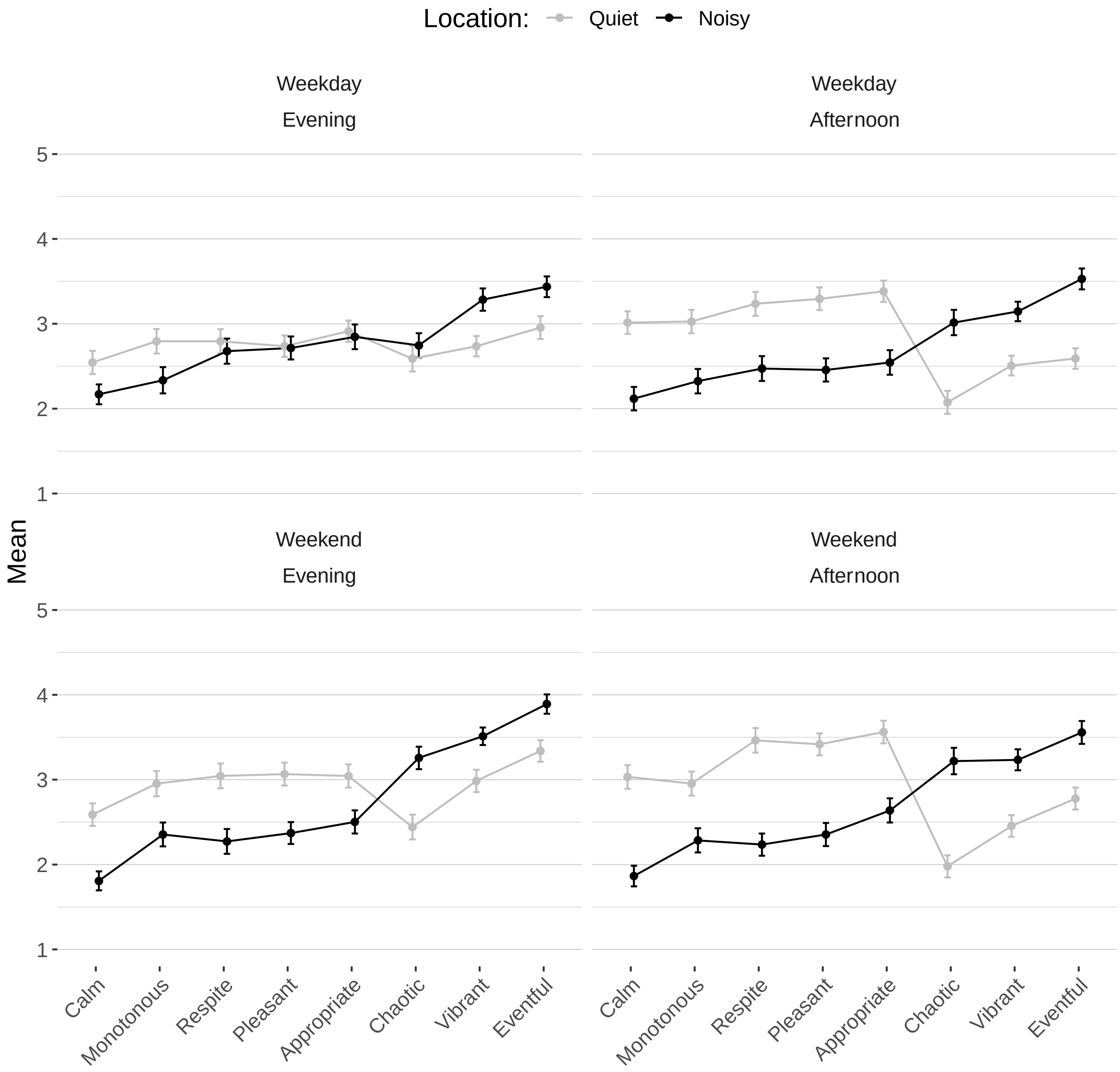

Figure 3.4. Means and SE of all scales as a function of day, time, and location for the laboratory data (N = 544).

ANOVA per scale in the lab. The repeated-measure ANOVA show a significant main effect of location ($p < 0.001$) and no main effect of excerpt for all scales ($p > 0.0064$). Day has a main effect on eventful (ATS = 17.87, $p = 0.001$), and time has main effects on appropriate (ATS = 16.67, $p = 0.004$), vibrant (ATS = 21.47, $p < 0.001$), calm (ATS = 10.65, $p = 0.003$), eventful (ATS = 18.06, $p < 0.001$), and restorative (ATS = 21.47, $p < 0.001$).

The interaction of day and location is significant for pleasant (ATS = 15.06, $p < 0.001$) and chaotic (ATS = 14.12, $p = 0.001$), while the interaction of time and location is significant for pleasant (ATS = 12.60, $p = 0.002$), appropriate (ATS = 14.60, $p = 0.001$), chaotic (ATS = 16.97, $p < 0.001$), and calm (ATS = 14.99, $p < 0.001$). There are additional interactions involving the excerpt as well for those univariate ANOVA: day by excerpt for pleasant (ATS = 15.54, $p < 0.001$) and eventful (ATS = 16.21, $p < 0.001$).

Location is the most consistently significant factor with marked differences for all scales. Moving from the "quiet" side to the "noisy" side: pleasant, appropriate, monotonous, restorative and calm lose, while vibrant, eventful and chaotic gain, more than half a point (Figure 3.5). For the factor of time of day, appropriate, calm, and restorative decrease, while vibrant and eventful increase, by about a quarter of a point from afternoon to evening. Finally, day of the week has an effect only on eventful, with an increase between weekday and weekends of a quarter of a point as well.

The effect of location is further complicated by interactions, with the quiet location being found more pleasant during the weekend than during the week, but still always more so than the noisy side, despite the latter being found less pleasant during the weekend than the week. Meanwhile, the noisy side is evaluated as more chaotic during the weekend than weekdays, but always more chaotic than the quiet side, which sees no difference between weekend and weekdays (Table 3.8).

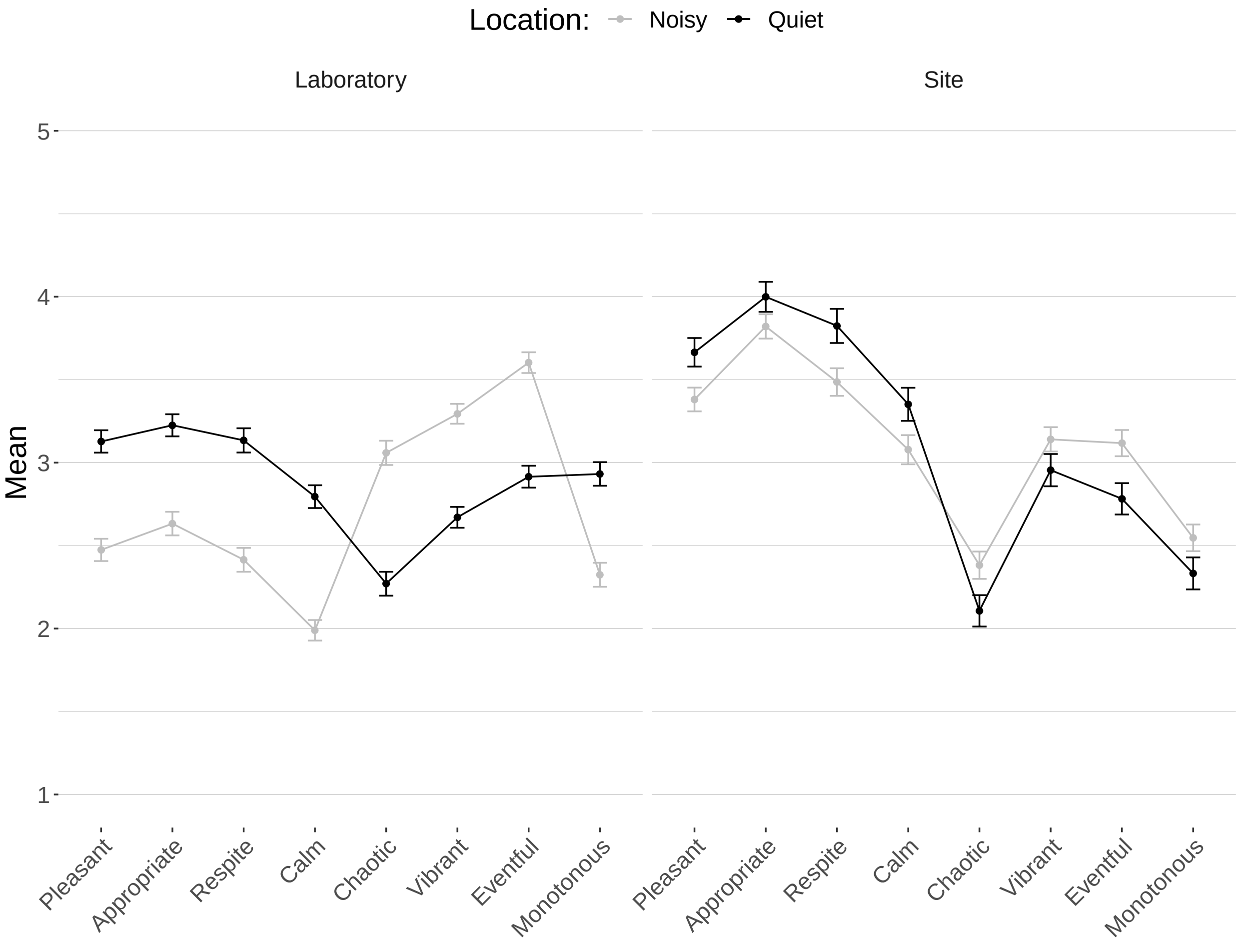

Figure 3.5. Means and SE of all scales for each location in the laboratory (N = 544) and on site (N = 185).

Table 3.8. Means and SE for scales with significant interaction effect between location and day in the laboratory (N = 544).

	Quiet		Noisy	
	Weekday	Weekend	Weekday	Weekend
Pleasant	3.01 ± 1.11	3.24 ± 1.10	2.59 ± 1.12	2.36 ± 1.09
Chaotic	2.33 ± 1.21	2.21 ± 1.16	2.88 ± 1.21	3.24 ± 1.19

The quiet location also sees a difference between afternoons and evenings, being more pleasant, more appropriate, calmer, and less chaotic during afternoons, while the noisy side sees no differences (Table 3.9). One may have noticed that all those scales weigh in on the first CFA dimension of *pleasantness*, so a short summary could be to say that weekends and afternoons are more “pleasant” as a general umbrella concept than weekdays and evenings, while the effect of day is reversed and the effect of time is lost on the noisier side.

Table 3.9. Means and SE for scales with significant interaction effect between location and time in the laboratory (N = 544).

	Quiet		Noisy	
	Afternoon	Evening	Afternoon	Evening
Pleasant	3.36 ± 1.08	2.90 ± 1.09	2.41 ± 1.12	2.54 ± 1.10
Appropriate	3.47 ± 1.07	2.98 ± 1.08	2.59 ± 1.18	2.67 ± 1.17
Calm	3.02 ± 1.12	2.57 ± 1.11	2.00 ± 1.08	1.99 ± 0.96
Chaotic	2.03 ± 1.10	2.51 ± 1.22	3.12 ± 1.25	3.00 ± 1.16

3.3.3.3 Comparison of critical factors between in situ and laboratory results

Contrary to our expectations, we did not see main effects of our factors of day, time, and location in the *in situ* data, not even from location, which is highly significant and markedly influential in the laboratory results. Those results hold both for the overall MANOVA and the post-hoc ANOVA on each scale. It is interesting to note that a visual comparison (Figure 3.5) reveals visible differences in ratings based on location, following similar patterns as the laboratory results: the quiet side is judged more pleasant and less eventful than the noisy side. However, the *in situ* differences between locations are not as wide as those in the laboratory study. These more pronounced results in the laboratory than *in situ* are reminiscent of the more salient factor loadings in the laboratory than *in situ* found in the *Dimensions* underlying soundscape judgments section. Figure 3.5 also shows that *in situ* results, regardless of location, are always more extreme than laboratory results for the scales contributing to the *pleasantness* dimension with higher ratings of pleasant, appropriate, calm and restorative, and lower ratings of chaotic.

3.4 Discussion

The driving force of this study is the objective of ensuring the ecological validity of soundscape reproduction and evaluation in the laboratory with the ultimate goal of bridging the gap between soundscape research and urban practice by increasing knowledge and developing tools to help urban professionals understand and imagine sound environments. Such a step opens the door for more quickly advancing and testing scientific theories, lowering the costs of mock-up designs, or using the laboratory as a communication space. However, before this step can be undertaken, the ecological validity of the methodological and technological choices needs to be asserted by ensuring the representativity of the participants, of the setup and stimuli, and of the task and procedure.

In this study, we ensured that participants were representative of the population of interest by recruiting neighbors of the space. In the case of a future application for urban professionals, this may translate to different practice decisions which are already recommended and employed in general, from familiarizing themselves with the space from the perspective of the stakeholders using said space to co-creating with stakeholders.

The study therefore focused on the other two points by: 1) validating the dimensions underlying soundscape evaluations on site and in the laboratory [RQ2], 2) investigating the influence of the mode of administration of the questionnaire and of the specific portion of recording reproduced on judgments [RQ3-4], and 3) comparing judgments collected on-site and in the laboratory with the reproduced soundscape corresponding to the site of interest [RQ1].

3.4.1 Validation of SSQP underlying dimensions

First, our findings confirm that participants hold similar dimensions of the underlying soundscape dimensions, as demonstrated by the CFA, both *in situ* and in the laboratory. The main difference was the additional correlation between pleasant and appropriate *in situ*, compared to the laboratory. The initial model was established in, and the additional correlation was supported by, previous work (Tarlao et al., 2019, 2021). Those results support the conclusion that 3D Ambisonic reproduction of soundscapes in the laboratory elicits similar latent dimensions as on-site listening in the use case of a small public space.

3.4.2 Validation of methodological choices

Second, based on the validated CFA results, we found scalar measurement invariance between the two modes of administration tested in the laboratory (computer-based and pen-and-paper questionnaires). In other words, the way participants understand the soundscape items and use the measurement scale is similar between computer-based and pen-and-paper modes of administration. We intend to investigate this further by exploring open-ended responses about participants' understanding and use of the scales.

Additionally, the results of the analyses of variance on laboratory results showed no effect of the chosen excerpt within a 10-min recording. These results point to some level of freedom in procedure and stimuli choices.

3.4.3 Influence of time, day, and location on soundscape evaluations

Finally, a direct statistical comparison between the data collected on site and in the laboratory was not possible by virtue of the experimental designs, so we examined (M)ANOVA results separately. On site, the analyses of variance showed no significant effects of the three contextual factors that were hypothesized to influence soundscape ratings (Bild et al., 2016; Jennings & Cain, 2013): day of the week, time of day, and location in the space, and their interactions. Previous work on the same site showed location, time of day, and day of the week influenced sound level, but did not look at soundscape evaluations (Fraisse, 2019).

In comparison, in the laboratory, the MANOVA showed a marked main effect of all three factors, as well as interactions of day and time, day and location, and time and location. Further explorations revealed that weekends were more eventful than weekdays, and afternoons were calmer and less eventful than evenings. Most markedly, location had a highly significant effect on all scales, which can be summarized as the quieter side being more pleasant and less eventful than the noisier side. This evident effect of location points to the need to record and reproduce multiple locations of any site of interest, even in this public space studied here, which was small, with traffic clearly audible at all locations in it.

Location also interacts with day and time, separately, in a way that can be summarized as the quiet side being more "pleasant" during the weekend, and during afternoons, while the noisy side is evaluated as less "pleasant" during the weekend, but not as a function of time of day. This latter interaction effect of time and location seems surprising given that the sound level on site was reported as higher during afternoons than evenings (Fraisse, 2019). However location was not taken into account in (Fraisse, 2019), where long-term sound levels were obtained at only one point in the middle of the site.

Interestingly, a visual exploration (Figure 3.5) of the *in situ* results reveals consistently more extreme ratings of the variables of the first CFA dimension (*pleasantness*) – i.e., higher ratings of pleasant, appropriate, calm and restorative, and lower ratings of chaotic, regardless of location – on site in comparison to the laboratory results. This result might be due to a holistic integration of other sensory modalities and of contextual factors in the judgments on site. For example, expectations of space users towards the inevitability and rhythm of traffic noise in the soundscape (O'Keefe & Kerr, 2015) could have helped alleviate its effects in relation to time of day and day of the week – maybe even through deliberate choice of timing to use the space. This effect may be related to visual information, which has been shown to influence soundscape judgments, both in laboratory studies and *in situ* (see Li & Lau, 2020 for a review). Another potential element of response is the effect of laboratory stimuli, calibrated to match levels on site, being found to be louder than would be experienced on site (Oberman et al., 2020). Indeed, some participants in this study found the laboratory sound levels high, despite being told that levels were carefully matched to what they would, and did, experience on site as neighbors.

Furthermore, the same visualization (Figure 3.5) of the profile of responses in the laboratory depending on the location – although following the same profile as the *in situ* results, if less extreme – reveals much more pronounced differences between locations, as captured by the (M)ANOVA results. This points to the desired outcome of laboratory experimentation, wherein isolating the variables of interest makes it possible to reveal their effects. In this manner, our laboratory study allowed us to pull apart the different influences from sensory modalities and other contextual factors and to focus on the auditory modality and our factors of interest – namely day, time, location.

3.4.4 Limitations and future directions

This study is a first step in confirming the ecological validity of 3D Ambisonic soundscape reproduction to collect soundscape evaluations in the laboratory. The results we obtained are in line with previous studies in soundscape research (Davies et al., 2014; Guastavino et al., 2005, 2007) pointing to the ecological validity of this technique for other tasks. In light of these encouraging results, we will extend our investigation to laboratory experiments manipulating other contextual factors, such as the activity at hand, on soundscape evaluations.

A limitation arising from the different experimental setting of the two studies is that participants in the laboratory were older on average. The different ages of participants between the laboratory study and the site study may have had an effect on soundscape evaluations (Bockstael et al., 2019), potentially in relation to higher noise sensitivity (Tarlao et al., 2021), via different hearing abilities (i.e., hearing loss).

Another experimental issue arose with the *in situ* data, wherein the factors investigated in this study emerged from the analysis of the *in situ* data, which were collected first. That is, during the initial *in situ* data collection, we did not systematically control for all the factors (not knowing which ones would be relevant) as we did in the lab using a factorial design (after the analysis of *in situ* data revealed relevant factors). As a result. sample sizes *in situ* were highly unbalanced with a range of 5 to 53 observations per condition (Table 3.1). As well, location on site was divided in two halves of the space, almost certainly aggregating observations from a gradient of sound experiences, while the recordings were captured at two opposite corners of the space. This could explain the more pronounced effects of location in laboratory settings.

Another point that may explain the lack of significant effects *in situ* is the holistic integration of other sensory modalities and of contextual factors in the judgments on site. In contrast, the laboratory experimental design did not present visual stimuli, as a deliberate choice for variable control, nor could it take into account other contextual factors such as the reason for visiting the space or the meaning attributed to the particular public square in the neighborhood. Finally, respondents on site were exposed to different soundscapes whereas, in the laboratory, all participants were presented with the exact same set of soundscapes and, as a result, on-site data could have more variation that we cannot account for. Similar concerns were raised by other work comparing *in situ* and laboratory soundscape judgments, though with binaural recordings (Hermida Cadena et al., 2017). We do intend to explore a way to account for such nuance by analyzing free-format questions about ambiance and sound sources audible in the soundscape collected both on site and in the laboratory experiment.

It is also interesting to note that the "monotonous" scale showed no main or interaction effects other than the effect of location, which may indicate a lack of clarity from the instrument as to the scale's meaning or applicability to soundscape judgments, in line with previous studies (Tarlao et al., 2016, 2019, 2021). This is also a question we aim to look into specifically with additional data collected during this study with open-ended questions.

3.4.5 Conclusions

To sum up, this study shows, on a theoretical level:

- Marked effects of location, day of the week, and time of day were found in the laboratory, but not on site
- 3D Ambisonic laboratory reproduction of soundscapes elicits similar latent dimensions than the equivalent *in situ* soundscapes

And on a methodological level:

- mode of administration had little effect on soundscape evaluations in the laboratory
- temporal variations within the same conditions (i.e., different excerpts from the same recording) seem to affect ratings little enough in comparison to the marked effects of location, day of the week, and time of the day.

An interesting finding that we did not foresee is that results on site seem to be much more “pleasant” in comparison to the laboratory results in general (i.e., including on the noisier side of the space), which hints at multiple possible cognitive processes, which potentially overlap. This could be attributed to several reasons: that other sensory modalities integrate with the auditory perceptions to alleviate the unpleasantness of city noise, that the meaning of the space within the neighborhood (e.g., historical significance or break from urban landscape) may increase user satisfaction and with it soundscape pleasantness, and that people know and expect the city to be noisy and therefore employ conscious strategies to mitigate said noise – such as using the space at specific times. Another potential argument at play could be that the immersive reproduction of traffic noise is an uncomfortable reminder of how pervasive traffic is in the city by making it harder to ignore in a laboratory setting.

This study shows that laboratory soundscape studies confidently reproduce the patterns of *in situ* perceptions, and that this controlled setting allows one to magnify the effects of studied factors that can be lost in the variability of unconstrained *in situ* experience. This has implications for researchers, who need to be aware of this inflation of effects for its benefits and disadvantages both for research purposes as well as for the development of practical applications.

In particular, with regards to our goal of asserting the ecological validity of Ambisonic reproduction of soundscapes with the aim of developing a tool for urban professionals, awareness of the biases of this reproduction will be essential to sound urban practice. However, the present results plainly show highly similar soundscape latent dimensions between laboratory and on-site responses despite the clear difference in the amount of variability and nuance of respondent experience, justifying the adoption of Ambisonics for such urban practice tools.

Finally, this paper points to how important context is in two different ways: first, the straightforward results obtained in the laboratory study show the influences of the contextual factors of time, day, and location; second, the lack of effects on site reveals how much variability is introduced by the many cognitive processes at play in everyday life situations.

3.4.6 Transition

This chapter focused on the investigation of the ecological validity of Ambisonic-based reproduction of soundscapes in the laboratory, with the aim of validating its use for both research applications in the laboratory and practical tools to support the integration of soundscape considerations in urban practice. Findings point to the representativity of Ambisonic rendering for soundscape reproduction in the laboratory and allows us to proceed with the last study of this research: the development and testing of a soundscape simulation tool for urban professionals, presented in **Chapter 4**.

Chapter 4 – Evaluating interactive soundscape simulation as a co-design tool for urban professionals

Cynthia Tarlao, Grégoire Blanc, Daniel Steele, Catherine Guastavino

Abstract

The sound of our urban environments, framed as noise, is an increasing concern as cities develop, diversify, and densify. But, in many environments, the common approach based on noise mitigation has proven insufficient to improve the quality of the urban auditory experience. The *soundscape* approach considers sound as a resource in sonically complex urban environments, rather than only a pollutant to be eliminated, and accordingly, allows for a more proactive and holistic management of sound environments. Urban professionals are regularly confronted with the complexity of managing urban sound and understand that available noise guidelines fall short in their reduction of such a complex experience. However, they rarely have the resources and knowledge to deal with urban sound in a resource-centered manner. In an effort to start bridging this gap, the present research explores the potential of a soundscape simulation prototype to be integrated in the design workflow of urban professionals. Through a formative, controlled evaluation conducted with urban professionals during an interactive workshop, this study reveals a number of avenues for the development of a tool for urban professionals, including the need to balance flexibility and accuracy, to present changes in real time, and to seamlessly switch between different compositions to support design comparisons. Our findings also hint at a shift away from the

visual-centeredness and a willingness amongst urban professionals to consider a more holistic urban sensory experience.

4.1 Introduction

The sound of our urban environments, framed as urban noise, is an increasing concern as cities develop, diversify, and densify, impacting both well-being and quality of life for a majority of the urban population (European Environment Agency, 2010). But research has shown that noise exposure levels alone do not offer a full representation and understanding of a sound environment (Raimbault et al., 2003). *Noise reduction* can even create or reveal other problems (Raimbault & Dubois, 2005). Worse even, the quantitative focus on noise reduction can render invisible in policy the less quantitative noise issues, such as neighborhood noise, and focus more resources on the more easily measurable but less widespread problems, such as aircraft noise (Bijsterveld, 2008).

Research is slowly revealing that the source(s) of sound and our associations to them matter in determining whether it is suitable for the environment and its users – for example, human sources are expected and desired in urban contexts (Guastavino, 2003, 2006). Even traffic noise could be seen as a resource if we consider that all the sounds of the city contribute to its *vibrancy* (Brown & Muhar, 2004). The *soundscape* approach considers sound as a resource (Schulte-Fortkamp et al., 2007) in sonically complex urban environments, rather than only a pollutant to be eliminated. Another tenet of the soundscape approach is that it makes space for perceptual and contextual suitability for a diversity of experiences (International Organization for Standardization, 2014). By thus centering the evaluation of positive outcomes on perception, it offers a more flexible and wider range of tools to promote urban sound environments of quality. In short, sound is a resource that can be managed.

Urban planners[9] are regularly confronted with the complexity of managing urban sound and find that available noise policies fall wholly short in their reduction of such a complex experience (Raimbault & Dubois, 2005). However, urban professionals rarely have the resources, tools, and knowledge to deal with urban sound in such a resource-centered manner. As a result, they usually approach urban sound as noise only, focusing on sound levels in decibels for the purpose of verifying only that it falls under a predetermined legal limit value (Steele, 2018). Some of the reasons highlighted in the literature include lack of most sound considerations in curriculums, lack of a regulatory framework, and lack of tools (Aletta & Xiao, 2018; Bild et al., 2016; Guastavino, 2020). Previous research (Raimbault & Dubois, 2005; Steele, 2018) has revealed the necessity of understanding the needs of urban professionals to help them integrate sound in their practice. The present study is an effort to address some of these concerns by designing and evaluating a prototype for a soundscape simulation tool for urban professionals.

4.1.1 Soundscape research into urban design concerns

The last decades of soundscape research highlight the limitations of sound levels to predict the sound quality of urban environments or capture the complexity of urban auditory

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[9] Note that, in the present work, we will call *urban professionals*, the wide range of practitioners involved in the decisions shaping the built environment of the city, including, but not limited to, urban designers, planners, architects (which have been called "professionals of the built environment" elsewhere (Steele, 2018)), as well as policy makers. However, we will keep the denominations of specific professions as they are mentioned in the specific studies detailed below.

experiences (e.g., Botteldooren et al., 2011; Dubois et al., 2006). This is true both of the fact that not all loud or noisy soundscapes are considered negatively (Dubois et al., 2006) and of its corollary, that silence is not always, or even generally, desirable (Botteldooren et al., 2011; Guastavino, 2006). Furthermore, the soundscape approach acknowledges the complex relationship between sound and experience, community, and place (International Organization for Standardization, 2014), following the footsteps of longer-standing fields such as that of sound studies (e.g., Bull & Back, 2003).

In keeping with this approach to the complex interrelationships between sound and experience, Dubois et al. (2006) discuss soundscapes as “effects from the point of view of the people being affected” (p. 872), the meaning of which is shaped by individual experience and shared knowledge in relation to the value ascribed to the sound sources and what they represent. In other words, people experience annoyance when the sounds heard are associated with uses, users, or contexts they find annoying (e.g., a basketball bouncing late at night) rather than acoustic properties of the sound itself (e.g., high sound level). This means that everyday sounds are perceived as pointers indicating the presence of someone or something producing sound. Indeed, Guastavino (2006) administered questionnaires to city users about urban soundscapes: more than 75% of the free-format descriptions referred to sound sources, corroborating this view. Additionally, it is interesting to note that sounds produced by humans (e.g., footsteps, conversations) represented more than 25% of the free-format descriptions of the ideal urban soundscape, denoting the expectation and desirability of the presence of human activities in the city.

These complex interrelationships between sound and experience encompasses a range of influences, from factors relating to the listener (e.g., expectations, personality) to factors pertaining to the situation at hand (e.g., social interaction, time of the day), which we will group under the umbrella term of contextual factors (Tarlao et al., 2021). Yet, Bild et al. (2016), through a cross-disciplinary literature review on the relationship between urban public space users and their soundscape, found that soundscape studies still generally fail to take into account contextual influences. These influences have recently garnered more research attention (e.g., Tarlao, Steffens, et al., 2021) but remain nonetheless limited. For example, Tarlao, Steffens, et al. (2021) found that age, gender, extraversion, noise sensitivity, and social interaction all significantly influenced soundscape evaluations of a public square, but more research is needed.

To integrate the urban sound experience – and the complex interrelationships between sound and experience – into urban planning and designing practices, Bild et al. (2016) suggest a framework centered on user activities. They point out that the urban planning process already focuses on activity and functionality outside of sound considerations, to which can be integrated knowledge from the soundscape approach (Bild et al., 2016). Drawing from soundwalks, focus groups, listening tests, and discussions with urban design professionals, Adams et al. (2009) sought to identify the various points in the planning process at which those professionals could incorporate soundscape. They advocate for incorporating soundscape from an early stage of the planning process, including the evaluation of the changes in the soundscape brought by the design choices "in as systematic way" (p. 9). Reporting on a case study on which they worked as acoustic consultants, De Coensel et al. (2010) assert that sound considerations need to be an integral part early in the planning process to be most effectively handled, rather than as an afterthought once structural and visual elements have been decided. In this process, sound can be approached as a resource, rather than as a pollutant to be kept under noise limits in environmental impact assessments and to be remediated once problems arise. Similarly, Maag et al. (2021) proposed a collaborative process to be integrated at different points of an iterative design process aiming to help stakeholders communicate about sound-related aspects of urban projects.

To this end, Bild et al. (2016) highlight the need for a sustained collaboration between researchers, practitioners, and technology developers with the aim of integrating the varied layers of information and knowledge present in the urban context for a more holistic understanding and design of urban spaces. The outcomes of such a collaboration would be multi-faceted with the development of metrics and technologies to help urban professionals understand the complex relationship between user and environment. Yet, the increasing development of technological tools to accurately measure, reproduce, and simulate sound environments in sound-related fields of research has not translated to their adoption in the practice of urban professionals. This is in part due to a lack of collaboration and communication between research and practice – beyond *ad hoc* projects, for example – but also a lack of accessibility and transparency of such tools.

4.1.2 Urban design approach to soundscape concerns

Although of recent increased interest from the viewpoint of researchers, the gap between soundscape research and urban design practice remains wide for a diversity of reasons including the aforementioned lack of tools and a lack of common language (Bild et al., 2016). Steele (2018) only found three studies (Cerwén, 2017; Pijpers-van Esch, 2015; Raimbault & Dubois, 2005) directly investigating the sound considerations of professionals of the built environment. The sparse literature shows that sound(scape) design is rarely a priority and that acousticians[10], (and far more rarely, any other type of sound expert) are hired at later stages in urban design projects, when essential considerations have already been decided (Defrance et al., 2016).

This does not mean that urban professionals have not expressed interest in a richer approach to urban sound and noise, as exemplified by early calls for guidelines and tools from the field (e.g., Brown & Muhar, 2004; Hedfors, 2003a, 2003b). Chalas' (1998) interviews with urban stakeholders (including elected officials, architects, noise technicians, community representatives) revealed three layers to sound considerations: physical, qualitative, and action-related. Stakeholders learned from experience that the physical approach to noise (centered around levels and mitigation) cannot account for the complexity of the lived experience and need to be supplemented by a qualitative approach. However, they also considered the qualitative approach insufficient to provide immediate and

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[10] Note that, even when consulted in a timely manner, acousticians center their practice on engineering solutions, with a heavy focus on sound levels and the physical sound phenomenon rather than users.

actionable solutions to complainants due to the more complex and sensitive nature of this approach, which requires longer-term investigations and precludes generalizations. They were therefore very interested in being proposed new transversal knowledge and resources to tackle urban noise issues – that is, involving a multiplicity of stakeholders, including experts and citizens. Brown and Muhar (2004) argued for the need to complement the usual noise abatement approaches with soundscape planning and offered a first attempt at guidelines to help urban professionals set soundscape planning goals outside of – and more fundamental than – acoustic concerns. Raimbault and Dubois (2005) also presented an assessment process and guidelines for noise mapping for policy decisions in an effort to offer methods to support the integration of sound concerns into the urban planning practice. More recently, Xiao et al. (2018) developed an "an agile participatory urban soundscape planning process model" based on interviews with key stakeholders in the implementation of soundscape projects in the UK.

These attempt to integrate sound consideration in urban planning, spread out over decade, indicate a sustained concern (Bild et al., 2016; Cerwén, 2017). However, Steele (2018) points out that this literature is still very much centered around noise abatement, and that the minority of urban professionals who do consider sound as a resource in their practice do not do so with the same language as soundscape researchers. Indeed, Raimbault and Dubois (2005) found that the way planners talk about urban noise is centered around the noise complaints and noise annoyance imperatives of their practice, rather than from a soundscape quality perspective. At the same time, they criticized the inadequacy of noise levels and standards to address the nuanced experience of urban sound. Additionally, limit values for noise levels, despite being recognize as reductive, offer a clear-cut and achievable requirement to handle the sound component of a project. In this manner, noise levels are easy to implement and to check off the list to focus on other factors (Steele, 2018). This highlights that, on the one hand, urban professionals recognize a need for more holistic sound practices, while on the other hand, they lack vocabulary, knowledge resources, and new approaches to fulfill this need.

However, it is notable that, although they may lack the corresponding vocabulary, planners are aware that even if too much noise is undesirable, sound remains an essential part of living in a city – "noise is life," as stated by an interviewee (Raimbault & Dubois, 2005, p. 344). And even when urban professionals try to consider sound as a resource in their projects, they lack the training and decisional power to implement creative solutions (Steele, 2018). They also interpret noise issues as a proxy to other issues as the only recourse city users have to appeal to authorities (Chalas, 1998; Raimbault & Dubois, 2005). Part of the issue is, then, that planners do not think of themselves as equipped to deal with such a complex component and fall back on the conventional regulatory approach of noise mitigation, despite being critical of such a reductive approach.

In consequence, Raimbault and Dubois (2005) conclude from their review of urban planning management studies that the urban sound question should be shifted from "a 'simple' physical noise level reduction" to understanding "how to conceive and design desirable soundscapes" (Raimbault & Dubois, 2005, pp. 346–347). This question of how to handle the process of design with sound in mind cannot be treated as a one-size-fit-all and will need to include "partnership, negotiation, and interactions" between the different partners on the project, and the population affected (Raimbault & Dubois, 2005, p. 346). Bild et al. (2016) also advance that a major impediment to the integration of approaches acknowledging and promoting user perception and cognition in urban planning is a difference in conceptualizations of the auditory environment. This illustrates the need for a "transdisciplinary learning model" (Steele, 2018, p. 190) including the perspectives of urban professionals in the production of resources to support the integration of sound – as a resource – concerns in the urban planning process.

To this effect in a cognate area, Pijpers-van Esch (2015) identified the need for better translation of expert knowledge in the field of microclimatology (which includes a sound component) into information that can be readily integrated into the design process, from simple explanations of basic physical knowledge to design guidelines using relatable references and examples. She proposed to make this information readily available and searchable in a knowledge base organized to support the planning process. More specifically focused on sound and soundscape, Cerwén (2017) draws similar conclusions: that "sound could, and should be better integrated into landscape architecture and related practices" (p. 18), and that this integration should be supported by the development of tools and strategies. This need for increased sound awareness and helpful tools pertinent for urban planning processes was also a main concern of the French planners interviewed by Raimbault and Dubois (2005) and the North American and European urban professionals interviewed by Steele (2018).

4.1.3 Needs and development of technological tools for urban soundscape design

Calls for the development of technological tools to support the design and communication of soundscapes were not only made by urban professionals, but sound(scape) researchers as well. For example, Brown and Muhar (2004) advocated for the design of “tools with auditory aspects” (p. 828) to fit into the planning process, including lower-level simulation tools allowing for spatial positioning of sound sources over a virtual design space. Botteldooren et al. (2011) also recognized the need to transfer soundscape knowledge from research to practical tools and methodologies, and especially offer “alternatives to classic noise maps” (p. 5). To this end, researchers in those fields have been developing and testing a variety of tools.

Hedfors realized that, to “help practitioners define sonic values and develop their language concerning auditory aspects” (Hedfors, 2003b, p. 4), it was essential to use sound representations in addition to the more traditional visual illustations methods. Sound representations, however, will entail a certain amount of technical knowledge and work, such as regarding the quality and representativeness of the sound recordings (Botteldooren et al., 2011). Of note is the referenced need for the tool to take into account temporality (Brown & Muhar, 2004; Defrance et al., 2016; Hedfors, 2003b). Indeed, evidence from urban soundscape characterization studies reveal an effect of time of day both on sound levels (Fraisse, 2019) and perceptions (Manzano et al., 2021; Tarlao et al., 2022). However, most visual planning tools do not account for temporality in their snapshot representations of spaces – thus sound, which is necessarily highly temporal, cannot be properly represented without stepping away from this “hegemony of the visual” (Levin, 1993) in urban planning processes.

Soundscape reproduction methods and tools have often been developed with research and archiving aims first (see Tarlao, Steele, et al., 2021 for a short review), with any urban design practice and communication goals often being happy by-products at best. On the urban practice side, the existing tools have generally been created from the point of view of acousticians to be as physically accurate as possible and thus are complex to handle, heavy to run, and expensive to obtain for most urban professionals – they are also not quickly adaptable to new circumstances. This lack of accessibility has recently become a repeated concern from the soundscape field (Aletta & Xiao, 2018; Bild et al., 2016; Guastavino, 2020).

Most sound environment prediction or simulation tools, whether open-source or commercial – such as CATT-Acoustics™ (https://www.catt.se/) and Odeon (https://odeon.dk/), are generally focused on room acoustics (i.e., indoor, private space) and similarly focus on accurate acoustic calculations, and the relevant fields (e.g., acoustics) are greatly interested in continued improvement in terms of accuracy and realism (Thery et al., 2019). However, such tools have limited penetration even in the targeted practitioner population (e.g., acoustic consultants), despite marked interest, due to cost and skill constraints (Thery et al., 2019).

One can imagine such concerns could be an issue with similarly costly and complex tools developed for outdoor simulation as well. For example, MithraSOUND© (https://www.geomod.fr/en/geomatics-3d-modelisation/mithrasound/) is a hyperrealistic simulation tool for outdoor acoustic scenes with a focus on traffic noise. It offers, based on real-time calculations, both immersive auditory renderings and noise level estimations. It is then, understandably, a complex tool, needing some level of acoustic expertise and the technological and financial resources to run it. MithraSOUND© was one of the tools presented to urban professionals to discuss their knowledge and experiences in relation to successful soundscape representation and design in the UrbaSON project (Defrance et al., 2016). This project involved urban professionals and acousticians to assess methodological and technological needs and requirements for the development of soundscape design support software. Urban professionals discussed their unequivocal expectation for the tools presented to offer a more qualitative and simplified process, "going further than the normative regulatory aspects" [our translation] (Defrance et al., 2016, p. 4). Such a qualitative tool would fit into a collaborative process, doing so as early as possible in the design process, so as to consider sound as a resource to promote well-being and a multiplicity of experiences. This goal is coherent with Thery et al.'s (2019) findings on the use of auralization by acousticians, which are used primarily to support collaboration and communication. The UrbaSON discussions (Defrance et al., 2016) revealed the need for two types of software: one lighter real-time less accurate software to be used as early as possible, including for communicating with citizens and clients, allowing for an iterative collaborative process; and another more akin to existing heavier acoustically accurate tools to be used at a later stage for finer modeling of the proposed design. Defrance et al. (2016) worked under the assumption that both types of software would be handled by the acoustic experts, but we would like to propose in this paper that a qualitative soundscape simulation tool could be valuable in the hands of urban professionals, both for them to include sound considerations early in their design process and as a communication and collaboration tool.

Along those lines, early on, Hedfors (2003a) requested the help of landscape architects and planners to evaluate the usefulness of a prototype of an interactive binaural tool to listen, compare, and experiment with recordings of two different sites (a pasture and a public city garden). We see here an outline for similar features of a light real-time qualitative tool allowing urban professionals to experiment with sound(scape) features. Similarly, Esquis'sons (Marchal et al., 2016), a more recent and more elaborate tool was developed as a "sound sketch tool" (p. 275) for the soundscape conception and representation of outdoor architectural designs. The authors explicitly hold the tool in contrast to existing modeling tools used for validation, which therefore create a "frozen artifact" (p. 277), highlighting the need for real-time updating and interactivity of such a tool for urban professionals. It should be noted that Esquis'sons is meant as an auralization tool based on the geometry of an envisioned building project, that is representing how buildings can act as barriers and reverberant surfaces. As the authors state (Marchal et al., 2016), it is aimed at helping urban professionals understand the acoustic consequences of changing some feature(s) of a built environment. In contrast, our soundscape simulator tool is designed for an even earlier stage of the urban design process, that is aiming to help urban professionals truly "sketch" out a soundscape like they would visually sketch a project, almost outside of physical constraints – so as to experiment with sound as a resource, and interactively discuss desired soundscapes with relevant stakeholders.

4.1.4 Interactive soundscape simulator prototype

Based on previous research, including workshops with urban professionals (Steele et al., 2020), it was found that most professionals of the built environment do not know where to start with soundscape and thus do not know what a tool to support its integration in their practice could look like and allow them to do. This echoes the work of Raimbault and Dubois (2005) with French urban planners, who did not have "specific expectations concerning new professional tools for analyzing soundscapes in cities" (p. 346) despite expressing concern regarding the integration of soundscape considerations into the urban design process. For this reason, and based on the limited feedback obtained with this previous work, we built a prototype of a soundscape simulator to be tested as a co-design tool. In this paper, we present a case study of this prototype.

The tool was meant to be easy to use to co-create a "sketch" of a sound environment (audio only) in real time – without superseding expert acoustic modeling – by allowing multiple users to listen at the same time, to walk around the virtually rendered space, and to interact with each other. To support this co-design process, it was imperative that the sound scene be rendered using a loudspeaker array rather than rely on binaural (i.e., headphones) reproduction. Therefore, we chose to use the Ambisonic rendering technique, which offers full flexibility for playback configurations (including, if desired, over headphones).

Ambisonics is a 3D sound recording and playback method based on a spatial representation of the soundfield. Ambisonics recordings capture sounds from all direction and represents the resulting soundfield independently of the playback system. It can therefore be decoded and presented on any configurations (e.g., multichannel loudspeaker arrays, binaural rendering over headphones) (Gerzon, 1985) with an optimal *sweet spot* in the middle of the loudspeaker array. First-order Ambisonics (FOA) soundscape reproduction has been found to elicit similar cognitive processes as on-site urban soundscapes (Guastavino et al., 2005; Tarlao et al., 2022).

Towards this soundscape “sketching” tool, we capitalize on the mature technologies developed by electronic musicians to perform real-time computer-aided music. These tools have been developed to allow sounds to be added together, filtered, and moved (and visualized) in space in all directions quickly and easily to support live music performances. As such, such toolboxes are ideally suited for the improvisatory needs elaborated upon above, where changes don’t require expensive re-calculations. To our knowledge, no other system developed by researchers allows users to give a trajectory to individual sources, to position sources in all directions of space (i.e., not just on the horizontal plane), and to visualize where the sources are placed and moving. Additional requirements for future iterations include integration with visual tools (like CAD), but the objective of this study was to obtain feedback from the urban professionals as to what worked and what more would be needed specifically in relation to the sound(scape) aspects – both technical (e.g., audio rendering, ability to control the level and position of sources) and procedural (e.g., soundscape composition process).

4.1.5 Knowledge mobilization workshops

Previous research concerning mobilization of soundscape research for urban designers showed that the workshop format, and particularly audio demonstrations, were effective in balancing the perceived high credibility of scientific research with the relatability of a researcher present for direct learning and back-and-forth questioning (Steele et al., 2020).

Collaborative workshops have an established history in fields engaging with a multiplicity of stakeholders, such as planning (Arciniegas & Janssen, 2012) – emerging first as a communication tool and evolving into a participatory and collaborative process. They are useful in generating engagement and commitment from the stakeholders and in disseminating research results through stakeholder networks (Simeonov et al., 2021). They also offer an interactive space of exchange for academics and practitioners to integrate their respective knowledge and expertise into identifying and implementing solutions to the problem at hand (Lusk, 2018).

As the primary users of a soundscape simulator tool to integrate into the urban planning process, centering the insight and guidance of urban professionals is essential to the process of designing this tool. The interactive workshop format was therefore chosen to allow them to use the tool in the collaborative manner it was intended for and to discuss their thoughts and expectations directly with the researchers involved in its development.

4.2 Workshop description

A full-day workshop was organised at the Centre for Interdisciplinary Research on Music and Media Technology, entitled "Co-designing soundscapes of public spaces: Integrating new technologies and approaches". It was offered in a mixture of French and

English, depending on participant need, and open to the general public but advertised to networks of practitioners of the built environment, soundscape researchers, and city officials. Participants included soundscape experts, acousticians, professionals of the built environment from the private and public sectors, and sound artists. The event was designed to introduce professionals to a wide range of soundscape concepts and immersive technologies (including virtual reality demonstrations, and the soundscape simulator presented in this work) through presentations and activities. The present paper focuses on the evaluation of a spatial soundscape simulator, based on three activities:

- soundscape co-design session with a custom-made spatial soundscape simulator, presented in section 4.2.4
- discussion groups to explore needs for technologies to support sound design practice and experience with sound in practice
- final large group discussion to listen to, evaluate (see Table 4.3), and discuss the soundscapes composed during the co-design session

Activities 1 and 2 were conducted in three small groups (9-10 participants each) that rotated through the various workshop activities. All participants participated together in Activity 3 at the end of the day.

4.2.1 Software

The simulator[11] was developed to allow the user to select and position sound sources in a 3D space in real-time and with both pre-determined and manual positioning and trajectories. The simulator was built in Max/MSP (Cycling '74) using the ICST toolbox (ZHdK-Zurich University of the Arts, 2015) to (see Figure 4.1):

- input different types of sound sources using audio recordings (Ambisonic, mono, stereo)
- apply filtering to the signal of sound sources to spatialize them in 3D space, including corresponding distance attenuation
- allow manual or automatic positioning of various sources in real time
- encode the entire composition in Ambisonics in real time

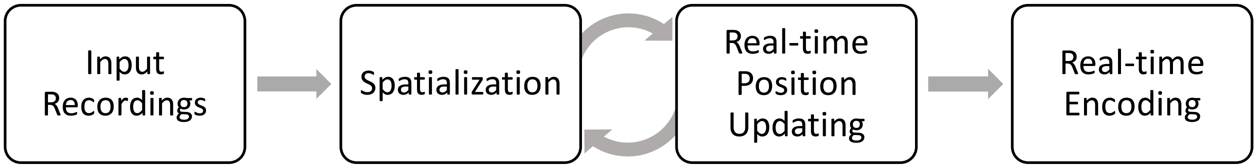

Figure 4.1. Simple simulator workflow.

A last step, which is dependent on the specific array used to play the composition, is to decode in real time the Ambisonic content thus created and encoded using the aforementioned toolbox. Using another toolbox (Heller, 2007), an Ambisonic decoder was developed for the irregular array installed in the listening room (see section 4.2.3). The

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[11] see a short binaural demonstration at https://youtu.be/cNHX6WayznE

development of the decoder is a separate step from the interface developed in Max/MSP, and the thus-obtained decoder is plugged into the simulator as the last step sending the output to the speakers. Finally, it was important to provide a clear and simple interface adapted for collaborative adjustments of the parameters, and a way to record snapshots of the co-created compositions, using the *preset* object in Max/MSP – which allows users to store and recall settings – rather than export an audio file, so as to keep track of the choices made. For more details, please refer to Blanc (2019).

4.2.2 Recordings

A newly-built public space was identified as a site of interest in collaboration with the Plateau Borough in Montreal (see Figure 4.2) and served as the primary source of recordings, spatial proportions, visualizations, and purpose for the imagined space in this study. It was a small (about 1,800 m^2) public square in Montreal on one of the main commercial streets of that area, with shops and restaurants along two traffic lanes also used by bus lines operating regularly (<10 minutes) during the day. On the other side, the space is bordered by residences and a footpath. On this site were recorded the “recorded soundscape” and the “urban background” used in the activity (see Table 4.1). The “urban background” is a recording of “the hum of the city” stripped to the barest of bones conducted at 4 am to obtain the “unremovable” background of city life to be used as the foundation of “original” soundscape compositions (as opposed to recorded “existing” soundscapes).

All available sources in this simulator prototype were previously recorded, either by the researchers or close collaborators, or obtained from open sound databases (see details in Table 4.1), including:

- First-order Ambisonic (FOA) recordings of sound environments using a Soundfield ST350 microphone connected to a Sound Devices 744T recorder, with simultaneous sound levels measurements using a Bruel & Kjaer type 2250 sound level meter, by the research team

- Mono and stereo recordings of additional single sources with a Zoom H2N, by the research team

- A few additional single sources obtained from an open sound database ("airliner_ascend.aif" by user Heigh-hoo (https://freesound.org/people/Heigh-hoo/sounds/51091/) licensed under CCBYNC 3.0), as well as collaborators Romain Dumoulin and Audiotopie

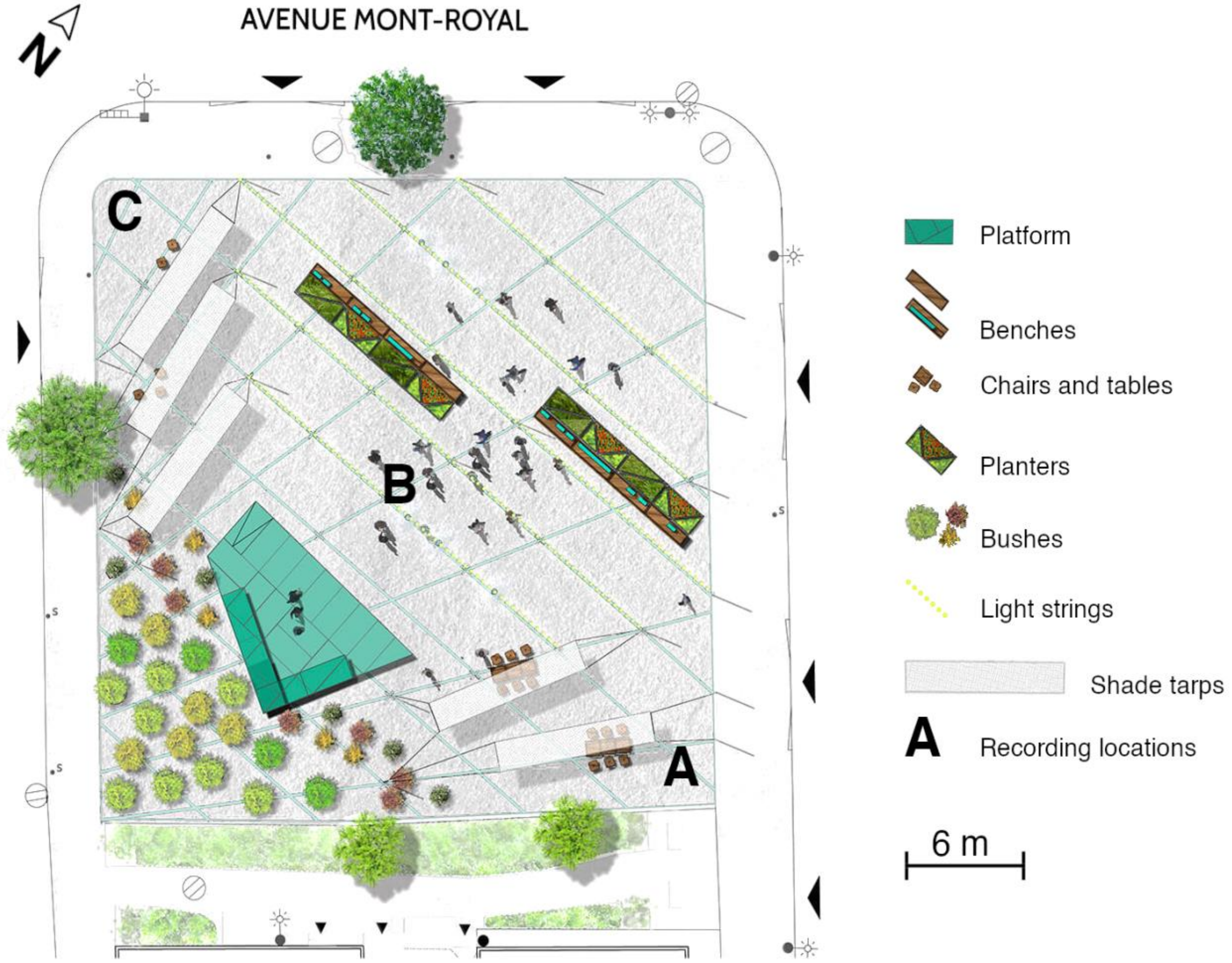

Figure 4.2. Simplified map of the study site. Design layout provided by design firm Castor et Pollux and used and edited with permission.

Table 4.1. Sources available in the simulator

Category	Sound source	Type	Predetermined trajectory/position?	Repositionable?
Recordings of public square	Urban background	FOA	-	No
	Recorded soundscape	FOA	-	No
Human activities	Sound art installation	Octophony	Yes	No
	Street piano	Mono	No	Yes
	Nightclub	Mono	No	Yes
	Terrasse	Mono	No	Yes
	Playground	Mono	No	Yes
	Bicycle 1	Mono	Yes	No
	Bicycle 2	Mono	Yes	No
	Skateboard	Stereo	Yes	No
Traffic	Heavy traffic	FOA	-	No
	Light traffic	Stereo	Yes	Yes
	Bus Left-Right	Mono	Yes	No
	Bus Right-Left	Mono	Yes	No
	Delivery truck idling	Mono	No	Yes
	Plane	Stereo	Yes	No
	Motorcycle	Mono	Yes	No
Mechanical noise	Construction work	Mono	No	Yes
	HVAC	Mono	No	Yes
Nature	Big water fountain	Mono	No	Yes
	Medium rock fountain	Mono	No	Yes
	Small trickling fountain	Mono	No	Yes
	Birds (composition)	FOA	-	No

4.2.3 Listening room

One of the main goals of the activity – and of the envisaged simulator tool – was to support in-person collaborative design discussions and processes. To do so, we needed a sweet spot wide enough to accommodate groups of 7-10 participants. The activity took place in a large music hall (17.07 x 23.77 x16.50 m – see Figure 4.3), the Music Multimedia Room (MMR) at the Centre for Interdisciplinary Research in Music Media and Technology (CIRMMT), which was temporarily equipped with 48 loudspeakers. This allowed the team to both ensure the participants could perceive the soundscapes appropriately at the same time and reproduce a similar sense of scale from the site of interest.

Figure 4.3. Participants walking around and listening in the MMR during the activity. Credit: Catherine Guastavino

4.2.4 Co-design activity

The co-design activity lasted approximately one hour. The two researchers involved in creating the software were running the simulator (playing recordings, adding/removing sources as instructed by participants, etc.) while another researcher moderated the discussion. Each group of participants gathered in the center of the room at the sweet spot but were free to walk around the space. After a brief overview of the simulator and the room, the discussion revolved around a three-part co-design session:

- Introduction – reflection and discussion on the listening experience of the multichannel playback of an unedited recording taken from the public space of interest for the workshop, both to introduce the immersive reproduction technique (Ambisonics) and to situate the participants with regards to the site of interest – 12 min
- Exercise part 1 – co-design of an ideal soundscape for the corresponding “imaginary” public space, building on the “urban background” and imagining unconstrained possibilities and resources – 12 min
- Exercise part 2 – co-design of a worst-case scenario to spoil the previous ideal soundscape by removing any two or three sources chosen in part 2 and adding three others. This exercise aimed to promote a discussion about the diversity of meaning and experiences with different sound sources in relation to different contexts and as experienced by a group of semi-diverse participants. This discussion was the foundation of the collaborative design in this exercise – 9 min
- Exercise part 3 – co-design of a realistic soundscape (“somewhere between good and good enough”) by mitigating a pre-set composition including: moderate car traffic on the

main commercial street, an overhead plane, and a *heating, ventilation, and air conditioning system* (HVAC) in the middle of one of the side streets, to simulate a typical urban soundscape that does not reach legal noise limits. Participants were instructed to use intervention strategies (see Table 4.2) rather than simply think of sound sources (taking into account aesthetics/visuals, cost, scope of practitioner, regulations), and to reflect on the context (e.g., neighborhood, streets) and the users and their activities in this public space. This exercise highlighted the need to examine place experience, engage in negotiation about the "ideal," and consider design strategies that could minimize impacts – 12 min

- Closing reflections on how their designed soundscapes would be experienced in everyday life, other possible choices for "good" and "bad" soundscapes, and the potential of such a technology for urban design and planning – 5 min

Table 4.2. Proposed interventions strategies

Slow down the traffic on the commercial street
Create ordinance against HVACs facing parks
Move the bus stop to a different block
Commission sound artists for an installation
Plant trees to add birds
Invite musicians for live music / Install a public piano
Install a fountain (one of three)
Install a playground for children
Permit a restaurant to open a terrasse
Permit a club to operate
Install low noise pavement (decibel reduction when traffic is over 30km/h)

Throughout the activity, a simplified map of the space (see Figure 4.4) was displayed on a screen, and participants could see the sources they added as labelled red dots. Sources could be placed anywhere in the presented space, including in elevation, and given trajectories if relevant (e.g., buses, bikes). Chosen sources played back in real-time and could even be moved as they were playing. Sound source levels could be controlled manually, although they were also modified by distance rendering in the software. Participants were invited to explain how they thought the chosen interventions would affect the different sources (e.g., removing sources, masking, or distracting).

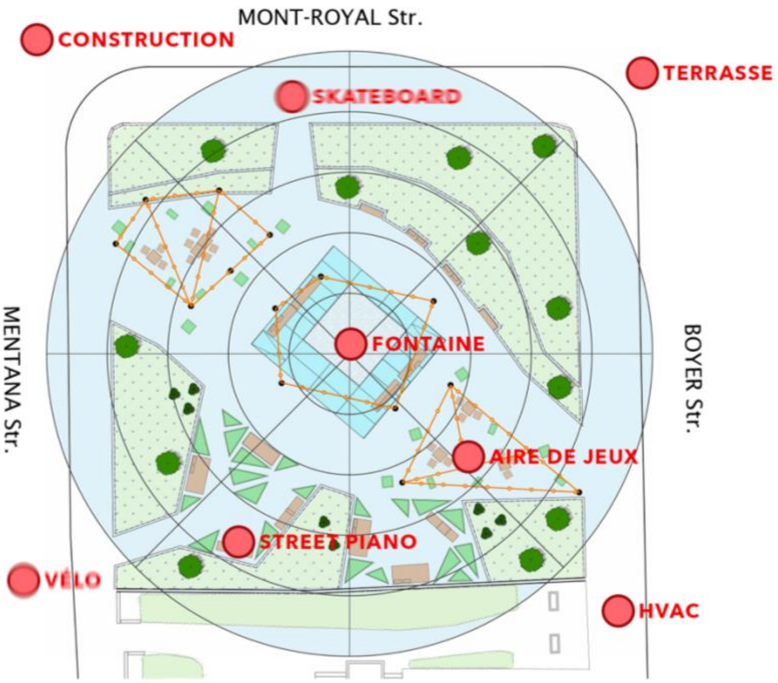

Figure 4.4. Visuals presented during the activity. Visualizations from the Ambisonic toolbox (blue circles and red dots) were overlayed on top of a simplified map of the space. The red dots represent the localization of labeled sound sources and could be moved manually by the researchers or automatically based on pre-entered trajectories.

4.3 Statistical analyses

During the last activity, the large-group discussion, all participants were asked to evaluate (see section 4.2) three soundscapes from the co-design session (one for each exercise: ideal, worst-case, realistic) using a short questionnaire (see Table 4.3) including scales from: the Swedish Soundscape Quality Protocol (SSQP – Axelsson et al., 2012) and the Perceived Restorativeness Soundscape Scale (PRSS – Payne & Guastavino, 2018); all scales have been previously used in outdoor urban soundscape studies, including the study site (Steele et al., 2021).

Table 4.3. Soundscape evaluation questions presented to participants during the last discussion. All were measured with 5-point Likert scales.

Source	Question	Variable name
	I find this soundscape to be:	
SSQP	Pleasant	Pleasant
	Appropriate for my activity	Appropriate
SSQP	Monotonous	Monotonous
SSQP	Vibrant	Vibrant
SSQP	Chaotic	Chaotic
SSQP	Calm	Calm
SSQP	Eventful	Eventful
PRSS	Spending time in this soundscape gives me a break from my day-to-day routine	Break
PRSS	Following what is going on in this soundscape really holds my interest	Interest
PRSS	It is easy to do what I want while I am in this soundscape	Do what want
PRSS	The sounds fit together to form a coherent soundscape	Coherence
	I find the sound level here to be loud	Loudness

Statistical analyses were computed in R 4.0.2 for Mac OS X and Rstudio® 1.3.1073, with a level of statistical significance $\alpha = 0.05$. A one-way repeated-measure MANOVA was conducted on collected soundscape evaluations (N = 27). Follow-up one-way repeated-measure ANOVA and paired pairwise t-tests with Bonferroni correction were conducted as *post hoc* tests.

4.4 Outcomes

The outcomes discussed in this section consist of a comparison of the soundscapes created in the co-design session with selected contributions from the discussions conducted in activities 2 and 3.

4.4.1 Soundscape compositions

The main activity's (activity 1) direct outcome was a set of three soundscape compositions per group: starting with 1) an ideal soundscape, where participants imagined having no limits of costs or feasibility; followed by 2) a worst-case scenario building on the latter to "spoil" it; and ending with 3) a mitigation exercise for a realistic scenario pre-built by the researchers.

4.4.1.1 Ideal soundscape

The ideal soundscape composition was built from the starting point of the *urban background* – that is, a recording of the city soundscape recorded at 4 am in the absence of activity and thus stripped of all direct sound sources. Following are the thought process of each group.

Group A, who participated in this activity last:

- started by adding birds, for which they questioned the Montreal provenance,
- then tested a skateboard,
- and followed by adding a fountain in the middle of the space, first the big water fountain, which was deemed too big for the context and replaced by the small trickling fountain.
- finally, added a terrasse in the south-west corner of the space, that is on one of the two corners farthest from the busy commercial street,
- and ended with testing the addition of a motorcycle passing by in said commercial street.

Group B, who came second, functioned more with a lot of trial-and-error, testing sources. At the end, they discussed their perceptions of the composition (note that their discussion revolved around perceptions rather than intentions), and explained that it felt full of life and human presence ("*on sent la vie, la présence humaine*"), and as being representative of the Montreal identity and evoking feelings like the much-liked La Fontaine Park nearby.

In their process to construct this soundscape, this group:

- started with adding birds as well. They also noted that the birds did not feel like Montreal, more like a cabin, but they liked them because they implied the presence of trees, although one participant who lives in the countryside noted bird sounds can be grating in daily life. However, participants would have liked to be able to see the temporal evolution of this source (e.g., test in the morning upon waking up),

- added a fountain. Participants first tested the medium rock fountain, which they indicated made the space more quiet and more peaceful and had an association to “relief on hot days”, but ended up choosing the big water fountain for its masking effects (“hiding” the traffic on the commercial street). Both were placed in the center of the square as well,
- tested and removed the skateboard,
- tested and removed the street piano (which was not always appreciated in daily life, with poor pianists fiddling being found annoying by some of the participants, while others do not agree),
- tested and removed the plane for its association to the notion of travelling,
- tested and removed the sound art installation, which was found “interesting” but needed to “not be monotonous” and change often enough for the residents (like the famous *21 Balançoires* (21 Swings)[12] on Montreal’s Place des Arts),
- and tested (and kept) the playground at the end.

Finally, group C, which was actually the first group to participate in this activity, engaged with the simulator not having had the other two activities first (group discussion and VR demonstrations). The observing researcher documented that this group reacted to the

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[12] https://www.quartierdesspectacles.com/en/activity/28245/21-balancoires-21-swings

simulator with a lot of surprise and curiosity and enjoyment. Once they started working on the exercise, the decisions they made were to:

- add a terrasse on the side of the space that bordered the commercial street,
- add a playground on the other side, closer to the quiet residential buildings,
- add the medium rock fountain in the middle of the space like the two other groups,
- add birds.

Trends in source selection can be seen in the resulting soundscape compositions (see Table 4.4): all groups added the bird sounds, a fountain (interestingly, each of the three types offered – small, medium, big – was selected by one group), and sounds of human activity (terrasse and/or playground).

Table 4.4. Final selection of each group for the ideal and worst-case soundscape compositions. Check marks indicate added sources, and x-marks removed sources.

	Group A		Group B		Group C	
Sound source	Ideal	Worst	Ideal	Worst	Ideal	Worst
Sound art installation						
Street piano						
Nightclub		✓				✓
Terrasse	✓				✓	
Playground			✓		✓	
Bicycles						
Skateboard	✓					
Heavy traffic		✓		✓		
Light traffic						✓
Buses						
Delivery truck idling						
Plane		✓				
Motorcycle	✓					
Construction work		✓		✓		✓✗
HVAC		✓		✓		
Big water fountain			✓			
Medium rock fountain					✓	
Small trickling fountain	✓	✗				
Birds	✓	✗	✓		✓	✗

4.4.1.2 Worst-case scenario

The worst-case scenario was built by editing the previous (ideal) composition, by either adding or removing sources:

Group A played around with a lot of the offered sources, not really discussing them together before suggesting them. They, in order:

- first removed the birds

- then added the HVAC, on the residential street to the west of the space, wondering about the type of system and noting that in a real scenario – on site – it would not only be annoying for its noise but for the vibrations it would emit,
- removed the fountain
- added the plane passing overhead and didn't find it annoying,
- added the nightclub source on the east side of the commercial street,
- added the sound art installation which was notably positioned in the north-west to south-east diagonal of the space and unmovable, which somewhat positioned it near the HVAC,
- added heavy traffic,
- added construction noise, noting that "it is Montreal!" in the summer.

Group B:

- started by adding construction noise, noting as well that it was exactly representative of the neighborhood in question ("*c'est ça le Plateau !*"), although participants found that it was too loud, chaotic, and continuous, thus masking everything else,
- then added heavy traffic,
- HVAC placed in the middle of the residential side, as if it was coming from the neighboring building on the pedestrian pathway at the back of the space, testing it by adding and removing it multiple times and noting that they couldn't really hear it from the center of the space,

- removed the fountain but added it back, seeing that it alleviated (“*apaisait*”) the construction noise, though by doing so, they were somewhat anticipating the next part of the exercise.

Group C seemed to have become more assertive by this point in the exercise. They:

- removed the birds,
- tested construction noise on the west corner of the commercial street, playing around with it a lot by adding and removing and adding it again, and removed again) – they noted as well that it masked everything and was representative of Montreal (“*C’est ça Montréal !*”) – in a second attempt, it was decided to remove it as it was stressful and this second attempt was meant to simulate evening,
- added light traffic,
- added the motorcycle, which was noted to be barely heard over the construction noise,
- added buses,
- added the nightclub source in the second attempt to simulate evening, noting it “grabbed the attention.”

Trends for this composition (see Table 4.4) are a little more variable. All groups added construction noise – all groups remarking that it is very representative of Montreal, and traffic noise (either heavy or light). Two groups both added the nightclub source and removed the birds. Two also added the HVAC source, and only one removed their fountain.

4.4.1.3 Realistic scenario

This part of the activity was slightly different from the two previous composition exercises, this time centered around interventions and strategies rather than individual sources and starting from the same combination of sources for all groups (namely, moderate traffic, plane, and HVAC).

Group A discussed the need to study and take into consideration how the neighbors would be affected, what they would need from the space, planning constraints, and the context of the space (e.g., some situations may not require building for children or reducing traffic, or one could imagine simulating the effect of snow or the presence of a hockey rink depending on the season). This group explored, in order:

- a first intervention consisting of moving the bus stop to an adjacent block – participants noted that they would be *electric* buses even if the sound component would be highly similar,
- secondly, creating an ordinance against HVAC systems facing parks, considering the possibility of adding high frequencies as well to “neutralize” the systems’ low frequencies,
- lastly, a combination of installing a playground for children in the middle of one of the residential streets perpendicular to the commercial street and planting trees to add birds,
- experimenting with the moderate traffic condition.

Group B were happy with the results of their interventions, finding the space sounder better and calmer, even “fun,” with the “creative interventions” they discussed. They, in order:

- suggested an intervention not listed, that of a shared street with a one-way street, being aware that it still meant traffic noise (engines and “friction”), even if lowered; no parking and no traffic light or stop sign to avoid sounds of breaks and revving engines; and possibly a bike lane or some level of pedestrianization (simulated by adding the terrasse and the skateboard),
- discussed installing a fountain, choosing the medium rock fountain and placing it right next to the HVAC system, at the same time as creating an ordinance against HVAC systems facing parks, the scenario’s system being considered “very loud” to the point of “preventing hearing anything else.” However, participants were aware that this is something that would be “hard to control” with an urban planner mentioning that such an ordinance-based approach has limits and that “physical interventions” help reduce nuisances without increasing the time spent on issuing violation tickets. An alternative was then suggested to invest in businesses working on increasing the sound performance of such systems,
- considered planting trees so as to mask noise by adding sounds of both birds and leaves, while a diversity of trees would be enjoyable and increase biodiversity, water retention, and heat dispersal. A big row of trees, possibly a wall of conifers, along both sides of the space (the sides of the main commercial street and the back alley) was

proposed. However, it was noted that “trees suffer” in Montreal due to heavy construction equipment (“*pépines*”),

- experimented with moving the bus stop to different block, noting that bus stops are quite close to each other the main commercial street the space of interest is located on.

Group C tested four combinations of interventions, emphasizing that it is important to first consider the functions and activities the space will offer. The consensus was that this space serves more as a transit and stopping place. It should also be noted that participants in this group all engaged actively in this last part of the exercise, certainly having gained in confidence but also due to some feeling like they could contribute more (higher “usability” and feelings of involvement in the task). This group, in order, explored:

- in the first test, reducing traffic speed and HVAC noise (although this was noted as unrealistic, being near impossible to simply reduce HVAC noise, and instead being more pragmatic to think of ways to “compose with it” and reduce its impact with other sounds), and adding a fountain, the small trickling one, as a mask that also adds “interest” to the space. Adding an art installation was also suggested as a “bonus,”
- in the second attempt, the HVAC was entirely removed, traffic was fully added back, and the fountain was kept,
- in the third option, the HVAC is added back (being noted to be “unbearable”), traffic is kept, and the art installation is added, making the soundscape “more bearable,”
- the fourth and last option tested included a reduced HVAC noise, the art installation, traffic, and birds.

The compositions for this last exercise have little in common: apart from all groups adding birds, the strategies used to mitigate the pre-designed realistic urban soundscape proposed varied from reducing the unpleasant sources (HVAC, plane) to adding pleasant sources as maskers (sound art installation, fountain, human activities). Interestingly, none of the groups removed the traffic source ultimately.

4.4.2 Additional feedback

4.4.2.1 Group profiles and tool interactions

All groups were made up of a majority of professionals of the built environment, a few sound researchers, and at least one sound artist each. Group A was distinctive as it was the only group including soundscape experts (particularly international, i.e., unfamiliar with Montreal), while most of its urban professionals were urban planning and design students and professionals. Group B and C were both made up of more than two thirds of urban professionals from the city of Montreal and from the private sector, including architecture, design, and planning.

In group A, some of the group members were noted to be “experts” while others were “amazed” by the system. The group was more disparate, with little consensus and separate conversations at times, although this led to the consistent exploration of multiple possibilities. This group seemed engaged and readily discussed the system, even asking questions to understand what they were hearing (e.g., regarding sound levels and directions). Participants in group B tried to “compare” and grasp the space and its sounds by turning around and moving widely about the space, and like group A, more so around the edges than the center and with eyes closed at times. Group C was noted by the research team to be more homogeneous in their learning of the system, everyone first listening while standing still and only moving around during a second listen.

In conclusion, a majority of participants, from all groups, moved around the listening space and tried closing their eyes as they listened.

4.4.2.2 Remarks from activity conclusion

Additional remarks were made by participants of each group discussions at the conclusion of the activity. In short, all groups mentioned a skewed perception of direction, in different ways, although all noted the immersion and realism of the experience. Additionally, all groups expected the other groups to make similar choices for their compositions, highlighting the desire for seemingly ubiquitously preferred sources. Interestingly, they all pointed out that, in hindsight, their own design choices did not encourage enough human activity and social sounds. Most differences between groups can be summarized as differences in expertise and practice (sound recording and perception in group A, urban design in group C).

Group A discussed the system's potential for design exercises to cultivate awareness and engage with citizens rather than make decisions, since it allows one to "enter the design", "gives a forum that renderings do not", and is "more intuitive than renderings". However, they were aware of the limitations regarding access to the necessary resources like a room of proper size and 360º recording equipment. Recording was seen as the most important aspect for success, with the sounds' contexts also being very important on different aspects: recording accuracy and quality, feeling of the space (e.g., size, reverberation), source (in)authenticity (e.g., congruency). Other potential applications mentioned by this group for such a tool included the possible use by sound artists in the case of sound art commissions for a specific space.

Group B noted that this was a nice creative exercise but that they felt more of an impression of a curved sound space with the trajectories of added sources not corresponding to their expectations of a linear path. However, they mentioned, like group A, that they might have added more social sources and more human activity, with the possibility of different types of human sources being chosen (e.g., playground/children depending on if there were more parents or not). They also discussed their choice of using some of the sources in ways that were not intended at first (e.g., adding a terrasse to simulate pedestrianization), wondering about the flexibility of the system.

Group C spoke more about the design of soundscape than the system: they found the exercise interesting in that it highlighted that it is hard to find enjoyable sound sources and that even pleasant sounds become tedious as they keep playing. The need for activities was noted, as well as the need for a specific vision for the space so as to guide design choices. Context was also remarked upon: specifically, that residential zones should not be forgotten in the decision process while, at the same time, parks are places of pedestrian transit ("*lieux de passage*") towards other places, especially when situated next to a busy commercial street. This group's conclusion was therefore an emphasis on understanding tensions (such as residential-commercial) in a pocket park like the space of interest. As for their expectations of other groups, they recognized that similarities should exist, like reducing the HVAC, while emphasizing context in relation to project design and personal experience. This group noted that any sound design outcome would depend on the user's vision for, and perception of, the space, the criteria and objectives of the project, and the user's lived experience in relation to previous problems or emotional associations to certain sounds and sources.

4.4.2.3 Small-group discussions

Group A was the first group to meet to discuss expectations and needs regarding technological support for their urban practice, meaning they had not experienced the soundscape simulator. This group was open to new tools and new approaches but expressed the need for a proof of concept first. Context was noted to be important in that all spaces to be (re)designed will be different from each other, and that the existing context is the basis on which anything new is created. As well, it was noted that a big challenge of such a technology to render a sound environment is that every position in a given space sounds different.

Group B was the last group to meet for discussions, meaning they had experienced all the technologies presented during the workshop. This group expressed a desire to integrate sound into the entire process and not just treat it in isolation, but noted a lack of regulations and tools, specifically in relation to considering context, which is not accounted for in noise limits. Having experienced the different technologies provided during the workshop, they had examples in mind as to how they would want to be able to use such technologies for specific projects that turned out to have costly sound consequences, including testing a design at different times and days, and for different situations. Specifically regarding the co-design activity, they were very enthused by the system itself and felt it would be very interesting for communicating with stakeholders and co-designing solutions to common problems, although some hesitancy was expressed about the risk of virtual tools leading to the isolation of design practice from real discussion with stakeholders. Finally, interestingly, a member of this group noted that, despite the lack of visuals and due to the spatial quality of the sound rendering, they "felt" the sounds they heard more than their schematic representation on-screen. On this note of the visual interface, it should be noted that a member brought up the issue of not knowing where they were positioned with regards to the sounds during the exercise. This latter point highlights the need for a clear interface more than the obligatory presence of visuals; another participant added that the need for visualizations would depend on the objective of the simulation, citing the example of a noise barrier for which the visual material does not impact the noise reduction[13]. In this spirit, it was proposed that the tool be used to generate scenarios with professionals (e.g., architects, urban designers) to be presented to the stakeholders, so as to offer tailored solutions rather than generic elements which would not be visually appealing. This idea implies the need for the tool to offer the possibility to quickly switch between scenarios and to import visual and sound renderings created with the designed elements. Like group C during the exercise, this group also mentioned here the need to discuss first and foremost the purpose ("*vocation*") of the space as a point-of-entry to discussion with the stakeholders.

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[13] Note that recent research has found potential benefits of natural visual design of noise barriers (Hong & Jeon, 2014).

Group C was in between, having participated only in the co-design activity we are focusing on here. A city planner pointed out a lack of resources and tools, other than acoustic modeling to ensure compliance with noise regulations, which requires hiring an acoustician. The city enforces this modeling requirement from owners and developers, which implies it is not feasible for smaller noise issues like neighbor noise. It was also noted that the regulations date back from the early 1980s and have not been investigated in terms of environmental impact.

4.4.2.4 Large-group discussions

In the last part of the workshop, the *realistic* soundscapes created by each group were played back for everyone and a group representative explained what they tried to accomplish. Group A first tried to decide what were "nice sounds" to add, such as birds (via trees), the skateboard, or the motorcycle; and then decided to keep the buses but try to mask the HVAC system by placing the playground source next to it. Group B first wanted to rethink the commercial street into a shared space with lower speed limits and shared lanes – which was not something the prototype offered – and then tried to mask the HVAC system with a fountain, as well as plant trees for a "multi-problem" solution (biodiversity, wind, landscape architecture). Group C first tried to reduce unwanted sounds at the source ("*à la source*") before adding anything new; and then realized they needed to add those unwanted sound sources back and try to balance them out instead with appropriate additions.

Following this, all participants discussed said realistic compositions. They saw that some sources are consensual – most evidently birds – with the goal of mitigating and masking consistently unwanted sources such as traffic. They also noted that all compositions converged towards a space designed for relaxation rather than liveliness, possibly as a consequence of the Montreal context notoriously dominated by construction noise. Finally, they emphasized again the role of context, in terms of temporal variation (season, day, hour) this time.

At this time, everyone was asked to evaluate three of the compositions (one of each: ideal, worst-case, realistic). A one-way repeated-measure MANOVA showed a significant effect of the composition on the evaluations (F(24,122) = 3.04, p < .001). Follow-up one-way repeated-measure ANOVA showed an effect of composition on all scales but *interest* (see Table 4.5). Paired pairwise t-tests with Bonferroni correction were conducted to investigate the compositions that differed from each other. For clarity, we refer the reader to Figure 4.5 only.

Table 4.5. Summary of ANOVA results with Bonferroni correction; eta-square (η^2) values represent effect sizes; ns: p>.05, **: p<.01, ****: p<.0001

DV	df_M	df_R	F	p-value	p corrected	signif.	η^2
Pleasant	2	52	96.732	3e-18	3.6e-17	****	0.673
Appropriate	2	50	58.947	7.05e-14	8.46e-13	****	0.582
Calm (GG†)	1.584	41.184	58.133	1.52e-11	1.82e-10	****	0.577
Monotonous	2	50	9.849	.000248	.002976	**	0.197
Vibrant	2	52	19.198	5.7e-07	6.84e-06	****	0.315
Eventful	2	50	25.28	2.59e-08	3.11e-07	****	0.397
Chaotic	2	52	60.791	2.45e-14	2.94e-13	****	0.575
Loudness	2	52	78.966	1.75e-16	2.10e-15	****	0.526
Do what want	2	52	72.804	8.42e-16	1.01e-14	****	0.597
Coherent	2	52	13.264	2.22e-05	2.66e-04	****	0.24
Break	2	52	52.106	3.8e-13	4.56e-12	****	0.565
Interest	2	52	2.534	0.089	1	ns.	0.046

† Note: Greenhouse-Geisser correction applied to *calm* due to violation of assumption of sphericity

Although it is important to keep in mind that these results are obtained from a small sample, especially given the within-subject nature of comparisons, it is interesting to confirm that the ratings for the three compositions are markedly different. What can be seen from Figure 4.5 is that the realistic composition is the most *pleasant*, *appropriate*, *calm*, and restorative (*do what want*, *break*, *coherent*), and the least *chaotic* and *loud*, of the three, although the ideal one is a close second with even non-significant differences for *pleasant*, *break* and *coherent*. In relation, the realistic composition is also found to be the most *monotonous* and least *vibrant* and *eventful*, in contrast to the ideal composition being found the least *monotonous* and most *vibrant* and *eventful*, although the worst-case composition is not significantly different from both in terms of *monotony* and from the ideal one in terms of *eventfulness*. The worst-case composition is otherwise always significantly different from both the ideal and the realistic compositions, unsurprisingly being the least *pleasant*, *appropriate*, *calm*, and restorative, and most *chaotic* and *loud* of the three. We can also observe that the *interest* scale was not evaluated much differently between compositions, perhaps denoting a lack of understanding or relevancy for audio-only experiences.

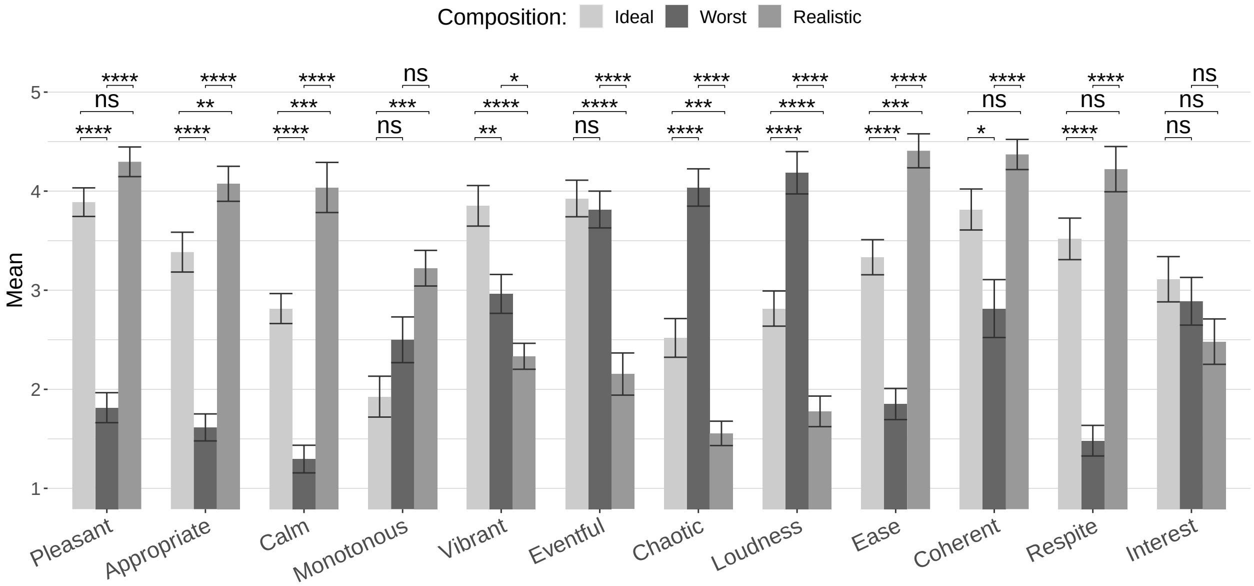

Figure 4.5. Means and standard errors of all the soundscape evaluations per composition (N = 27). Significant differences obtained with paired pairwise t-tests with Bonferroni correction; ns: p>.05, *: p<.05, **: p<.01, ***: p<.001, ****: p<.0001.

These results validate that participants were able to compose perceptibly different soundscapes corresponding to different objectives, except for the question of *interest*. But during the follow-up discussion, participants mentioned the difficulty in evaluating soundscapes on this scale, for example in the case of an annoying sound which therefore attracts attention but does so because it is a bother rather than a wanted sound. Therefore, it was determined to be difficult to summarize the entire sound environment with one adjective. Furthermore, the discussion revealed that the ideal composition was found more vibrant and better able to capture interest thanks to the playground sounds, specifically the children animating the space, with the sound of swings being a nuisance. It was also noted that the perceived sound levels for each composition did not feel similar, which is a valid concern, given that the simulator was a prototype with limited sound level calibration, but which also highlights the difference of perception in terms of sound level depending on the valence and appreciation of the sound environment.

Finally, participants indicated positive conclusions about the entire experience of the workshop, including their increased awareness that the sound experience needs to be taken into account in a better manner in urban planning. At the same time, they also realized that they possess implicit knowledge and expertise on the topic – which this workshop helped make explicit. The importance of interdisciplinarity was also emphasized, including the need to consult “all types of people” – i.e., not just experts but also the relevant populations. One engineer mentioned that the workshop itself was interesting for them as they “don’t usually work and deal with people.” Participants further mentioned the need to educate experts and non-experts without minimizing the human aspects by relying too much on “individualizing technologies” – which is something they liked from the workshop, especially the discussions. Participants talked about using such a simulator tool to “shap[e] the approach to designing soundscapes” and to “creat[e] sound ecology as a design product.”

4.5 Discussion

This study is one of multiple formative iterations as part of a user-centered design process toward the development of a tool to support the integration of soundscape considerations into the workflow of urban professionals. Based on previous work including interviews (Steele, 2018) and workshops (Steele et al., 2020) with urban professionals, and subsequently followed by demonstrations and activities with a breadth of stakeholders (at the *Journées du bruit environnemental* 2019), this iterative process aimed at identifying the needs from prospective tool users. During this process, laboratory studies were also conducted to validate the reproduction technique for soundscapes (Tarlao et al., 2022), and future work will integrate the lessons learned from the present research into the next tool iteration (Yanaky et al., 2020).

The objective of this study was to explore the potential of soundscape tools that tip the balance towards flexibility over precision in order to make a design aid for urban professionals rather than for acoustic professionals. Not only were we interested in developing the best technological tool for urban professionals, but specifically in understanding the context of urban practice so as to best support it, with and without the tool. Following in the footsteps of Steele's (2018; in press) examination of how urban professionals take sound into consideration, the present work aimed at understanding how to change the culture and approach to sound in urban design and practice – through a soundscape simulator prototype as a first step with short-term implementation and outcomes, keeping in mind the longer-term goals of changes in policy and curricula. This investigation was conducted through an interactive workshop for knowledge mobilization, with balanced groups of participants, and using a balanced experimental design of three activities. To allow urban professionals to experience and to discuss the simulator interactively with the other participants and the researchers, they participated in three activities: a soundscape co-design session in small groups, discussion groups on technological needs to support sound design practice, and a final discussion about the co-designed soundscapes with the entire audience.

During the co-design activity, all groups added bird sounds, a fountain, and sounds of human activity to their ideal soundscape composition, which is in line with previous work showing preference for natural and human sources in ideal soundscapes (Guastavino, 2006; Lafay et al., 2019). Trends for the worst-case scenario are a little more variable, with all groups adding construction and traffic noise, while two out of the three groups added the nightclub and/or the HVAC and/or removed the birds, and only one removed the fountain. Mechanical and construction sounds were also previously found to be associated more with non-ideal urban soundscapes compositions (Guastavino, 2006; Lafay et al., 2019). The realistic compositions were even more varied, with only the traffic and birds in common. A diversity of strategies was used, even with the limited sound source offering of the prototype: one group started from an angle of experimenting with adding different desirable sounds, another first tried to reduce or mitigate unwanted sources, and the last approached the exercise by thinking through the purpose of the space in question as a shared space supporting multiple uses (e.g., transit and stopping). The ready retention of traffic noise in the realistic scenario is not entirely surprising when seen from the lens of expectations in urban settings. For example, Lafay et al. (2019) found that traffic sources were chosen just as much to be part of an ideal realistic urban soundscape than a non-ideal one.

The discussions indicated that people experienced some level of spatial distortion but were overall impressed with the realism and immersion of the simulator’s rendering. These two seemingly incompatible impressions point to the promising potential of the tool for soundscape (co-)design in eliciting an experience that feels realistic and audibly spatialized. The way that members of the general public, rather than the experts of mixed specialties represented here, would experience and use the soundscape simulation tool is an open question, and one could hypothesize that they would be less critical about flaws and even more appreciative of the tool's flexibility. Such considerations will matter for uses of the simulator involving communication with the general public, such as public consultations. Interestingly, most participants closed their eyes at one point or another to listen more attentively – one participant even "felt" the sounds in space better due to the lack of visuals. It is interesting that visuals were not necessarily desired by participants, beyond the need to clearly present positions of the listening point in relation to the sources. We believe that both this and the fact that urban professionals are so ready to be proposed resources to better integrate sound considerations in their workflow is a sign of a shift away from the vision-only focus (Pallasmaa, 2012) of urban practice.

The soundscape ratings also confirmed that participants were able to co-design three perceptibly different compositions with three different purposes, further reinforcing the conclusion that the simulator offers the intended potential to support the integration of soundscape into the design practice. These results are especially encouraging given that they stem from changes in soundscape only, without differences in space, purpose, or visuals. This last conclusion is a step further from previous work showing that Ambisonic reproduction of urban soundscapes elicit similar cognitive processes as on-site environments (Guastavino et al., 2005; Tarlao et al., 2022) in that the manipulation and composition of soundscapes using Ambisonic rendering over loudspeakers are found to elicit realistic and measurably differentiable perceptions as well.

It is important to keep in mind that participants were asked to evaluate the sound outcome (soundscape compositions) of an activity they participated in, and at the end of an entire day of discussions about sound – that is, they were primed and taught to listen. Additionally, laboratory reproduction, even when perceptually validated, offers a more controlled environment and reduces the complexity of *in situ* experience (Tarlao et al., 2022). The results in Tarlao, Steele, et al. (2021) hint at a holistic integration of contextual factors and other sensory modalities in soundscape judgments while on site, factors and modalities that are deliberately controlled in the laboratory. This highlights the need to complement this laboratory-based technological tool with field work and to keep in mind that this approach is not meant to replace the tools already available to professionals (e.g., on-site usage analysis, historical analysis), but to be an additional tool to fit in the existing workflow.

This study explores a proof-of-concept that sound design can have an impact on experience, perhaps especially for urban professionals who rarely work under this understanding, given the well-documented and long-lamented hegemony of the visual (Levin, 1993; Pallasmaa, 2012). In the urban planning context, sites are typically considered sonically static, with a static sound environment dictated by neighboring uses. That is, urban professionals often work under the expectation that the sound environment as it exists before a new project will stay that way and will not be impacted by the project. Their consideration of the sound environment is therefore limited to concerns about shielding future users of their project from the already existing sound environment – encroaching noise from outside the project (Bijsterveld, 2008; Steele, 2018) – while ignoring the sound outcome of their design decisions. This study acknowledges and helped the invited urban professionals to acknowledge that their design choices, and the activities and users they invite in the designed space, also produce sound – sound that affects the users in return.

The large loudspeaker-array rendering also allowed participants to walk around the rendering area. Few mentioned any impressions about this specific opportunity offered by the system, but the experimenters noted that a majority of participants did walk around, often with their eyes closed. It should be made clear that this should not change one's perception like walking around a physical space does, as long as one remains in the rendering area. However, this is related to a point emphatically appreciated by the participants: the interactive nature of the exercise and workshop. They expressed that the tool could be an invaluable resource to 1) co-design solutions and scenarios with multiple professionals and stakeholders, thus supporting interdisciplinary practice and discussions, and to 2) communicate said solutions and scenarios to stakeholders – i.e., immerse them in the projected sound environment. The interactive nature of the system was especially highlighted by the concern of some participants that virtual technologies (e.g., using individual head-mounted devices for virtual reality rendering) may isolate the designer from the human aspects by leading to a curtailing of the important step of discussing issues and solutions with stakeholders.

It is noteworthy that participants were interested in being proposed new tools to support their practice but, similarly to Raimbault and Dubois (2005), had no specific expectations before testing the tool. This may be in part related to their recognition that current technological support tools are complex and expensive, requiring acoustic expertise, thus limiting their use to regulatory compliance. After testing the tool, participants were able to conceptualize better how and what they would like to be able to use it for. One such desire which should guide the further development of the tool is that they would want to be able to test a design at different times, days, and seasons, and for different situations. Context as a space's existing history and identity was also emphasized by participants as an essential factor to appropriately design a new project. This highlights their desire to approach sound in a more holistic manner by taking into account context as they are already used to doing with other aspects of the design process. The future of this area will also depend on policy and regulations changing, which is another literature growth area (Laplace et al., in press).

Notably, temporal context has been shown to influence sound level in field studies (Fraisse, 2019) and soundscape judgments in laboratory studies (Tarlao et al., 2022), with differences across times of the day and days of the week. These results reinforce the idea that temporality needs to be a simulation setting for any tool geared towards soundscape design, with enough range to include within-day to between-season conditions. The extremely temporal nature of sound may even be one of the reasons it has been slow to be integrated with visual forms, which can be presented statically. It was also found that location in an urban space, even as small as a pocket park, has a marked effect on soundscape judgments (Tarlao et al., 2022), and should therefore also be taken into account while designing the soundscape of a space.

It was therefore proposed that the tool offer the possibility to generate tailored solutions with professionals (e.g., architects, urban designers) to be presented to the stakeholders. This implies the need for the ability to quickly switch between created scenarios and to import the visual and audio renderings of design elements created by the professionals, as well as relevant audio recordings of the local context. These findings are in line with previous work (Defrance et al., 2016) in which French urban professionals also asked for the ability to compare scenarios and to take into account the temporal rhythms of urban life in a simplified soundscape simulation software used to communicate and collaborate with stakeholders iteratively.

Finally, all groups expected similar choices for a given composition from the other groups: to 1) reduce the negative impact of unwanted sounds (e.g., HVAC, traffic), and 2) maximize the positive impact of wanted sounds (e.g., natural sounds). In hindsight, participants expected other groups to place more emphasis on the sounds of human activities, which could be attributed to the fact that they are an inherent part of urban life. It was also pointed out that expertise and practice influenced how participants approached the exercise and the tool. Regardless, they found the workshop reinforced their understanding and desire to incorporate sound in a holistic manner in urban planning. This points to the need for outreach and education both to soundscape concepts and to the tool itself. To this end, our team is developing a short soundscape design course for urban professionals, which will make use of the tool to exemplify soundscape concepts for the participants. In parallel, we are also developing a series of short tutorials to be integrated in the simulator to guide the user through the use of the tool and on what soundscape can and cannot accomplish. The workshop was also found to help those professionals who do not typically consider the human aspects to understand the need to involve all stakeholders in the design process. Knowledge mobilization and public outreach about soundscape should therefore be aimed at all stakeholders, including non-experts.

4.6 Conclusions and recommendations

This exploratory study of the use and perceptions of a soundscape simulator prototype for the urban design practice conducted as part of a knowledge mobilization workshop reveals a number of avenues for the development of a tool for urban professionals:

- The tool should strike a balance between flexibility, realism, and immersion on the one hand and acoustic accuracy on the other.
- Users should be able to hear the changes they make in real time.
- Users should be able to switch between compositions (e.g., at different times of the day, seasons, circumstances such as presence of an event) for a same project seamlessly.
- The tool should offer the possibility to view visuals or not.
- Users should be able to import visuals (e.g., CAD drawings) and audio recordings (e.g., sounds representative of the local identity).
- During development, the researchers should make a concerted effort to avoid creating a tool that will cut-off the practitioner from discussion with the stakeholders.
- The tool should incorporate tutorials to introduce soundscape concepts and explain what the simulator can and cannot do.

This tool cannot and will not replace the work and expertise of acousticians, including the essential tool of acoustic modeling, but it is meant as a drafting and testing interactive tool to help urban professionals understand the sound consequences of their design choices and make conscious decisions regarding the soundscape. Analogously to the practice of visually sketching designs before even approaching a CAD-designer, this tool is aimed at supporting the practice of (collaborative) “sound sketching” before approaching an acoustician. It will also be aimed at supporting interactive communication with clients and stakeholders, including public consultations, and be integrated in the larger undertaking of soundscape knowledge mobilization and outreach towards urban professionals. The simulator prototype used during the presented workshop can also already be used for scientific research purposes and we expect the future iterations to open it up to a wider researcher audience by simplifying the user experience and reducing the technical requirements.

As it exists now, the simulator offers Ambisonic and binaural rendering (for loudspeaker and headphone reproduction, respectively) but it requires at least some basic knowledge of Max/MSP to switch between them, as well as to add sources, control their location, and save the composition. More complicated still, the Ambisonic decoder needs to be configured to each specific loudspeaker array configuration (here, we developed our decoder with a Matlab toolbox and compiled it with Faust) which requires precise measurements and signal processing knowledge. Regardless, the prototype can very easily be portable through the binaural rendering option, which would fit the needs of smaller urban professionals who do not have the resources to dedicate a room to a loudspeaker array for Ambisonic reproduction. The trade-off of portability is the loss of the interactive element, wherein listeners will be wearing headphones – probably one at a time – and therefore be unable to discuss with others what they hear in real time. More generally, users, whether they rely on existing recordings (including from environmental sound databases) and/or they record their own sources to use for soundscape composition, will need to know the basics of acoustics and sound recording to choose and/or obtain samples appropriate for use in composition. Finally, users will need to keep in mind that any outcome from the tool cannot be completely acoustically accurate and does not supplant the work of acousticians, nor will it perfectly reproduce the on-site experience. Indeed, laboratory reproduction, by nature and purpose, controls for many factors known or theorized to influence soundscape perception on site (e.g., space user expectations, weather) (Tarlao et al., 2022).

The next steps for this simulator will be to ensure the tool is both usable and engaging to the targeted audience (Yanaky et al., 2020). As previously pointed out, a number of soundscape simulation tools exist in the research field but their penetration and adoption into the practice of urban professionals remains marginal at best (Bild et al., 2016). Part of the issue is that those tools do not fit well into the professional workflow, while it is also arguable that those simulation tools are generally not aiming to be easily usable for non-research audiences. It will therefore be imperative to build on the outcomes of this workshop in order to guide the development of the next iteration of the simulator so that it can meet the implicit expectations and requirements revealed in this workshop (Yanaky et al., 2020).

Chapter 5 – Conclusion

This thesis was an effort to address the knowledge gap between soundscape research on the experience of city users and urban planning practice by investigating contextual factors affecting soundscape evaluations and prototyping a soundscape simulation tool for integrating sound consideration into the practice and workflow of urban professionals. There are two bases for this dissertation. The first is the fact that currently used noise mitigation approaches, focused on reducing sound levels, fail to consider the complexity of many urban experiences. The second is that urban professionals are ill-equipped to approach urban sound in any other way. While soundscape research could potentially inform urban practice by offering a flexible proactive approach to enhance the quality of urban sound experiences, it is perceived as too abstract by professionals to be applied to specific projects (Steele, 2018).

This thesis consists of three studies that address this gap by 1) developing a better understanding of how the specific context of an urban project influences the urban sound experience, and 2) developing and evaluating new tools to facilitate the integration of sound considerations in the practice of urban professionals.

Three interconnected studies have been carried out, spanning a breadth of methodologies, conditions, and participants (see **Table** 5.1). The work presented here made use of quantitative and qualitative methods, was conducted on site and in the laboratory, and involved city users and urban professionals. The first study (**Chapter 2**) investigated the soundscape experience of city users in four Montreal urban public spaces and the contextual influences of person-related (age, gender, noise sensitivity, and extraversion) and situational (social interaction) factors, contributing to both theoretical and methodological advancements. This work validated the French translation of soundscape assessment scales in the context of bilingual Montreal, confirmed the two-dimensional underlying conceptualizations of soundscape evaluation in terms of *pleasantness* and *eventfulness*, and proposed a first parsimonious model of contextual influences on soundscape evaluation. Understanding how context (including personal factors) influences the urban sound experience can allow urban professionals to identify the needs of different city user groups and to design inclusive policies and spaces. The second study (**Chapter 3**) examined the ecological validity of soundscape reproduction and evaluation in the laboratory, as well as additional contextual influences (time of day, day of the week, and location on site) on soundscape evaluations. This work is based on the on-site results of the first study and leads into the third one by validating the use of Ambisonics for an immersive audio simulator to help urban professionals integrate the soundscape approach to their practice. It also exemplified the complementarity of site and laboratory studies by revealing influences of time, day, and location in the more controlled laboratory setting. The third and last study of this thesis (**Chapter 4**) made use of collaborative design exercises and group discussions to explore the experience of urban professionals with a soundscape simulator prototype. As part of an iterative design process to develop tools that urban professionals can and want to integrate in their workflow, it was aimed specifically for knowledge mobilization and sharing between urban professionals and soundscape researchers. Therefore, outcomes from this study include recommendations and avenues for improving the simulator, as well the acknowledgment by urban professionals of the sound consequences of their design choices, and the activities and users they invite in the designed space.

This chapter is structured in four sections: first, a summary of methods and results for each study; second, contributions and significance of this research; third, limitations and future steps of the presented research; and finally, closing remarks and recommendations.

5.1 Summary of results and contributions

This dissertation contains multiple contributions towards knowledge and applications for the integration of soundscape considerations in urban decision making. The original research objectives and questions presented in **Chapter 1**, as well as the corresponding studies, are reiterated below, followed by a summary of each study and its contributions. **Table** 5.1 also summarizes the methods used and the research questions answered by each study.

RO1: Contextual influences on soundscape evaluation

- **RQ1**: How do the identified contextual factors influence soundscape evaluations? (**study 1 – Chapter 2** and **study 2 – Chapter 3**)
    - study 1 focuses on situational (social interaction) and person-related (age, gender, noise sensitivity, extraversion) factors
    - study 2 focuses on situational factors (time of day, day of week, location on site)

RO2: Development and evaluation of a soundscape simulation prototype

- **RQ2**: Are laboratory-based 3D-audio soundscape reproduction and evaluation ecologically valid? (**study 2 – Chapter 3**)
- **RQ3**: What are urban professionals' expectations for, and evaluation of, the use of the simulator in the context of soundscape co-design? (**study 3 – Chapter 4**)

Table 5.1. Summary of studies and methods per research question

	RQ1	RQ2	RQ3
Study 1	- on-site questionnaires - structural equation modeling		
Study 2	- on-site questionnaires - laboratory experiments	- on-site questionnaires - laboratory experiments	
Study 3			- simulator prototyping - group discussions

5.1.1 Contextual influences on soundscape evaluation

The first step of this thesis was to investigate the soundscape experience of city users (**Chapter 2**), answering to the **first research objective** and the **first research question** of the present work. Not only is it essential for the sake of characterizing urban sound environments, but also to understand how the soundscape experience is shaped by context – whether by situational or person-related factors.

Most of the soundscape field studies have been conducted on one specific site at a time, thus limiting the generalization of results. By analyzing the data of more than 1400 questionnaires from a broader range of sites – including parks and public spaces, this first study contributes both at a methodological and theoretical levels to the body of knowledge in soundscape research through 1) the validation of the Quebecois French translation of the main assessment tools used in soundscape research – questions from the SSQP (Axelsson et al., 2010) and the PRSS (Payne, 2013), and 2) the confirmation of the two-dimensional underlying conceptualizations of soundscape evaluation in terms of *pleasantness* and *eventfulness*.

Finally, the primary theoretical outcome from this study lies in the investigation of the role of contextual factors through the building and testing of a model of their influences on soundscape evaluation. Based on the literature, soundscape evaluations were hypothesized to be influenced directly by noise sensitivity and social interaction (using the space alone vs. in a group), and indirectly through these, age, gender, and extraversion. All factors included in the model significantly influenced soundscape evaluations in a complex pattern including interactions between factors, presented in detail in **Chapter 2**. This reveals the importance of context in urban sound experiences and points to the need to 1) further investigate contextual influences, 2) communicate this knowledge to the decision-makers of the urban space, and 3) ensure that laboratory experiments elicit similar perceptions to on-site experiences, the former being much more controlled than the latter.

5.1.2 A soundscape simulator for urban professionals

5.1.2.1 Ecological validity of laboratory soundscape reproduction

Following this first step of investigating the urban soundscape experience, the rest of this dissertation focused on the **second research objective** of the present work, the development and prototyping of a soundscape simulator for urban professionals. To this end, it was important to ensure the ecological validity of the methodological and technological choices made for the soundscape reproduction and evaluation in the laboratory – exploring the **second research question**. Specifically, ecological validity entails representativeness of participants, of setup and stimuli, and of task and procedure (Brunswik, 1943).

In this second study (**Chapter 3**), participant representativeness was ensured by recruiting residents of the neighborhood so that they would be familiar with the space of interest. In the case of urban practice, this exemplifies how the contributions of this thesis, and of the soundscape field in general, are not meant to replace any of the existing tools and practices already available and recommended to urban professionals, such as on-site usage analysis or consultation. Setup and stimuli representativeness, and task and procedure representativeness were the focus of this second study. To this end, this study investigated 1) soundscape conceptualizations elicited in the laboratory with Ambisonic reproduction, in comparison to *in situ*, 2) the influence of the methodology (i.e., mode of questionnaire administration and recording excerpt), and 3) the influence of specific situational factors (location in the space, day of the week, time of the day) on soundscape evaluations in the laboratory, in comparison to *in situ*.

In short, findings indicate that laboratory reproduction elicit similar perceptions than *in situ* experiences. Participants held similar conceptualizations of the underlying soundscape dimensions in the laboratory, as compared to *in situ*, thus hinting at similar perceptual processes. And methodological choices did not reveal significant differences, pointing to some level of freedom in procedure and stimuli choices with regards to the representativeness of the methodology. Finally, the influence of time, day, and location on soundscape evaluation exhibits similar patterns in the laboratory than *in situ*, although with more significant and larger differences in the laboratory. This latter result exemplifies how the more controlled laboratory environment can reveal the effect of the thus-isolated variables of interest, while an *in situ* study offers a more comprehensive and multisensorial picture.

These findings confirm the conclusions of the first study – that context matters, and that laboratory reproduction is a complement to, rather than a replacement of, *in situ* experience. Primarily, however, these results allowed us to confidently proceed with the development of a soundscape simulator based on Ambisonic reproduction for urban professionals.

5.1.2.2 Evaluation of an interactive soundscape simulator for urban professionals

The final step in this thesis is the development and evaluation of a software prototype to help urban professionals integrate soundscape considerations in their practice. Thus, through a formative evaluation of the prototype with urban professionals, this study (**Chapter 4**) explored the **third research question**, as part of the second research objective. The prototype was developed with specific requirements in mind, based on previous work from our team (Steele, 2018) and on particular anticipated uses: the tool was built to support 1) *instantaneous* 2) "*sketching*" for the 3) *co-design* of sound environments. These three elements entail real-time updating, an immersive and spatialized experience (i.e., using Ambisonics), and the ability to communicate with others during use (i.e., presentation over loudspeakers).

Through collaborative design exercises, group discussions, and quantitative soundscape evaluations during a knowledge mobilization workshop, this last study explored the use and perception of our soundscape simulator prototype by urban professionals. This work was anchored in the specific values of “broadened participation and skill development” of participatory design (PD) (Suchman, 1993, p. viii) and aimed to gather insight into fitting the final design for our soundscape simulator into the existing workflow and knowledge of urban professionals (Spinuzzi, 2005). Before experiencing the tool, participants were interested in being proposed new tools to incorporate soundscape in their practice but had no specific expectations or requirements, while after testing, they were able to discuss, not only what worked and what didn’t, but also how and where they would integrate the tool in their practice. Participants were impressed by the realism and immersion of the tool, and were able to design sensibly different soundscapes, using a variety of strategies. These results confirm the tool’s potential for the integration of soundscape into the design practice, and especially for co-design and communication applications.

This final step of the thesis, by centering meaningful user experiences, opens the door for higher adoption and use for a multiplicity of applications: from lowering the cost of mock-up designs and of noise mitigation strategies, to supporting design communication and consultation, to promoting learning in urban professional curricula, to aiding the advancement and testing of scientific knowledge and theories. As an additional tool to add to the urban professional toolbox, the soundscape simulator will complement the tools already available to professionals (e.g., on-site usage analysis, historical analysis). The next development iterations for the simulator will include the feedback and outcomes of the present work to ensure it is usable and adapted to the urban professional workflow (Yanaky et al., 2020).

5.2 Significance of the research

The theoretical, methodological, and practical contributions are summarized in the following table (**Table** 5.2), and below.

Table 5.2. Summary of contributions from each research question.

	Theoretical	Practical	Methodological
RQ1	- increased generalizability - model of contextual influences		- validation of French translation
RQ2	- ecological validity - contextual influences	- soundscape reproduction tools	- soundscape assessment best practices
RQ3	- urban professionals' use of simulator	- soundscape simulation tools - recommendations for tool improvement	

5.2.1 Theoretical contributions

The investigation of city user experience (**Chapter 2**) contributed to advancing knowledge with regards to:

- the generalizability of soundscape evaluations over different types of urban sites [RQ1];
- the modeling of contextual (personal and situational) influences on soundscape evaluation [RQ1].

The investigation into the ecological validity of laboratory-based soundscape reproduction and evaluation (**Chapter 3**) contributed to the body of knowledge on:

- contextual (situational) influences on soundscape evaluation [RQ1].
- the representativeness of laboratory-based Ambisonic reproduction of soundscapes in comparison to *in situ* soundscape evaluations [**RQ2**].

Those first two studies provide ground to advance theory development in the soundscape research field. The first study (**Chapter 2**) does so through a first of its kind soundscape structural equation modeling (SEM) study of influences on soundscape ratings collected over multiple urban public spaces. Thus, it offers a starting point to build a more holistic understanding of soundscape evaluation, specifically in relation to non-acoustic and non-sensory factors and over a breadth of urban contexts. The second study (**Chapter 3**), through the comparison of *in situ* and laboratory results, specifically provides first steps toward the reconciliation of the two parallel bodies of research emerging in soundscape (Axelsson et al., 2019). The soundscape research community has recently been grappling with the dichotomy of site vs. laboratory insights – reflective of the diversity of methods, sites, and approaches – such as is evidenced by the recent standardization efforts (e.g., ISO (2014, 2018, 2019), SATP (Aletta et al., 2020)) for enhanced comparability across studies (Axelsson et al., 2019). The insights offered by this study – for example, that *in situ* soundscape evaluations are more positive and less negative than in the laboratory – are crucial first steps to the integration of the diversity of results obtained in the soundscape field, both to reconcile disparities and to inform future methodological considerations.

Finally, the formative evaluation for a soundscape simulation prototype (**Chapter 4**) provided insights into the use and perceptions of urban professionals with regards to a soundscape simulator prototype for the urban design practice [**RQ3**]. This type of knowledge is central to the tool development process in PD (Spinuzzi, 2005) and these insights add to the theoretical guidance for our iterative process to develop resources and tools for urban professionals (conducted in the context of the Sounds in the City partnership funded by SSHRC since 2016) (Steele, 2018).

5.2.2 Methodological contributions

In the process of ensuring that both French- and English-speaking participants understand the soundscape items in a similar manner so as to be able to collapse the data for further analysis, we explored the validity of our French translation of common soundscape assessment tools in the first study (**Chapter 2**). This study validated our French translation as invariant from the English version – specifically to the level of metric invariance, which allows to combine or compare those two groups with statistical methods relying on the distance and relations between variables (e.g., regressions).

By virtue of exploring the ecological validity of different soundscape assessment tools and soundscape reproduction, the second study (**Chapter 3**) provided additional evidence in the growing body of work attempting to establish best practices for soundscape assessment [**RQ2**]. This study investigated, not only the perceptual representativeness of Ambisonic reproduction of soundscapes, but also the effect of methodological choices rarely examined: namely, the mode of questionnaire administration and sample selection – showing no significant differences and thus pointing to some level of flexibility in soundscape methodologies.

As previously mentioned, this study suggests ways to reconcile the two parallel methodological schools (*in situ* and laboratory) used in soundscape research (Axelsson et al., 2019). It offers insights, not only theoretical (as mentioned above), but methodological as well: for example, the similar but more significant patterns of influences found in the laboratory, in comparison to *in situ*.

5.2.3 Practical contributions

Tools were developed as part of the second (**Chapter 3**) and third (**Chapter 4**) studies of the present research to allow us to 1) reproduce [**RQ2**] and 2) simulate and manipulate [**RQ3**] soundscapes. These tools are aimed to support laboratory-based ecologically valid soundscape research and to promote the integration of sound considerations into the daily practice of urban professionals. The third study (**Chapter 4**) also provided recommendations for improving the soundscape simulator prototype based on the feedback from urban professionals [**RQ3**]. Not only can such urban soundscape reproduction and simulation tools enable urban professionals to explore design ideas, understand the sound consequences of design choices, and create immersive auditory “sketches” of their designs to communicate with stakeholders, but the developed tool, with its focus on communication, will also facilitate the co-design of urban sound environments and experiences of quality with experts and stakeholders alike.

Urban professionals who participated in the last study (**Chapter 4**) were impressed by the realism and immersion offered by the simulator tool, and they were able to use it to co-design perceptibly different soundscapes for different purposes. The workshop reinforced their understanding and desire to incorporate sound in a holistic manner in urban planning. After testing the tool, they were able to conceptualize better how and what they would like to be able to use it for, which allowed to formulate recommendations (see section 4.6) for further development stages. Outcomes from this workshop will thus guide the development of the next iteration of the simulator so that it can meet the implicit expectations and requirements of urban planners (Yanaky et al., 2020).

5.3 Limitations and future directions

This section discusses general limitations of the research reported in this dissertation. Specific study limitations are detailed in each corresponding chapter.

The primary practical goal of the present research was to develop a tool to help urban professionals integrate soundscape considerations in their daily practice, and especially from the perspective of facilitating collaborative design discussions. As such, the formative evaluation generated a wealth of knowledge about co-design deliberations in exchange for a less controlled approach to user experience with individual participants. This will be explored, especially in relation to engagement and usability, with the development of a virtual reality-based tool, which will offer more portability and a lower cost (Yanaky et al., 2020).

Furthermore, it is important to note that empowering urban professionals to consider sound can only go so far, as their agency can often be limited by social divisions (Fainstein, 1999). These limitations persist as urban fields move toward increasingly participatory processes, and some might even argue that they are compounded by additional difficulties like demagogy and lack of accountability (Fainstein, 1999), or the centering of specific values and histories leading to the exclusion of some sections of the community (Agyeman, 2013).

Additionally, our team's work differs from established PD methodologies in three ways: 1) the iterative process spans a longer period than PD generally considers and 2) involves a range of practitioners rather than a dedicated and representative few, and 3) the prototype tested can be seen as more advanced than recommended in the PD framework. We do, however, adhere to the values of PD (mutual knowledge sharing, user collaboration, skill development, workflow fit). Additionally, we do not aim to develop a technology for a specific subset of users (e.g., workers of a specific company) and urban professionals represent a breadth of overlapping professions with a broad range of work practices and workflows. Finally, the very nature of the tool (3D audio simulation) requires extensive development and rigorous testing before involving prospective users.

Methodological considerations were also essential in this work, including questions of soundscape assessment. Having established that soundscape ratings are quantitatively similar between *in situ* and laboratory studies, and between pen-and-paper and computer-based questionnaires, the laboratory study (**Chapter 3**) kept aside open-ended questions specifically aimed at understanding how respondents conceptualized and evaluated the soundscape scales. It is important to keep in mind the influence of culture on both the understanding of the measurement scales and the sound perceptions. This is exemplified by some of the differences found between French and English in our work but could be more marked for other languages and cultures. This qualitative exploration of how respondents interpret the different soundscape scales has been a recurring question (Raimbault, 2006) and will be crucial to investigate for the refinement of soundscape knowledge and evaluation tools.

It should also be made clear that such a quantitative evaluation of the urban sound experience is not the only appropriate investigative method and should be coupled with qualitative methods to reveal a fuller picture of said experience. Although not presented in the scope of this work, our team strives to engage with relevant stakeholders by way of interviews and observations to explore the city user experience (Bild et al., 2021; Steele et al., 2019).

Last but not least, further theoretical questions were raised by this thesis. First, the question of generalizability of findings, which was introduced in the site study (**Chapter 2**), encompasses a breadth of facets, from different morphologies of urban public spaces to other types of urban spaces (e.g., streets, suburban and periurban spaces) to other countries, cultures, and languages. In this study, we only investigated the former and partially the latter thanks to the bilingual context of Montreal. Suburban and periurban considerations are of special importance in the Canadian context (Gordon & Janzen, 2013). Future research is needed to determine the extent to which these methodologies and findings would transfer to these contexts. Second, the laboratory study (**Chapter 3**) revealed a more nuanced – and less significant – picture of soundscape quantitative evaluations on site than in the laboratory.

Part of the solution to understand this nuance may lie in the soundscape qualitative descriptions collected both on site and in the laboratory, which remain to be analyzed in the future. Third, user activity, which has been repeatedly theorized as an essential factor on the soundscape experience (Bild et al., 2016) and shown to matter in the multisite study of urban soundscape experiences (Chapter 2) via the social interaction variable, was intended to be manipulated and investigated in laboratory experiments. But this study had to be postponed due to the COVID-19 pandemic.

In conclusion, the present dissertation investigated several aspects of urban soundscape experience and design with the aim to offer knowledge and tools for urban professionals to integrate sound considerations in their practice. The well-being of city users and the suitability of sound environments to urban space use will depend on collaborative processes involving all stakeholders and incorporating holistic and nuanced understandings of the complexity of urban spaces. Through the investigation of the sound experiences of city users and a formative evaluation of a soundscape simulation prototype for collaboration and communication, this research provides insights into ways to address the sound-related concerns arising in an increasingly urbanized world, and hopefully lead to long-term and global changes in approach to the urban sound experience.

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Appendices

Appendix A Urban soundscape evaluations – missing values, item translations, covariance matrix, and in situ questionnaire

Table A 1. Summary of missing value proportions (%) per site and Likert variable.

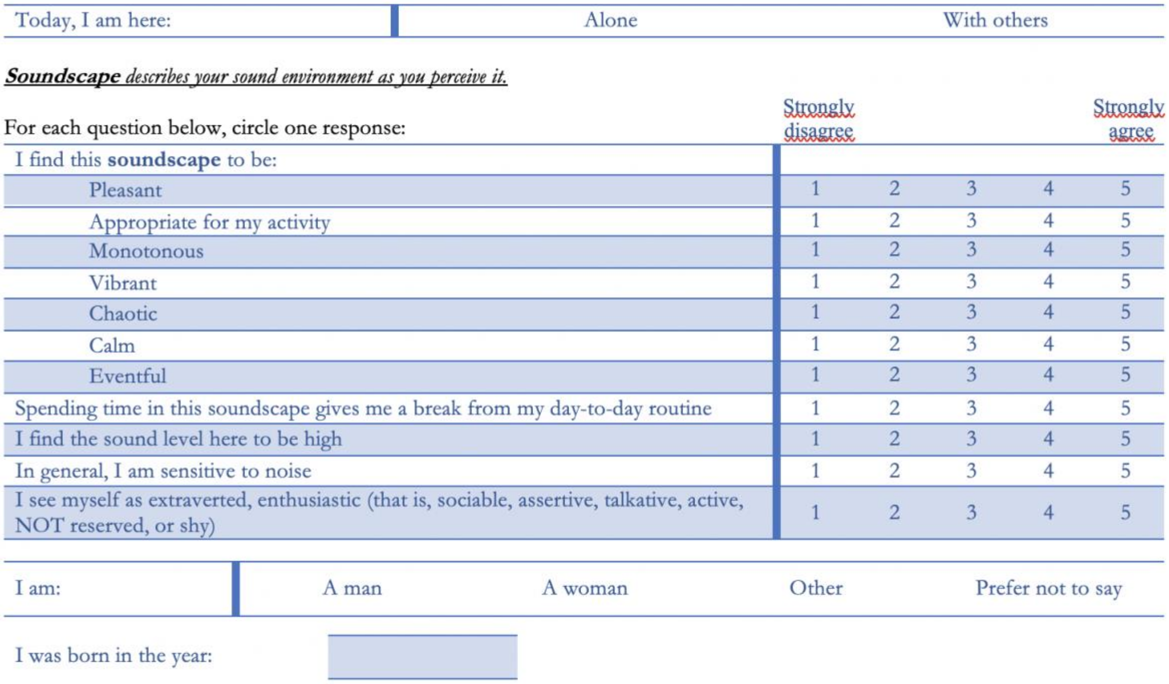
Site	Plst	App	Mono	Vib	Chao	Calm	Ev	Rest	Loud
PS	2.0	1.7	6.1	4.4	4.7	2.7	3.5	1.9	1.4
PP	1.3	1.9	4.5	5.8	2.6	1.9	3.9	0.6	0.6
GP	0	0	4.9	2.4	2.4	2.4	2.4	0	0
PZ	1.0	0	5.8	1.9	3.9	1.0	1.0	0	1.0
Total	1.8	1.5	5.8	4.4	4.3	2.5	3.4	1.5	1.3

Table A 2. English and French translations of soundscape items tested in all CFA.

Item	English formulation	French formulation
Pleasantness	Pleasant	Agréable
Appropriateness	Appropriate for my activity	Appropriée pour mon activité
Monotony	Monotonous	Monotone
Vibrancy	Vibrant	Dynamique
Chaoticness	Chaotic	Chaotique
Calm	Calm	Calme
Eventfulness	Eventful	Animée
Restorativeness	Spending time in this soundscape gives me a break from my day-to-day routine	Passer du temps dans cette ambiance sonore me permet de faire une pause dans ma routine quotidienne
Loudness	I find the sound level here to be loud	Je trouve le niveau sonore élevé en ce lieu

Table A 3. Covariance matrix and means underlying SEM analysis.

	Pls	App	Chao	Calm	Rst	Loud	Vib	Evtf	Mono	SocInt	NSS	Age	Gdr	Extr
Pls	0.942													
App	0.582	0.952												
Chao	-0.357	-0.301	0.920											
Calm	0.503	0.382	-0.371	0.961										
Rst	0.453	0.356	-0.265	0.360	0.971									
Loud	-0.353	-0.269	0.375	-0.397	-0.225	0.959								
Vib	0.163	0.140	0.100	-0.011	0.135	0.105	0.939							
Evtf	0.078	0.102	0.180	-0.138	0.124	0.174	0.408	0.939						
Mono	-0.148	-0.124	0.130	0.001	-0.140	0.047	-0.181	-0.092	0.914					
SocInt	0.024	0.046	-0.034	0.032	-0.003	-0.035	-0.007	-0.008	0.000	0.224				
NSS	-0.084	-0.066	0.092	-0.098	-0.050	0.200	-0.043	0.037	-0.094	-0.038	0.975			
Age	-0.996	-1.911	1.156	-1.542	0.127	1.300	-0.831	-0.167	-1.348	-1.619	3.076	194.584		
Gdr	-0.021	-0.037	0.013	-0.006	-0.011	-0.002	-0.014	-0.023	0.047	-0.015	-0.044	0.669	0.249	
Extr	0.022	-0.014	-0.040	-0.015	0.039	0.015	0.000	0.082	-0.011	0.020	-0.037	-0.086	-0.005	0.981
Means	0.002	0.018	-0.023	-0.006	0.008	-0.015	0.001	0.001	-0.033	1.660	-0.013	34.674	0.471	-0.005



Today, I am here:	Alone	With others

***Soundscape** describes your sound environment as you perceive it.*

For each question below, circle one response:	Strongly disagree				Strongly agree
I find this **soundscape** to be:					
Pleasant	1	2	3	4	5
Appropriate for my activity	1	2	3	4	5
Monotonous	1	2	3	4	5
Vibrant	1	2	3	4	5
Chaotic	1	2	3	4	5
Calm	1	2	3	4	5
Eventful	1	2	3	4	5
Spending time in this soundscape gives me a break from my day-to-day routine	1	2	3	4	5
I find the sound level here to be high	1	2	3	4	5
In general, I am sensitive to noise	1	2	3	4	5
I see myself as extraverted, enthusiastic (that is, sociable, assertive, talkative, active, NOT reserved, or shy)	1	2	3	4	5

I am:	A man	A woman	Other	Prefer not to say

I was born in the year:

Figure A 1. Presentation of the questions for the analyzed variables – English version.

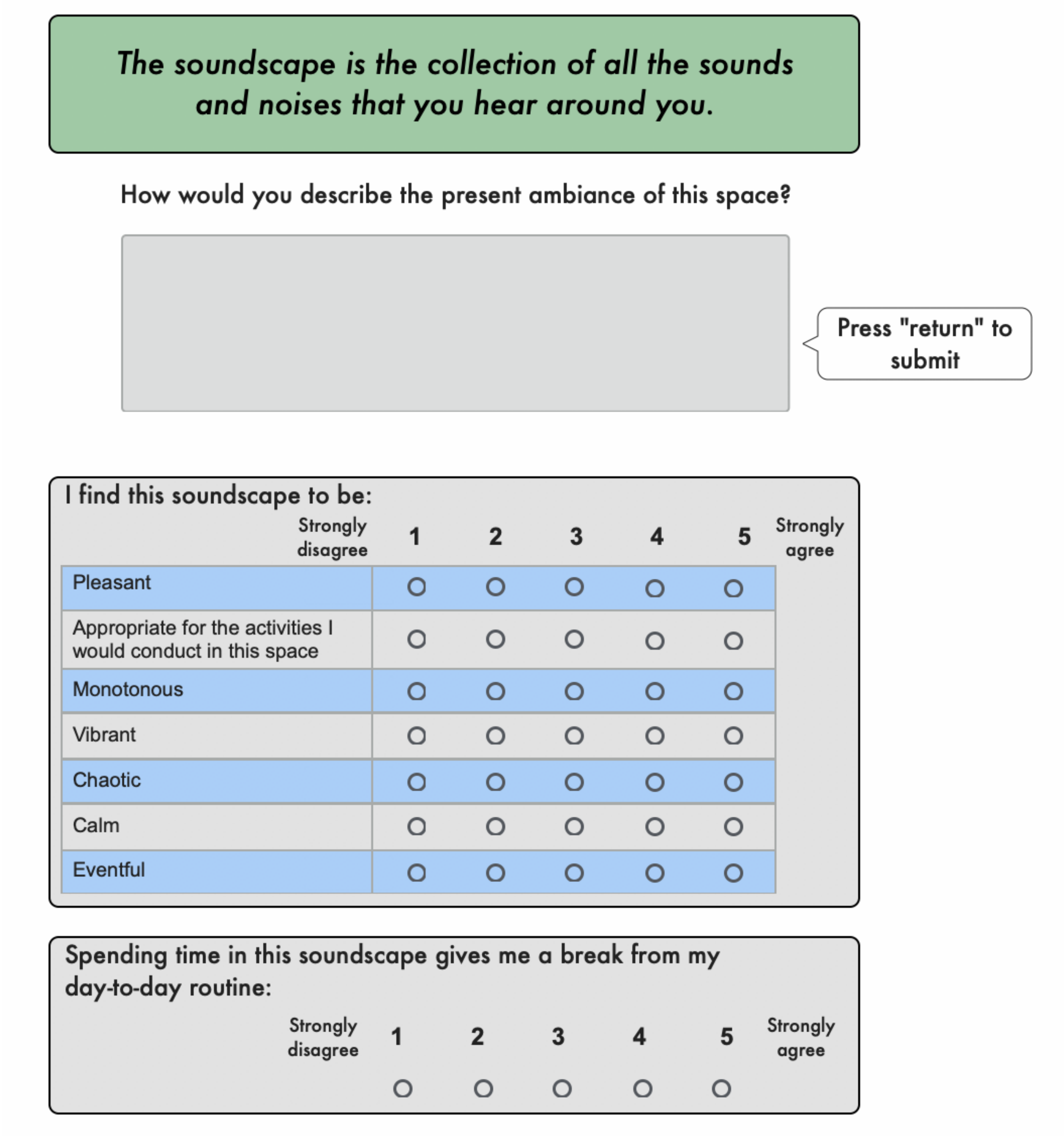
Appendix B Ecological validity study – Supplementary information (statistical tables) and additional appendix (computer-based laboratory questionnaire)

Table A 4. Modified ANOVA-type statistics (MATS) and their resampled p-values (wild bootstrap – 1000 iterations) for MANOVA of on-site data (N = 185).

	Test statistic	p-value
Day	6.782	0.543
Time	5.142	0.725
Day x Time	5.389	0.692
Location	6.556	0.556
Day x Location	6.361	0.583
Times x Location	9.692	0.339
Day x Time x Location	12.002	0.208

Table A 5. Modified ANOVA-type statistics (MATS) for ANOVA (p-value resampled with wild bootstrap – 1000 iterations) over each scale – no significant p-values (N = 185).

	Pleasant	Appropriate	Monotonous	Vibrant	Chaotic	Calm	Eventful	Restorative
Day	1.982	0.031	2.335	0.208	0.737	1.143	0.001	0.345
Time	0.108	0.221	0.66	0.042	0.468	0.364	0.663	2.616
Day x Time	0.847	0.243	0.117	0.325	0.577	2.061	1.158	0.061
Location	0.124	0.009	3.038	0.07	0.055	0.174	0.359	2.728
Day x Location	0.595	0.673	0.035	0.827	0.626	0.534	0.098	2.973
Time x Location	0.428	0.216	4.83	1.787	0.824	0.000	0.318	1.289
Day x Time x Location	1.123	0.081	2.562	0.186	4.421	2.127	0.409	1.092



The soundscape is the collection of all the sounds and noises that you hear around you.

How would you describe the present ambiance of this space?

I find this soundscape to be:

	Strongly disagree 1	2	3	4	5 Strongly agree
Pleasant	○	○	○	○	○
Appropriate for the activities I would conduct in this space	○	○	○	○	○
Monotonous	○	○	○	○	○
Vibrant	○	○	○	○	○
Chaotic	○	○	○	○	○
Calm	○	○	○	○	○
Eventful	○	○	○	○	○

Spending time in this soundscape gives me a break from my day-to-day routine:

Strongly disagree 1	2	3	4	5 Strongly agree
○	○	○	○	○

Figure A 2. Laboratory questionnaire presented on the computer.

Appendix C Soundscape co-design workshop – Schedule, script, and materials presented to participants (lists of sources and interventions) for workshop activity

Prepared by Dr. Daniel Steele, Dr. Edda Bild, Cynthia Tarlao, and Grégoire Blanc

Schedule (45 minute per session)

Faffing about – 3 minutes	10:15
Intro – 5 minutes	10:18
Part 1 – Real recording playback: 12 minutes	10:23
Part 2 – Ideal soundscape design: 12 minutes	10:35
Part 3 – Spoiling ideal soundscape: 9 minutes	10:47
Part 4 – Realistic soundscape design: 12 minutes	10:56
Closing questions – 5 minutes	11:08
Send them away	11:13

PAS DE PHOTOS
PAS DE NOURRITURE

Intro

Moderator offers:

- an introduction to the MMR
    - This room is funded by a CFI grant, and is not yet even finished. It's called the Music Multimedia Room. It's historically been used for musical performances as well as scientific studies on audience responses to music. We may be the first to be using it for co-designing urban soundscapes.

  - When you are standing in the middle, you are in the sweet spot. This is a one hour exercise, so we understand if you need to sit for a break. Please take a chair on the side and listen the best you can, and rejoin when you are comfortable. **PLEASE, BE CAREFUL NOT TO TOUCH THE WALLS**. We apologize for the inconvenience.
- simple overview of the setup, like what software and technologies are within (simply!!!!!)
  - This demo is a combination of multiple pieces of software. Using MaxMSP, a "patch" is playing separate audio content to each speaker and recreating a scene for us in high fidelity. Laser measurements were taken to calculate the precise position of each speaker so that the quality of the "audio image" would be high.
- briefly outline the four-part exercise and explain how they will be directing it
  - Using the screen here, you will point at this representative map of the space and indicate where you'd like to place the various sound sources listed on the sheet you've been handed. Please don't flip the sheet until the fourth part of the exercise.
  - We encourage you to close your eyes occasionally to concentrate on the listening exercise.

Part 1: Real recording playback

"We start with the playback of a recording taken in 962/Fleurs de Macadam, to show you how the system works. The Fleurs de Macadam is a small urban space off Mt. Royal, with plenty of seating amenities and a nearby busy road. This recording was taken in the middle of the space some time in the middle of the day. The recording has been "calibrated" so that the level you are hearing here is exactly as loud as it is in the real space.

Please listen, move around in the space and discuss with each other about what you hear. Take a moment to close your eyes while listening.

Think of the following points:

- Describe the soundscape you are listening to…

- What do you hear?
- Describe the feeling it gives you. Does it sound how you would expect it? Does it sound like you are in the park? Is it as loud as you would expect it to be?
- Does spending a few minutes listening help make it more realistic?

Take notes on their comments and exchanges

Part 2: "Ideal soundscape" design

"Now that you've grown accustomed to the system, let's build up the soundscape of a space like this one from scratch. **Don't limit yourselves to any of the "real" limitations of the space we just talked about.**

Imagine a small urban park, off a busy street, with plenty of seating amenities and some trees and grass available.

Let's create the "ideal soundscape" for this space; how would it be ideal for it to sound like? Think about what *you* like in an urban soundscape, it doesn't have to be necessarily realistic given the context!"

- We start from a background recording - « la rumeur de la ville » taken at 4 AM
- Let's build something pleasant on top of it, add various sources
- From your list of sources, choose 3 or 4 together that you would like to have the most
- You can:
  - Add them in different locations
  - Play with their volume
  - Remove them
  - Silence them
  - Play them in a loop (over and over)

Checklist:

- ***Save** the "ideal soundscape" they created*
- *Take notes on comments and exchanges*

Part 3: Spoiling the "ideal soundscape"

Now it's time to "spoil" this "ideal" soundscape with sound sources that would make it an unpleasant experience. Imagine the worst-case scenario for this location.

- What sources would you add? Choose 3 together
- What sources would you remove from the "ideal soundscape?" Choose 2 or 3 together.
- Based on your experience here, what makes a sound source positive or negative? Pleasant or unpleasant?

Checklist:

- ***Save*** *the "spoiled soundscape" they created*
- *Take notes on comments and exchanges (**JL**)*

Part 4: Realistic soundscape design

"Now that you've designed an "ideal soundscape" and you've also turned it into a worst-case urban scenario, let's design a realistic soundscape for this urban space, somewhere between good and good enough." Let's do some sound design to mitigate these sources. We start with a "typical" setting for this space with traffic noise, buses passing, some HVAC noise, and other sounds.

"Take a moment to listen. Think of:

- The context in which the space is situated (type of neighborhood, streets)
- The activities that could be taking place in the space and who would be using it, for how long, etc.

Flip over your sheet with sound sources. You will now deal with interventions rather than sources.

There is a list of mitigation strategies and interventions that can be implemented in order to influence the soundscape of the space. Each intervention has an influence. Some of the strategies might be available to only a few of you professionally speaking, but working as a team you can each think what is within *your* professional power (e.g., slowing traffic might not be an available strategy for a landscape architect, but installing a fountain to mask the noise of traffic is; slowing traffic might however be a strategy available for a city planner). Briefly think of the visual consequences of each of your interventions. Also, don't constrain yourselves to the examples on this sheet. Each intervention may be potentially very costly; for example, adding a fountain requires new plumbing to the space. Do these constraints discourage you from making the decision? Make a consensus of 3 interventions together that you would like to perform.

Checklist:

- ***Save*** *the "realistic soundscape" they created*
- *Take notes on comments and exchanges*

Closing statements

Later, you will get to hear what the other groups came up with. How do you think they might have done this exercise differently?

How would you evaluate these soundscapes you created?

Is there a design or planning potential for this exercise?

Sound sources list

Delivery truck idling
Motorcycle
Bikes
Skateboard
Continuous traffic heavy
Continuous traffic light
Buses
Small fountain trickling
Medium fountain on rocks
Large fountain on water
Playground (with children on swings)
Birds
Terrasse with conversation
Club (muffled music)
Music, live (street piano)
Sound art from speaker system
Construction (*voirie*)
Plane passing overhead
HVAC from neighboring building

List of sample mitigation strategies and interventions:

Slow traffic

Create ordinance against HVACs facing parks

Move bus stop to different block

Commission sound artists for an installation

Plant trees to add birds

Invite musicians for live music / Install a public piano

Install a fountain

Install a playground for children

Permit a restaurant to open a terrasse

Permit a club to operate

Install low noise pavements (decibel reduction when traffic is over 30km/h)