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Soundscape and public realm – a quasi-experimental comparison between Individual Vocabulary Profiling and Public Space Index assessments during COVID-19 lockdown

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ABSTRACT

This paper investigates the individual soundscape attributes in open public spaces that relate to the quality of the public realm. To achieve this, 76 individual soundscape attributes were collected using the Individual Vocabulary Profiling (IVP), and 25 dimensions of the Public Space Index (PSI) were observed for two public areas. The correlation and differences between the IVP and PSI data are examined. The research presents three key findings: 1) people's judgments of places are significantly influenced by the soundscape at specific moments and locations; 2) five soundscape dimensions emerged as individuals described the public realm: peacefulness, intensity, presence of nature, comfort, and vividness; 3) IVP and PSI indicators demonstrate higher correlation values when subjects utilize "audio" and "visual" attributes, rather than multimodal "audiovisual" attributes. The findings provide empirical support for the proposition that non-acoustic variables play a critical role in shaping the perception of environmental sounds.

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Public realm; public space; soundscape; urbanism; acoustics

Introduction

The soundscape of open public spaces is a critical component of the public realm, shaping individuals' perceptions, experiences, and the capacity for daily social interactions and urban vitality. While urban studies have gained prominence – particularly in response to global challenges like the COVID-19 pandemic (Mehta 2020) and its impact on vulnerable groups (Bild et al. 2019; Doucet et al. 2020), research correlating soundscape perception with public realm indicators remains limited. This study contributes to soundscape modelling by empirically examining evidence the relationship between individual soundscape attributes and public space quality metrics through correlation analysis conducted in a field study. It conceptualizes the soundscape as "the perception of the acoustic environment by individuals or society in a specific context of place, time, and activity" (Brown 2011). The research investigates whether and how the acoustic and visual

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attributes perceived and rated by individuals correspond to the public space features that shape the public realm.

The study of exploration of soundscapes has been extensive, leading to the recommendation of ISO 12013–1 2014, which defines soundscape as "the acoustic environment as perceived or experienced and/or understood by a person or people, in context" (2014). Many recent soundscape studies have adopted ISO soundscape descriptors as a standardized framework for characterizing an area's soundscape over a defined period. Similarly, the Swedish Soundscape Quality Protocol (SSQP) (Axelsson, Nilsson, and Berglund 2009) has been widely applied to provide a consistent depiction of sound in the built environment. However, given that soundscapes are dynamic and vary with each context, researchers have emphasized the need for more detailed attributed when comparing the same environment under different soundscape conditions (Aletta et al. 2022; Lokki et al. 2011).

Furthermore, despite evidence indicating that visual elements influence soundscape perception (Aletta et al. 2022; Amphoux and Tixier 2017; Tan et al. 2022), existing protocols, namely the ISO and SSQP, do not account for visual perception of environments. Recently, the ISO/TS 16,755–1:2025 published a definition and conceptual framework to study the non-acoustic factors influencing the perception, interpretation and response to the environmental sounds has been published, which shows the novelty of the topic.

To address this gap, this study employs the Individual Vocabulary Profiling (IVP) technique to derive attributes, including both audio and visual elements This approach offers a user-dependent attribute list followed by multifactor analysis to extract the primary perceptual dimensions.

Llorca-Bofí, Heck, and Vorländer (2024) previously applied IVP to examine the relationship between individual soundscape attributes and 2D isovists within a neighborhood. However, the use of objective isovist metrics in that study did not provide insights into the use of public space. To evaluate these features, the present study integrates the Public Space Index (PSI), which incorporates behavioral mapping to document people's activities and spatial features over a designated period. By employing IVP to collect verbal descriptions of the audio, visual, and audiovisual characteristics of these public spaces under typical daily conditions, this study aims to explore the correlation between PSI and IVP, ultimately enhancing our understanding of how soundscape shape urban experiences.

The study was conducted under the exceptional circumstances of the COVID-19 pandemic, which influenced the data collected due to the unique historical context of that time. However, operational challenges during this period resulted in a limited number of participants, affecting the robustness of the analysis. Consequently, the authors chose to present the findings as a quasi-experimental study. Such study designs, often characterized as nonrandomized pre-post intervention studies, are widely used in experimental sciences (Harris et al. 2006). They are particularly valuable when randomized controlled trials impractical and unethnical, especially for evaluating the benefits of specific environmental scenarios (Cook and Campbell 1979; Shadish, Cook, and Campbell 2002; Trochim 2001). These characteristics make quasi-experimental designs ideal for exploratory and qualitative research.

The paper examines two outdoor public spaces in the Driescher Hof neighborhood of Aachen, Germany: the central market and shopping area, as well as a park,

both of which were studied between April and May 2021 (referred to as "Market" and "Park" for the remainder of the study). The Aachen Municipality has identified Driescher Hof as a disadvantaged neighborhood, which is part of Germany's Social City (*Sozialer Stadt*) urban renegeneration program. Initiated by the German Government in 1999, the Social City program aims to enhance the quality of life in neighborhoods with a higher proportion of vulnerable groups, such as the elderly and immigrants, by improving social infrastructure through spatial, social, and economic interventions.

The following section introduces the theoretical foundations of this research. Next, the methodology is outlined alongside a description of the study's urban contexts, followed by an analysis of the results. The discussion section interprets the findings, and the paper concludes with recommendations for applying this analytical approach to both existing and planned urban renegeration projects.

Public realm, public space and soundscape

Public realm and public space

This research conceptualizes the public realm as social life within physical spaces where casual encounters among strangers take place (Lofland 1998). It emphasizes open public spaces such as parks, streets, and plazas, where individuals observe and interact across cultural, gender, and economic divides, thereby shaping the public realm through social, economic, and cultural exchanges (Sezer 2018). Public spaces play a crucial role in fostering social support and resilience, particularly evident during the COVID-19 pandemic when they were essential for maintaining social connections, especially for vulnerable groups like the elderly (Buffel et al. 2023; Sezer and Maldonado 2017).

The urban design literature underscores the key qualities of public spaces, advocating for human-centric designs that prioritize mixed uses, safety, and pedestrian-friendliness (Gehl 1971; Sezer 2020). Vibrant public realms are characterized by diverse land uses, street markets, and active street façades (Sezer and van Melik 2023). Lynch and Carr (1979) link urban form to qualities such as legibility, accessibility, and adaptability. Mehta (2014) developed a Public Space Index (PSI) to evaluate social life in public spaces, incorporating dimensions such as inclusiveness, meaningful activities, pleasurability, safety, and comfort.

Inclusiveness measures how well spaces accommodate a variety of users and activities, while meaningful activities cater to everyday needs such as shopping and socializing (Mehta 2014). Pleasurability pertains to the visual and sensory richness of a space, influenced by factors such as permeability, vegetation, and the presence of people and animals (Lynch 1960). Safety is determined by the design, maintenance, and perceived security of a space (Bentley et al. 1985), whereas comfort relies on elements like micro-climate, street furniture, and psychological ease (Carmona et al. 2003). Perceptions of comfort can vary across cultures, highlighting the need for adaptable public space design (Mehta 2014).

Analysing public realm in open public spaces.

Urban design literature identifies several key qualities of public space that are essential for studying the public realm. Public spaces are viewed as the core of everyday encounters among strangers, offering an active urban life (). A human-centric approach emphasizes the importance of creating spaces that prioritize human experience, ensuring they are mixed-use, safe, and pedestrian-friendly – key features of the public realm (Jacobs 1992; Gehl 1971). Additionally, characteristics such as a diverse range of land uses, the availability of shops and businesses, the presence of street markets, and areas that allow people to observe and be observed, along with active street façades, serve as indicators of a vibrant public realm (Montgomery 2007). Lynch and Carr (1979) established connections between urban form and qualities like legibility, imageability, accessibility, and adaptability of public spaces.

Mehta (2014) proposed a Public Space Index (PSI) for the systematic and comparative evaluation of social life in public spaces and its role in fostering the public realm, drawing on foundational work by Lynch and Carr (1979), Montgomery (2007), Jacobs (1993), Franck and Stevens (2006), and Loukaitou-Sideris and Ehrenfeucht (2009). The PSI encompasses dimensions such as inclusiveness, meaningful activities, pleasurability, safety, and comfort. While these characteristics are presented individually, they also share interconnected features that collectively enhance the quality of public spaces. Other theoretical frameworks for analyzing the public realm tend to focus on specific aspects. For example, Varna and Tiesdell (2010) emphasize the spatial elements that influence user behavior and experience, exploring the relationships between physical design and the social dynamics of public space. In contrast, Németh and Schmidt (2007) concentrate on public space governance and management, particularly regarding accessibility and social inequality. While Németh and Schmidt (2007) developed indicators specifically assessing safety and security in publicly accessible spaces, Mehta (2014) provides a holistic indicator of the social use of public space based on five dimensions.

Inclusiveness refers to a space's ability to welcome diverse activities and user groups, regardless of age, gender, or background. Indicators include social diversity, varied activities, and the accessibility of shops and amenities, which influence perceived openness (Loukaitou-Sideris and Ehrenfeucht 2009; Mehta 2014). Meaningful activities involve meeting everyday needs such as shopping, commuting, or socializing, as well as hosting cultural and community events. Spaces that facilitate these activities become valuable to users (Mehta 2014). Pleasurability pertains to the sensory and visual appeal of public spaces, which affects how people perceive and navigate them. Factors include building façades, vegetation, and lighting, with the presence of people and animals enhancing the experience (Lynch 1960; Mehta 2014). Safety relates to how secure individuals feel, influenced by the design of the space, the presence of others, and available amenities. Perceptions of safety are also shaped by maintenance, vandalism, and security measures (Bentley et al. 1985; Oc and Tiesdell 2000). Comfort encompasses a space's capacity to support daily activities, with factors such as microclimate, furniture, and sidewalk width influencing physical comfort. Social and psychological comfort is shaped by the design and atmosphere of the space, with cultural context also playing a significant role (Carmona et al. 2003; Mehta 2014).

Public realm and soundscape

Sound plays a vital role in how we perceive public spaces, underscoring the importance of soundscape analysis in evaluations. Soundscapes are shaped by human perception of the acoustic environment, which comprises sound sources, transmission paths, and receivers. This research considers soundscapes as being influenced by both natural and human factors (Brown 2011; Duffy 2020; Palmese, Carles, and Rodriguez 2023; Southworth 1969), closely linking them to the public realm. A rich tradition of soundscape research examines its impact on well-being, health, and social resilience. The following section reviews studies that connect soundscapes to key indicators shaping public spaces, organized into two groups.

The first group of studies investigates people's assessments of soundscapes through in-situ questionnaires and acoustic recordings. Key elements identified include soundscape descriptors (overall sounds), sound descriptors (specific features), and sound sources (entities producing sound) (Augoyard and Torgue 2005; Barrie 2020; Davies et al. 2013; Thibaud 2001; Zhang and Kang 2007). Research has also explored soundscape behaviors such as distress, comfort, and pleasantness (Jo and Jeon 2020; Axelsson, Nilsson, and Berglund 2010). Witchel's research indicated that sound features, such as the tempo of music, can influence behavior in public spaces – faster music may encourage quicker walking and foster generosity (Lavia et al. 2016). Hao, Johnson, and Cope (2020) reviewed soundscape descriptor models, linking them to acoustic indicators. Lenzi, Sádaba, and Lindborg (2021) analyzed soundscapes in a central square in Bilbao during the COVID-19 lockdown, highlighting significant shifts in the acoustic environment, consistent with findings from other studies (Palmese and Carles Arribas 2020).

Young Hong and Yong Jeon (2017, 2020) investigated how urban land use shapes street soundscapes. They found that in central business districts and commercial areas, traffic noise diminished pleasantness while increasing eventfulness, whereas human sounds in commercial streets enhanced both. Bild et al. (2019) also connected soundscapes to public spaces by demonstrating that social interactions influenced people's perceptions of their auditory environment, impacting the meaningfulness of public activities.

The second group of studies examines the effects of soundscapes on individuals in controlled laboratory conditions using simulations. These methods provide insights into how public spaces affect perception. Masullo et al. (2021) discovered that water installations in parks influenced mental restorativeness, suggesting that the design of fountain sounds can enhance comfort. Similarly, Jiang et al. (2018) revealed that shared-street design and traffic restrictions created a calmer, more pleasant soundscape. Aletta, Kang, and Axelsson (2016) emphasized the role of memory in acoustic perception and raised concerns about the ecological validity of lab studies. Davies, Burce, and Murphy (2014) addressed this issue by employing Ambisonics to deliver more realistic soundscape assessments. Guastavino et al. (2005) also highlighted the challenge of ecological validity when reproducing acoustic environments, stressing the need for a more authentic representation of these settings. In response, Davies, Burce, and Murphy (2014) argued that acoustic environments recorded and reproduced using Ambisonics – a full-sphere surround sound

format – can provide ecological validity for soundscape assessment. This approach enhances spatial immersion by delivering temporal and spatial information tailored to a specific receiver position.

Studies on public realm and soundscape

Subjective comparisons of soundscapes in open public spaces pose significant challenges, as the sonic experience of these places depends on multiple environmental factors. These factors include intra-subject and inter-subject preferences, environmental sounds, the social and cultural backgrounds of listeners, and weather conditions. The contribution of soundscapes is difficult to isolate from variabilities in both the environment and human perception. In other fields, such as food tasting or user experience (UX), sensory analysis is employed to address these complexities. Sensory evaluation, particularly descriptive testing aimed at registering and measuring human perceptions, requires panels of non-trained evaluators who rank and rate a product using their senses. This method is gaining traction in the realm of sensory evaluation of sound for the automotive industry (Postel, Hegarty, and Bech 2011; Zacharov 2019) and hearing devices (Legarth et al. 2010).

In architecture and urban studies, sensory analysis presents unique challenges, particularly due to the high variability of urban conditions and the diverse cultural backgrounds of inhabitants. However, the use of individual attributes helps mitigate the issue of predefined attribute interpretation. Instead of relying on established soundscape descriptors (2014), which may have different meanings across various urban communities, sensory analysis employs the IVP technique, allowing participants to use their own words to describe scenarios. IVP has recently been successfully applied to studies of spatial sound reproduction (Bech and Zacharov 2006; Lokki et al. 2011). These techniques show promise for effectively evaluating complex and multidimensional stimuli, such as recordings of soundscapes in urban environments.

Methodological approach

This research studies how acoustic attributes relate to public realm quality in open public spaces. More precisely, it explores if and how a place's acoustic features are associated with its public realm features. For this, the study conducts two sets of analyses on public realm and on audiovisual features. It seeks correlations between two groups of findings based on the conceptual framework presented in Table 1. The IVP attributes are collected as follows:

- "audio" attributes, referring to words describing assessments purely from acoustic stimuli;
- "visual" attributes, referring to words describing assessments purely from video stimuli;
- "audio+visul," as the collection of both "audio" and "visual" attributes;
- "audiovisual" attributes, referring to words describing multisensory assessments from video and acoustic stimuli.

Table 1. Conceptual framework for the correlation between both datasets: soundscape invididual Vocabulary Profiling (IVP) in the horizontal axis, and the public space index (PSI) in the vertical axis.

			Soundscape IVP				
			4 participants, providing 4 Audio and 4 Visual attributes			4 participants, providing 6 Audiovisual attributes	All attributes by all participants
			Audio attributes	Visual attributes	Audio + Visual attributes	Audiovisual attributes	Audio+ Visual + Audiovisual attributes
			Cluster A	A	A	A	A
			Cluster B	B	B	B	B
			Cluster C	C	C	C	C
			Cluster D	D	D	D	D
			Cluster E	E	E	E	E
Public Space Index (PSI)	Researcher's observations + in-situ questionnaires	I. Inclusiveness					
		II. Meaningful activities					
		III. Pleasurability					
		IV. Safety					
		V. Comfort					

Evaluating public realm using the public space index

The first part of the analysis aims to obtain information on the public realm. It studies the qualities of public space relevant to its capacity to stimulate socialisation between different public space users. The analysis combines in-situ observations and behavioural mapping by adapting Mehta (2014)'s five dimensions of public space's quality (Figure 1): inclusiveness, meaningful activities, pleasurability, safety, and comfort. Table 2 presents the variables for each dimension and their measuring criteria. We choose this index for our

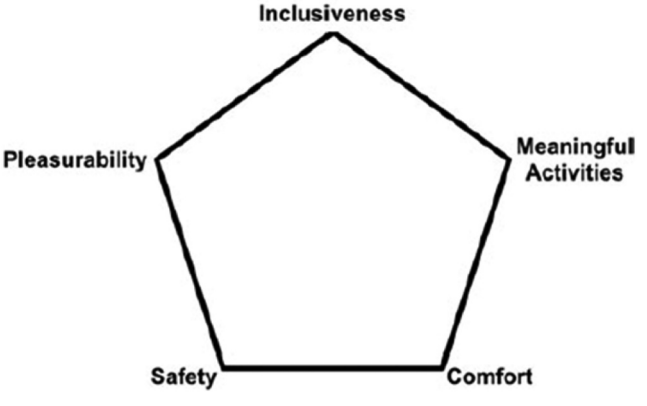

Figure 1. The five dimensions/aspects of public space (source: Mehta 2014, 58).

Table 2. Dimensions of sociability in public spaces after Mehta (2014), variables and ranking scores.

Public Space Index (PSI) dimensions and its variables	Measuring criteria	Ranking score	Market	Park
I - Inclusiveness				
Presence of people of diverse age	Counts based on observations	0: limited, 1: low, 2: medium, 3: high, 4: maximum	4	3
Presence of people of diverse genders	Counts based on observations	0: limited, 1: low, 2: medium, 3: high, 4: maximum	2	4
Range of activities and behaviours	Counts based on observations	0: limited, 1: low, 2: medium, 3: high, 4: maximum	4	3
Opening hours of public space	Determined by signs	0: <10hrs, 1: 10hrs, 2: 15hrs, 3: 20hrs, 4: 24hrs	1	4
Perceived openness and accessibility	Use's subjective rating	0: not at all, 1: sometimes, 2: generally, 3: mostly, 4: completely	4	1
II – Meaningful activities				
Presence of community gathering	Counts based on observations of businesses or other specific activities	0: none, 1: one, 2: two, 3: few, 4: many	2	4
Range of activities	Counts based on observations on activities and behaviours	0: none, 1: very limited, 2: medium, 3: high, 4: maximum	4	3
Variety of businesses and other uses at the edges	Counts based on observations	0: none, 1: one, 2: two, 3: few, 4: maximum	3	1
Perceived suitability of space layout and design to activities and behaviour	User's subejctive rating	0: not suitable at all, 1: somehow suitable, 2: moderately suitable, 3: very suitable, 4: maximum	2	2
Perceived usefulness of businesses and other uses	User's subjective rating	0: not at all, 1: somewhat, 2: moderately, 3: very much, 4: a lot	4	2
III – Pleasurability				
Visual and physical connection and openness to adjacent street/s or spaces	Counts based on observations	0: almost none, 1: somehow tentative, 2: moderately well connected, 3: very well connected, 4: highly connected	3	1
Permeability of building façades	Counts based on observations	0: not at all, 1: some parts somewhat permeable, 2: moderate, 3: partly very permeable, 4: very permeable all along	2	1
Variety of elements providing sensory complexity	Counts based on observations	0: none, 1: very little, 2: moderate, 3: high, 4: maximum	1	3
Perceived attractiveness of space	User's subejctive rating	0: not at all, 1: somewhat, 2: moderately, 3: very much, 4: maximum	1	3
Perceived interestingness of space	User's subjective rating	0: not at all, 1: somewhat, 2: moderately, 3: very much, 4: maximum	1	2
IV – Safety				
Visual and physical connection and openness to adjacent street/s or spaces	Counts based on observations	0: almost none or very poor, 1: somehow tentative, 2: moderately well connected, 3: very well connected, 4: highly connected	3	1
Physical condition and maintanence appropriate for the space	Counts based on observations	0: not at all, 1: some parts somewhat permeable, 2: moderate, 3: partly very permeable, 4: very permeable all along	2	2
Perceived safety from crime daytime	User's subejctive rating	0: not safe at all, 1: somewhat unsafe, 2: mostly safe, 3: very safe, 4: high perception of safety	4	4
Perceived safety from crime after dark	User's subejctive rating	0: not safe at all, 1: somewhat unsafe, 2: mostly safe, 3: very safe, 4: high perception of safety	2	0
Perceived safety from presence of surveillance camera or guides	User's subjective rating	0: make me feel unsafe, 1: not at all, 2: provide some sense, 3: very much provide a sense of safety, 4: maximum feeling of safety	2	2

(*Continued*)

Table 2. (Continued).

Public Space Index (PSI) dimensions and its variables	Measuring criteria	Ranking score	Market	Park
V – Comfort				
Places to sit without paying goods and services	Counts based on observations	0: none, 1: few, 2: several some parts of space, 3: several in many parts of space, 4: all over the space	2	4
Physical condition and maintanence appropriate for the space	Counts based on observations	0: not at all, 1: some parts somewhat permeable, 2: moderate, 3: partly very permeable, 4: very permeable all along	1	4
Perceived physical conditions and maintanencce appropriate for the space	Counts based on observations	0: not safe at all, 1: somewhat, 2: moderate, 3: very much, 4: maximum	3	1
Design elements discouraging use of space	Counts based on observations	0: none, 1: one or two, 2: few, 3: several, 4: many	2	3
Perceived nuisance noise from traffic or otherwise	User's subjective rating	0: none, 1: one or two, 2: few, 3: several, 4: many	4	4

research, as it is based on an extensive urban design literature, allows a numeric ranking between different thematic analyses, and allows for a comparison with other data sets – in this case soundscape features.

The sites

The study focuses on two types of open public spaces – a neighbourhood Market and a Park – in Driescher Hof in Aachen, Germany. Driescher Hof is a post-war peripheral neighbourhood in south east Aachen with mid-rise housing units and mix-use shopping areas. More than half of neighbourhood residents have immigration background from Turkey, Russia, Poland, Syria, among other countries. The neighbourhood is characterised by its elderly population and single-person households. The municipality of Aachen has identified ageing, loneliness, welfare dependency, and low education as some of the social challenges of the neighbourhood within the framework of the Social City urban regeneration programme (Soziale Zusammenhalt 2020). The selection of two types of public spaces which are different in their spatial layouts and functions aims to gain relevant information regarding their quality and respective soundscape features. Figure 2 presents a partial map of Aachen and the location of Driescher Hof and selected public spaces.

The fieldwork

The fieldwork evaluated two public spaces, *Market* and *Park*, based on the five dimensions of the PSI and related variables through structured and unstructured side observations. Additionally, the researchers conducted 15 unstructured interviews. The interviews included open-ended questions on, for example, user's perception of public space for its openness and accessibility, perceived safety and attractiveness, as well as perceived nuisance of noise, for example from traffic or otherwise. The researchers also asked questions on the frequency of visits, time spent, types of activities to identify the character

Figure 2. Map of Aachen indicating the location of Driescher Hof and two public spaces.

of socialisation in public spaces. Observations, photography, video recording, and field-notes were used to collect data.

The observations and interviews are ranked as very limited (0), low (1), medium (2), high (3) and maximum (4). Table 2 presents a detailed list of rankings for each variable.

The field visits were carried out on weekdays (Fridays) and weekends (Saturday) during the busiest time for each public space, mornings, afternoons, and evening hours, in the period of April–May 2021. This period was the peak of the COVID-19 pandemic social restrictions of the North Rhine-Westphalia region of Germany in which people had to work from home; schools, organisations, religious buildings, and other public institutions were closed; and home visits were not advised. However, supermarkets and other shops selling essential goods were open, keeping their daily activity. Open public spaces, such as parks, squares, and playgrounds, were available for socialisation under the conditions of wearing a mask and 1,5 m social distancing.

Evaluating soundscapes using IVP

To study acoustic features, the research collects attributes by the IVP technique from participants describing acoustic, visual, and/or audiovisual descriptions of those spaces under typical daily conditions using 360 audiovisual reproduction of those spaces, as it was implemented in previous studies (Llorca-Bofí et al. 2022; Llorca-Bofí, Heck, and Vorländer 2024), based on the work of Lokki et al. (2011) and Zacharov (2019). This method is suitable for this analysis, since soundscapes are hard to compare in situ for a number of people at different times of the day – as explained by Aletta et al. 2020, if the surrounding changes, the acoustic evaluation also changes. By using calibrated audio-visual reproduction of the spaces, on the contrary, the statistical significance of the evaluation results is higher. Additionally, since the COVID-19 situation did not facilitate group meetings in public spaces, performing the test using an online platform was chosen as a preferable option. In this context, the research extracts five different attribute datasets, including: attributes describing acoustic properties, visual properties, and audio-visual properties, and the combinations "audio + visual," and "audio+visual+audiovisual." The research conducted the empirical analysis as the following three steps:

First, it captured the acoustic environments with a ZOOM-VR recorder, with a first-order ambisonics microphone, with B-format output files. The visual environments were captured with a Insta360 Pro 2 camera, with panoramic monoscopic videos of 7680×4320 pixels resolution. Audio-visual post processing was done in Adobe Premiere, including metadata to be uploaded as YouTube 360 videos. The videos, containing spatial audio information, were reproduced from the assessor's personal computers at home. This feature made the study possible in times of Covid-19, since access to the lab was blocked for health reasons.

Second, it collected the data on perception of soundscapes. The analysis consists of ten participants answering a questionnaire at home using a prepared website interface, which completed the IVP, and each of them elicited four, five, or six attributes. Forty percent of the assessors were women. Each attribute was applied to rate all eight urban sequences, resulting in 8 sets of evaluations. Attributes were collected in English since all participants were fluent in speaking the language. Participants suggested their own attributes. A pre-screening of the attributes was done together the participant and the examiner excluding words with ambiguous meaning and keeping the words with a clear meaning for the participant (see Figure 3). As the numbers of attributes vary between assessors, the total number of collected attributes was 76. Because one attribute was applied for all signals, it is possible to see how attributes are grouped with n the entire data set. The playlist was accessible via YouTube.[1] This research complied with the RWTH Aachen University Code of Ethics and was approved by the Institute for Hearing Technology and Acoustics at the same university on 11 May 2022. Informed consent was obtained from each participant.

After collecting the participant's attributes and rates, as the third step, the researchers classified the participants' answers – elicited attributes – into collective categories. We could make the manually based on the short description of each attribute. However, we consider automatic clustering more suitable for our research, as it reveals how the attributes follow some objective laws when people describe them. The researchers calculated the Euclidean distances between the ratings for each sequence to cluster the

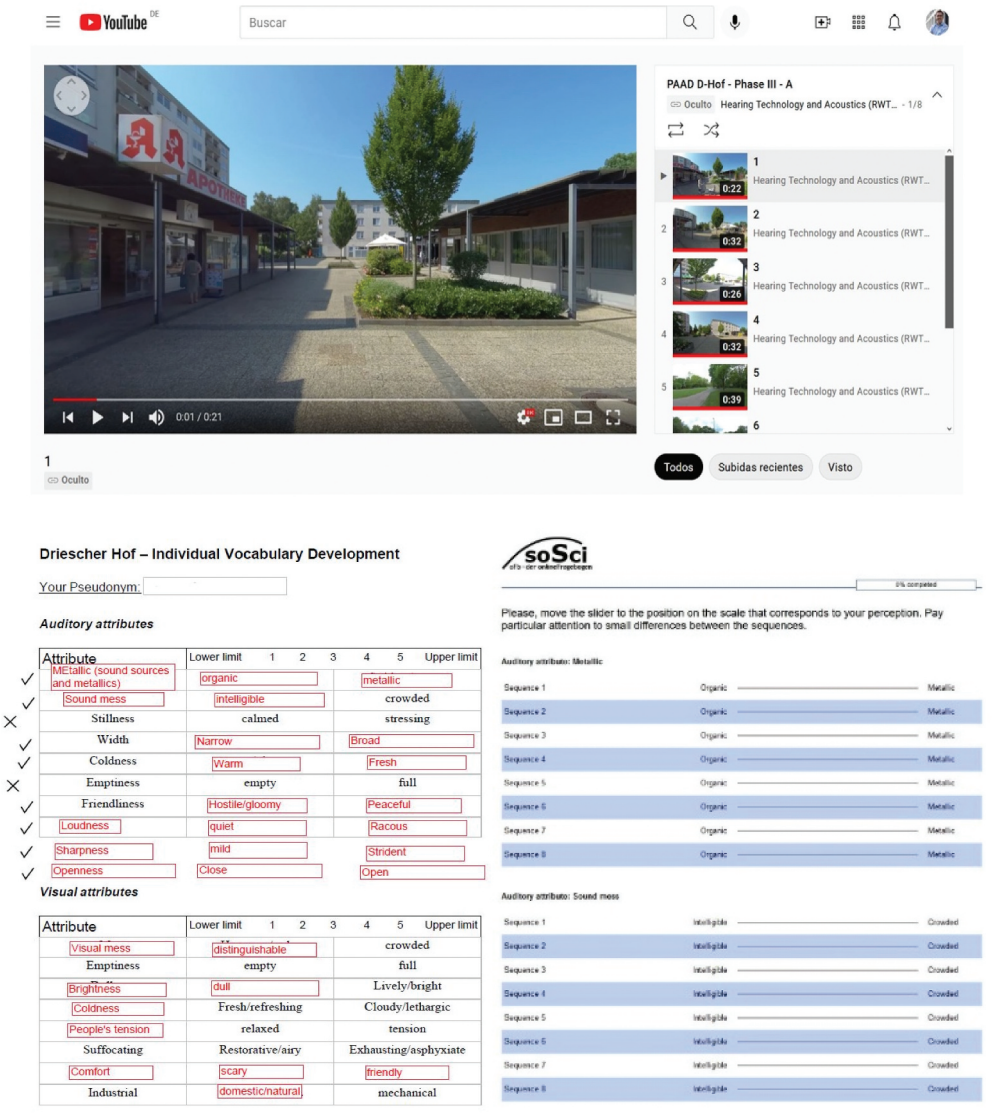

Figure 3. User interface for the soundscape test for each phase: youtube playlist of 360 videos for the stimuli reproduction, attribute elicitation sheet and online questionnaire.

attributes. As a result, the research obtained eight different distance matrices. Later, the study calculated the mean between the eight distance matrices, resulting in a mean distance matrix. The mean distance matrix contains attributes with similar mean distances between attributes – meaning that those attributes are similarly rated along the eight urban sequences, and big mean distances between attributes – meaning that those attributes are differently rated along the eight urban sequences. The Euclidean distance of the mean distance matrix is used to cluster the attributes under a cutoff value of 34, which is the value giving enough clusters to be different among them but still maintaining enough attributes in each cluster. In conclusion, the clustering highlights which

attributes behave similarly. The clarification of the results requires a graphical description of the data, as explained in the results section.

Best-fit permutation between PSI and IVP

After extracting the evaluation data from PSI and IVP, the comparison between both fields is done in order to find which attributes of IVP are closer to the dimensions of PSI. On one hand, one value for each of the PSI dimensions is given for the Market and for the Park areas. This value is expressed in the format of five quantities, as the literature proposes (Mehta 2014). It is important to note that the PSI evaluations have been done for a given area in a period of time, in this case the Market and Park areas, under some hours of observations.

On the other hand, one value for each of the five IVP clusters is obtained for each urban sequence. The urban sequences correspond to recording points over the Market and the Park as it is explained in the next section. The mean over the values obtained for the Market and the mean for the values in the Park have been calculated. Five different attribute datasets have been used to obtain the IVP clusters, thus resulting in five different IVP approaches.

Each of those IVP approaches has been compared one by one with the given PSI dimensions. The best-fit permutation between the PSI dimensions and the found IVP clusters is the goal when comparing them. This has been achieved using the smallest mean over the five dimensions between all possible permutations between PSI and IVP dimensions, simultaneously for the Market and the Park. In other words, the pair-wise distance between all possible permutations of PSI and IVP dimensions has been calculated, and the smallest for both Market and Park areas has been selected.

Results

The following two sections present the fieldwork findings for the quality of the public realm and soundscape analyses.

Results of the public realm analysis

Table 3 presents the results of the evaluation of the public realm under the themes of inclusiveness, meaningful activities, pleasurability, safety, and comfort for two public spaces. Figure 4 presents spider web diagram comparison of the findings in two case studies.

Regarding the quality of public spaces, the Market presents a higher ranking than the Park. The Market provides services for the basic needs of the neighbourhood residents, including a supermarket, pharmacy, a kiosk and a restaurant/café offering takeaway food, all open during the COVID-19 lockdown until 5 pm. We observed, as expected, many shoppers in the square, primarily women in their 40s and some with their young children. The researchers also noted a few older men in the square with their shopping bags, standing, and socialising with each other.

The square is well organized and maintained, with some greenery at the entrances. However, the repetitive building facades, lacking visual permeability in some cases,

Table 3. Dimensions of sociability in public spaces after Mehta (2014), variables and ranking scores.

Public Space Index (PSI) dimensions and its variables	Market	Park
I - Inclusiveness		
Presence of people of diverse age	4	3
Presence of people of diverse genders	2	4
Range of activities and behaviours	4	3
Opening hours of public space	1	4
Perceived openness and accessibility	4	1
II – Meaningful activities		
Presence of community gathering	2	4
Range of activities	4	3
Variety of businesses and other uses at the edges	3	1
Perceived suitability of space layout and design to activities and behaviour	2	2
Perceived usefulness of businesses and other uses	4	2
III – Pleasurability		
Visual and physical connection and openness to adjacent street/s or spaces	3	1
Permeability of building façades	2	1
Variety of elements providing sensory complexity	1	3
Perceived attractiveness of space	1	3
Perceived interestingness of space	1	2
IV – Safety		
Visual and physical connection and openness to adjacent street/s or spaces	3	1
Physical condition and maintanence appropriate for the space	2	2
Perceived safety from crime daytime	4	4
Perceived safety from crime after dark	2	0
Perceived safety from presence of surveillance camera or guides	2	2
V – Comfort		
Places to sit without paying goods and services	2	4
Physical condition and maintanence appropriate for the space	1	4
Perceived physical conditions and maintanencce appropriate for the space	3	1
Design elements discouraging use of space	2	3
Perceived nuisance noise from traffic or otherwise	4	4

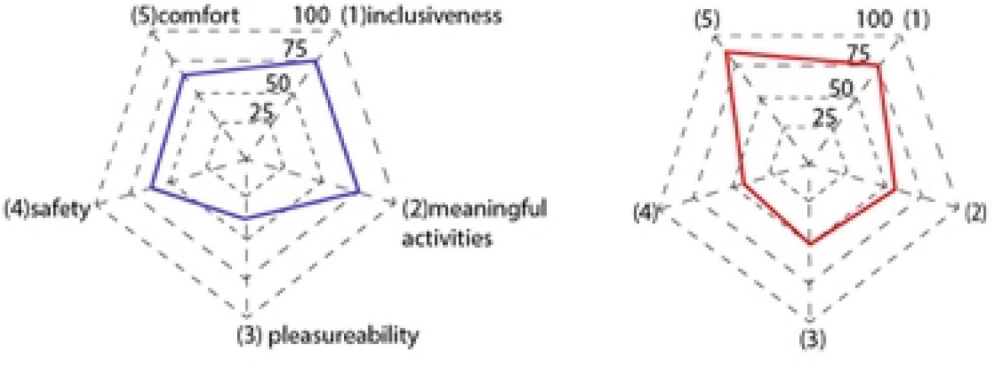

Figure 4. Spider web analysis of the PSI dimensions findings for the two case studies, Market and Park according to inclusivity, meaningful activities, pleasurability, safety and comfort.

reduce its appeal and pleasurability. There's only one seat in front of a café (closed during lockdown) often used by locals, mostly older men. An elderly resident noted that more seating would improve comfort and socializing. Despite this, residents find the Market safe and comfortable, providing chances to meet neighbors. The variety of shops is adequate, and the Market's role in social life grew during lockdown, helping counter loneliness.

Figure 5. Ground plan of the Market and surroundings. The four recording positions for the IVP analysis are marked.

The Park (Figure 5), which is a spatial connector between the Market and the other parts of the neighbourhood, provides various recreational facilities. These include a playground, picnic tables, and a basketball field. We observed a wide range of social groups using the different parts of the Park. The youngsters, mostly boys in their 18s, gathered around the basketball field. The active scene of the basketball game created a vibrant sphere to the Park. The playground is another busy part of the Park with young children and their mothers picnicking at the tables adjacent to the playground. These two specific places in the Park are main attractions where people gather and create a lively social sphere. The rest of the Park visitors we observed during our field visit are young women walking and chatting, and young men sporting, dogwalkers, and people passing by on bicycle.

We observed that the Park presents mixed qualities in terms of its maintenance. Although the basketball field, seating furniture, and playground are in good condition, a dry fountain and its pool seem like a neglected part of the Park. We understood from our interviews that the fountain is in this state already for a few years and the residents do not notice it significantly.

The Park lacks physical and visual permeability, specifically in its north entrance, due to the wide facades of the four-storey residential buildings and high trees. This physical layout creates a sense of closure on this part of the Park, and consequently, a feeling of unsafety. As the residents informed us, they feel particularly unsafe during the evenings, specifically in winters, due to its lack of visibility. Additionally, the Park is a gathering place for the youngsters, who listen to loud music during the night-time, which creates a sense of discomfort by other residents. There were few unrecorded neighbourhood incidents regarding this kind of conflict, as some residents have stated.

Despite its pitfalls, the Park has many positive characteristics, an attractive gathering place for the neighbourhood. It creates a sense of oasis within the residential area which is

significantly characterised by its built environment rather than its green areas. It is welcoming place for residents of different social groups. This is particularly evident in the time of pandemic social restrictions in which people need facilities to gather and socialise in outdoor spaces.

However, day-time and night-time uses of the Park are significantly different. The vibrant day time activities such as children playing, adults socialising and sporting, and other recreational activities are less when the Park gets darker.

Results of public realm's soundscape analysis

Figures 5 and 6 show the recording positions from which the soundscapes have been evaluated. The positions were distributed in the whole areas to maximize the range of different soundscapes.

Figure 7 shows all individual results for each location recording. In the horizontal axis, the eight different urban locations are displayed. In the vertical axis, the individual rating of each attribute is depicted over a scale from 0 to 100. The name of the attribute is displayed at the right side of each point. The lines in the background (colored) connect the eight times each attribute has been used – namely, for each urban sequence. Each point in the graph shows the rating each attribute was given at a certain urban sequence. The first impression on the data shows a big variety in the ratings between each attribute. However, after a visual inspection of the data, some groups of attributes can be detected. For example, there is a big group of attributes which were highly rated in sequence 1, which is rated lower for sequence 2. One can follow how each attribute is rated by reading the attribute at the right side of the figure and following the line to the left direction. Each point shows the rating this attribute was given for specific urban sequences.

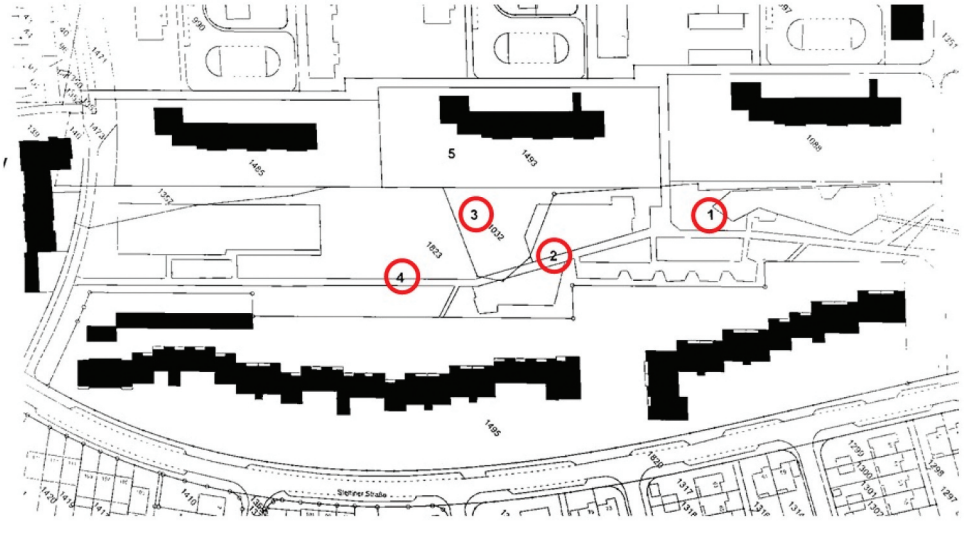

Figure 6. Ground plan of the Park and surroundings. The four recording positions for the IVP analysis are marked.

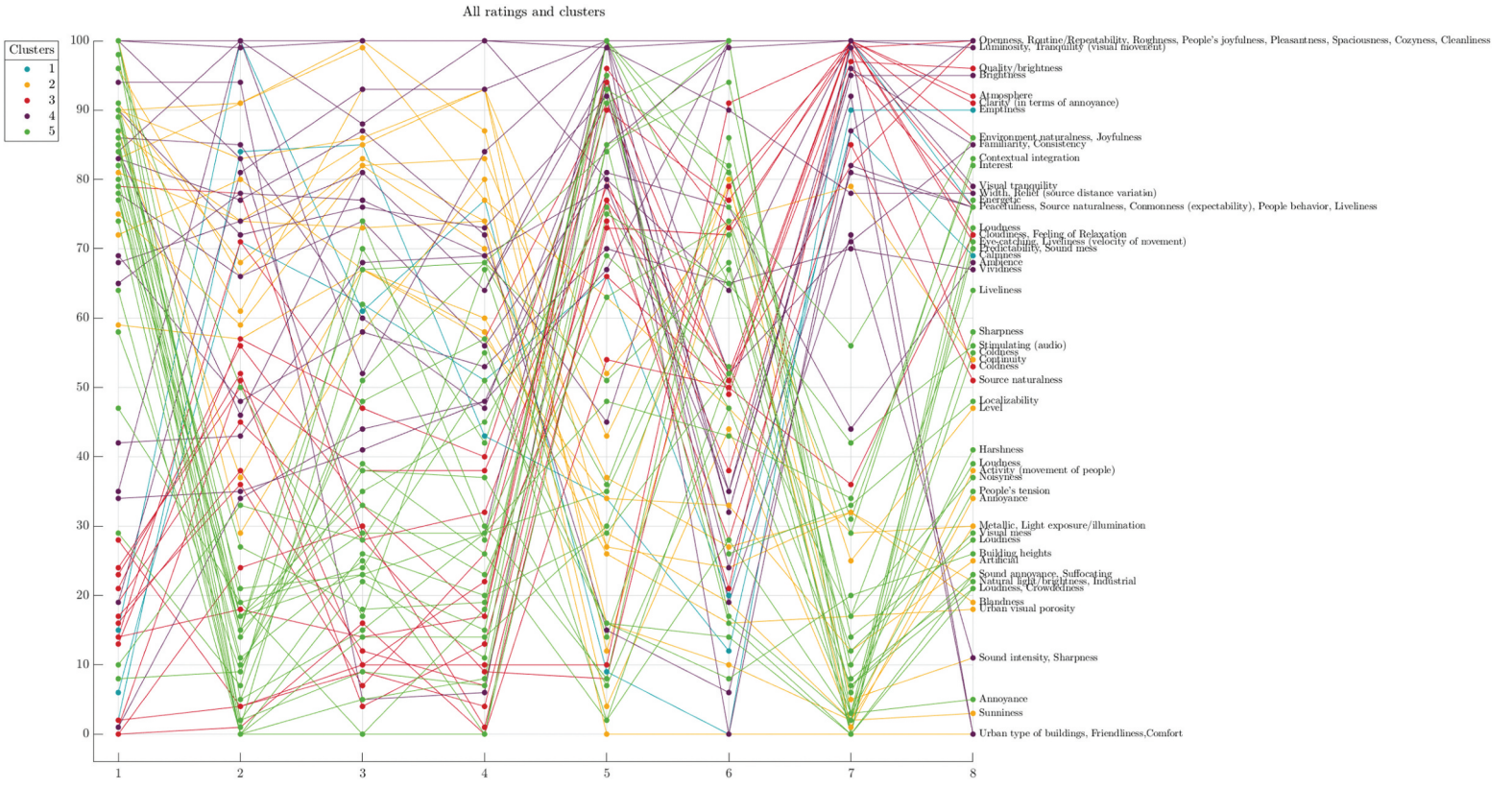

Figure 7. All attributes and ratings for the 8 recorded soundscape positions. In the X-axis the 8 different urban sequences are represented. In the Y-axis, the scale from 0 to 100 scale used to rate the sequences. On the right side, all the attributes elicited by the judgers. Each line in color represents a different attribute. Each point represents the rating of such attribute. The colors represent the different clusters based on the dendogram (Figure 8). Figure 9 shows the same data separated per clusters.

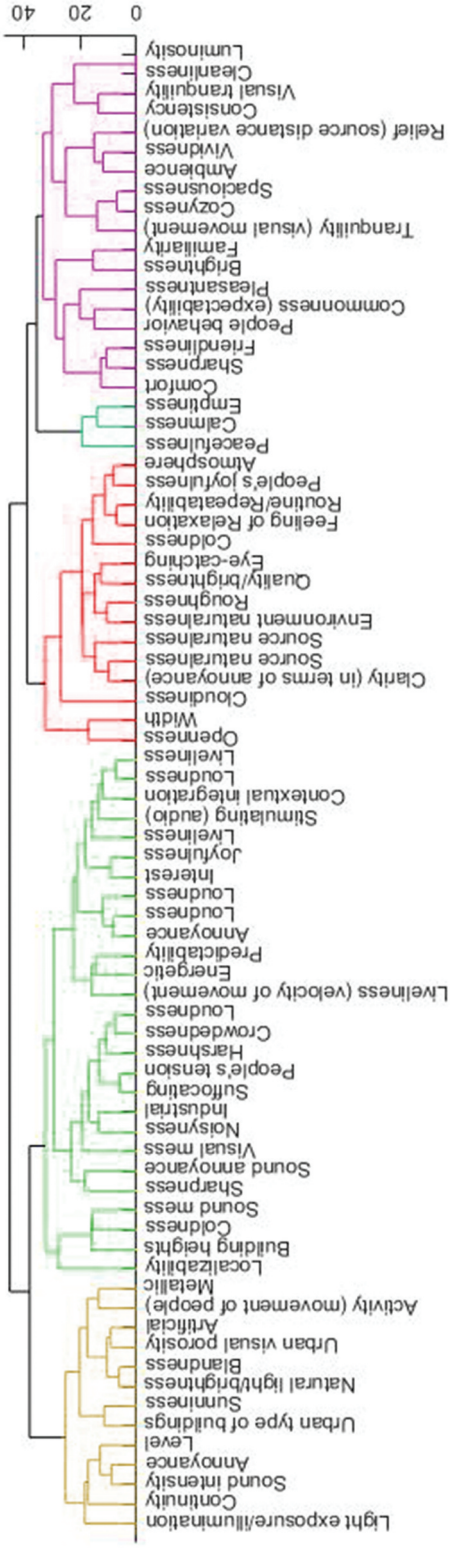

Figure 8. Dendogram clustering all attributes in 5 different groups.

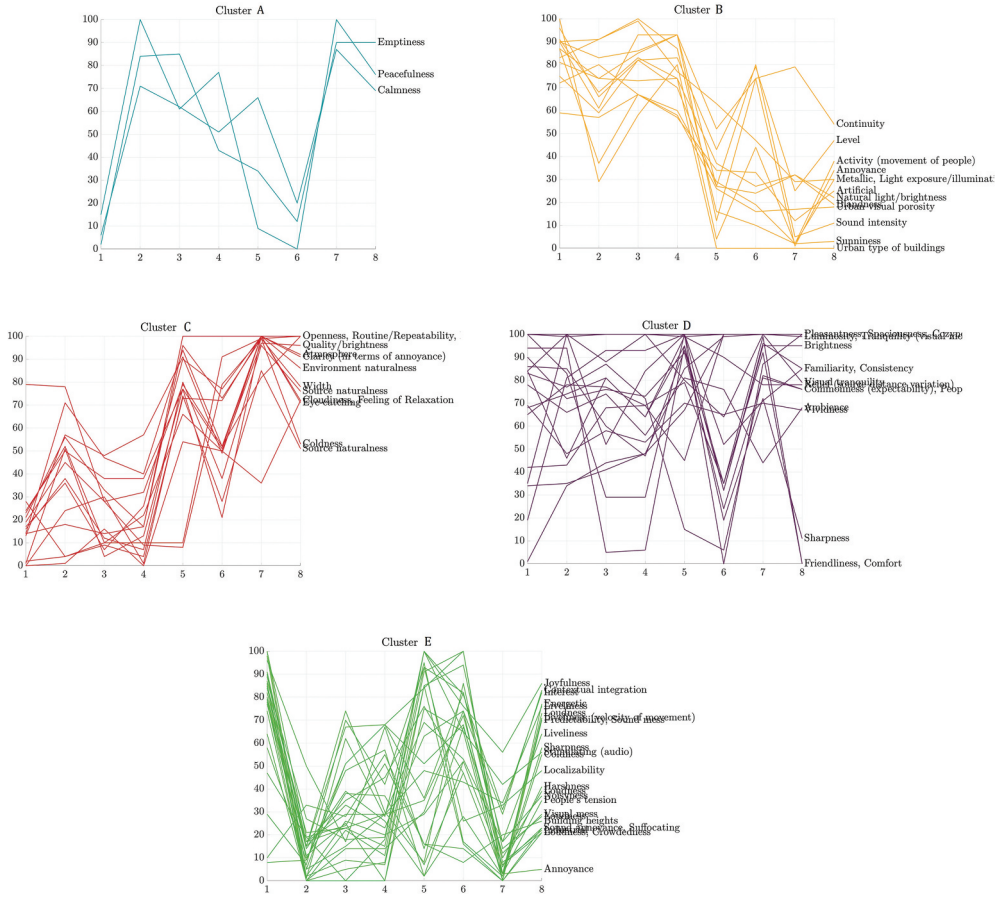

Figure 9. Clusters A, B, C, D, E for the IVP analysis. Each cluster is represented by one color (blue, yellow, red, lila and green). For each cluster, the X axis shows the eight urban positions (1–4 corresponding to the Market and 5–8 corresponding to the Park). The Y axis indicates the value range (1–100). Each colored line corresponds to an attribute rating for each urban position. The data plotted here correspond to the Audio+Visual+Audiovisual dataset.

After the visual inspection of the data and the detection of potential clusters, the systematic clustering was done, which can be seen in Figure 8. This graph (dendogram) illustrates the distances between attributes, as explained in the methods section, in a tree form. The groups of attributes contain visual and acoustic elicitation attributes, which were expected from the instructions of the test.

In Figure 9, each cluster is depicted separately. The behaviour of each cluster is clearly distinguished here, especially for clusters 1, 2, 3, and 5. They reveal a coherent behaviour between the attributes across people, which reveals how accurately a group of attributes describe the sequences. If we take a closer look at the attributes included in the dendogram, we discover that a mix between audio and visual attributes are used, which indicates that in the spaces are judged in both modalities.

To be more precise, in Cluster A three attributes are included – emptiness, peacefulness, and calmness. The clustering is named under the term "peacefulness" as

representative word on it. It can be noted that sequences 1, 5 and 6 are the lowest rated in this regard, whereas the rest of sequences receive a mid-high rate on them. This does not strictly correspond to the separation between market place and Park, but rather to the places where more noise was perceived – namely shopping trolleys, kid-s shouts, and mechanical machines. This result confirms the existing literature about the relation between the soundscape and the peacefulness induced at the receivers (Brambilla et al. 2013).

In Cluster B, a large number of attributes are included. The authors derive that the attributes are packed under the quality of "intensity" included in those areas. It includes both visual and acoustic cues, and it clusters attributes regarding the "sunninnes," "activity," and "level" of noise or "sound intensity." Interesting enough is the clear distinction between the two main urban areas: the market place is generally rated high, whereas the Park is rated as low. The name of the attributes suggests that here the negative aspects of the noise are rated, whereas in Cluster A, the positive and restorative aspects of the soundscape are highlighted. Additionally, the visual equivalent to the noise annoyance in Cluster B includes "light exposure" and "brightness," which indicate a proximity with the high level of noise.

Cluster C shows an opposite quality than Cluster B. Here, the attributes are rated as low for the market place, and high for the Park. The authors name this cluster after the term 'presence of nature. The attributes include concepts ranging from "environment naturalness" and "width," to feelings like "people's joyfulness" and "coldness." Both acoustic and visual cues include aspects in relation to the nature. In contrast to cluter 1, Cluster C clearly distinguishes the places with natural sound sources and green visuals (sequences 5–8) to the rest.

Cluster D includes an extensive collection of different attributes which also differ in the ratings. The attributes include a mix between visual commonness (without variation), sound "ambiance," and "comfort." Is named after the term "comfort." The ratings vary along the sequences without a clear pattern. This might indicate that this is a less consistent cluster, which could include other smaller clusters potentially coherent if the number of participants and collected data would be bigger.

Finally, Cluster E collects a big number of attributes with some relations with "vividness." Those attributes are highly rated for sequences 1, 5, and 6, which shows an inverse behavior than Cluster A. In fact, the main aspects rated here are at the opposite of the feeling of relaxation and calmness. The "sense of movement," "tension," "annoyance" and "loudness" constitute the opposite qualities of those spaces.

To sum up, there are a few topics which can be considered as trends when judging such urban spaces: nature, calmness, activity, and annoyance. Those can be judged both visual and acoustically. Clusters 1 and 5 seem to show an opposite behavior, as well as clusters 2 and 3. Clusters 1, 2 and 5 depict different aspects of sound and visual related with feelings, whereas Cluster C talks about nature.

Results of the best-fit permutation between PSI and IVP

The best-fit permutation analysis reveals which found IVP cluster fits best with the predicted PSI indicators. This reveals one first result on how the attributes are used across urban sequences:

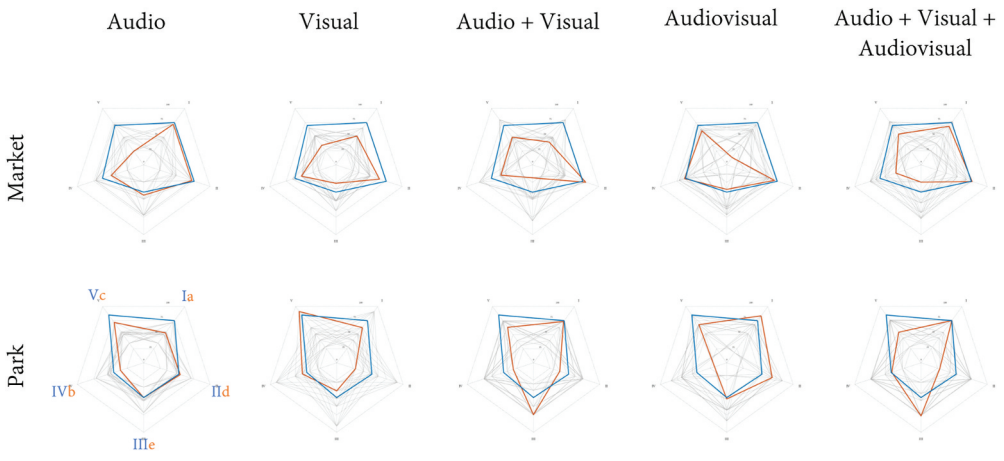

Figure 10. Best-fit correlation between public space index (PSI – in blue) and individual Vocabulary Profiling (IVP – in orange), for both Market (higher row) and Park (lowest row) areas. The same PSI evaluation is compared over 5 different IVP datasets: attributes from Audio, visual, Audio+Visual, Audiovisual, Audio+Visual+Audiovisual (from left to right). In grey lines, all IVP possible permutations against PSI are plotted.

In Figure 10, spider plots reveal that the fit between IVP and PSI values differs depending on which dataset is considered. For example, PSI and IVP values are very close among them when we consider only the Visual dataset or only the Audio dataset. However, distances between PSI and IVP are bigger and varying between positive and negative if we consider the combined Audio+Visual dataset. This reveals that the PSI method, which is based on in-situ observations, can be better predicted by individuals in participatory processes using separate words for the audio and for the visual modality.

Another interesting observation is that the PSI indicator V (Comfort) is the most difficult to predict with the IVP method when using the Audio and Visual datasets - in both cases, differences are above 25 points-. On the contrary, for the dataset Audiovisual, PSI V is very close to its corresponding IVP D (Pleasantness). This fact reveals that the PSI method includes aspects which are better rated using multimodal concepts - such as comfort - and other aspects closer to a specific modality - such as pleasurability, which is very close to sound annoyance. Further exploration of the correspondences between the PSI and IVP clusters and attributes can be seen in Table 4.

Finally, plotting the differences between the best-fit values of PSI and IVP on the map of the Park and the market gives an overview on the relative differences. Figure 11 gives an overview of such data including the name of the corresponding clusters. The darker the colors are, the bigger the differences are. In that figure, we see a tendency towards bigger differences as soon as the datasets are more multimodal. Whereas for the Audio and Visual datasets the differences are rather small (13 points as a mean), differences get bigger (35 points as mean) for the multimodal datasets, such as Audiovisual and the last dataset combinations.

Table 4. Each cluster attribute data, for each best-fit correlation between PSI and IVP. The IVP data is shown for five different datasets: attributes from Audio, visual, Audio+Visual, Audiovisual, and Audio+Visual+Audiovisual datasets. The mean distance values for each dataset are indicated in italics.

		Individual Vocabulary Profiling (IVP)				
		4 participants, providing 4 Audio and 4 Visual attriburtes			4 participants, providing 6 Audiovisual attributes	All attributes by all participants
Public Space Index (PSI)	Public Space Index dimensions	**Audio attributes** (permutation: 104: 14523) *PSI-IVP Market: 12.17* *PSI-IVP Park: 8.71*	**Visual attributes** (permutation 32: 43512) *PSI-IVP Market: 18.36* *PSI-IVP Park: 11.98*	**Audio + Visual attributes** (permutation 29: 45132) *PSI-IVP Market: 18.89* *PSI-IVP Park: 15.22*	**Audiovisual attributes** (perm 71: 31254) *PSI-IVP Market: 16.17* *PSI-IVP Park: 10.50*	**Audio+ Visual + Audiovisual attributes** (permutation 39: 42351) *PSI-IVP Market: 12.44* *PSI-IVP Park: 7.68*
	I. Inclusiveness	**Cluster A**: Friendliness	**Cluster D**: Brightness, presence of green (plants), emptiness, covering, openness, comfort	**Cluster D**: Openness, brightness, width	**Cluster C**: environment naturalness, eye-catching	**Cluster D**: pleasantess, spaciousness, cozyness, cleanliness, luminosity, tranquillity (visual voement), brightness, framiliarity, consistency, visual tranquillity, reflief (source distance variation), commonness (expectability), people behaviour, ambience, vividness, sharpenss, friendliness, comfort
	II. Meaningful activities	**Cluster D**: Unevenness, level of nature, relief (source distance variation), crowded, continuity, level, annoyance, sound intensity	**Cluster C**: Exposure to sun (subject), activity (movement of people), people's tension, light exposure, illumination, artificial, suffocating, industrial, people socializing, sunniness	**Cluster E**: exposure to sun (subject), continuity, level, annoyance, light exposure/ illumination, articial, people socializing, sound intensity, sunniness, friendliness, comfort	**Cluster A**: Consistency, visual tranquillity, peacefulness	**Cluster B**: continuity, level, activity (movement of people), annoyance, metallic, light exposure/ illumination, artificial, natural light/brightness, blandness, urban visual porosity, sound intensity, sunniness, urban type of builidngs

(*Continued*)

Table 4. (Continued).

	Individual Vocabulary Profiling (IVP)				
	4 participants, providing 4 Audio and 4 Visual attriburtes			4 participants, providing 6 Audiovisual attributes	All attributes by all participants
III. Pleasurability	**Cluster E**: Annoyance, localizability, human voice, loudness, bird chirping	**Cluster E**: Cloudiness, liveliness (velocity of movement), coldness	**Cluster A**: Routine/repeatability, roughness, quality/brightness, clarity (in terms of annoyance), source naturalness, cloudiness, coldness, source naturalness.	**Cluster B**: joyfulness, contextual integration, energetic, liveliness, predictability, liveliness, stimulating (audio), harshness, loudness, noisiness, loudness, sound annoyance, loudness, crowdedness, annoyance	**Cluster C**: Openness, routine/ repeatilibyt, roughness, peole's joy, quality/ brightness, atmosphere, clarity (in terms of annoyance), environment naturalness, width source naturalness, cloudiness, feeling of relaxation, eye-catching, coldness, source naturalness
IV. Safety	**Cluster B**: Loudness, sound mess, sharpness, metallic.	**Cluster A**: Emptiness, traffic density movement, colour of buildings.	**Cluster C**: Loudness, liveliness (velocity of movement), sound mess, sharpness, coldness, activity (movement of people), people's tension, metallic, visual mess, suffocating, industrial	**Cluster E**: Building heights, natural light/brightness, blandness, urban visual porosity, urban type of buildings	**Cluster E**: Joyfulness, contextual integration, interest, energetic, liveliness, loudness, liveliness (velocity of movement), predictability, sound mess, liveliness, sharpness, stimulating (audio), localizability, harshness, loudness, noisiness, people's tension, visual mess, loudness, building heights, sound annoyance, suffocating, industrial, loudness, crowdedness, annyance

(*Continued*)

Table 4. (Continued).

	Individual Vocabulary Profiling (IVP)				
	4 participants, providing 4 Audio and 4 Visual attriburtes			4 participants, providing 6 Audiovisual attributes	All attributes by all participants
V. Comfort	**Cluster C**: Openness, quality, brightness, clarity (in terms of annoyance), width source naturalness x2, coldness	**Cluster B**: Routine, repeatilibity, spaciousness, roughness, cozyness, tranquillity (visual movement)	**Cluster B**: Spaciousness, cozyness, tranquillity (visual movement), emptiness, traffic density movement (cars), unevenness, level of nature, relief (source distance variation), colour of buildings, presence of green (plants), crowded, annoyance, emptiness (nº of people), localizability, covering openness, human voice loudness, birds chirping	**Cluster D**: pleasantness, people's joyfulness, atmosphere, familiary, commonness (expectability), people behaviour, feeling of relaxation, calmness, a bience, vividness, sharpness	**Cluster A**: Emptiness, peacefulness, calmenss

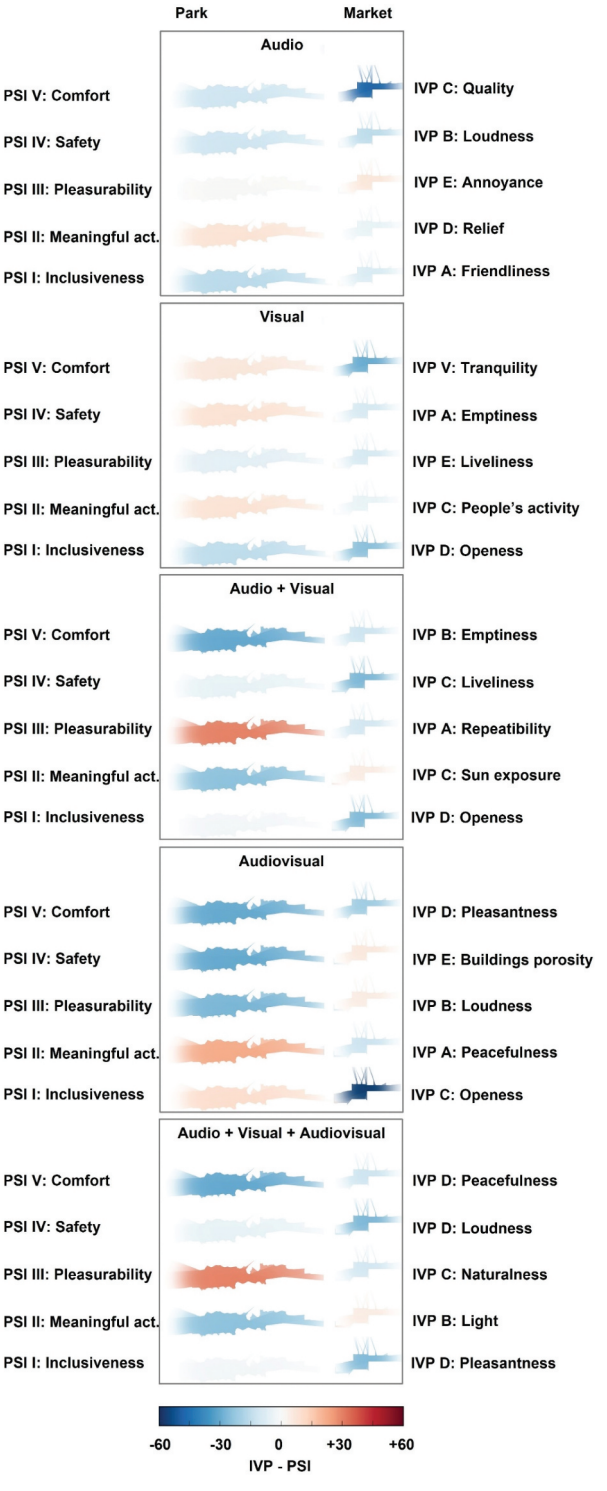

Figure 11. Differences between the PSI (left) and the IVP (right) best-fit correlation values, based on data from Figure 10 and mapped on the Park and market isovists areas. The 5 PSI name dimensions is the same for each dataset. The 5 IVP clusters change for each dataset since are the best-fit depending

Discussion

From the results depicted in Figure 10, we can observe several connections between both PSI and IVP methods, and extract conclusions on the role of soundscape in the urban realm evaluation. In particular three different aspects: (1) the matching between PSI and IVP depends on the urban area Market and the Park; (2) not all data sources of IVP correlate equally to the five dimensions of PSI.

Firstly, it can be observed that the mean distance between PSI and IVP dimensions in the Park evaluations is smaller than in the Market, for all five datasets. Whereas the mean distances between the PSI and IVP evaluations ranges between 12,4 and 18,4 in the Market, the mean distances range between 1,65 and 3,37 in the Park. This indicates that the PSI indicators record better activities recorded in the Park than in the Market. This observation makes us think that whenever a place contains a high variability of activities, the PSI indicators differ more than the IVP indicators. This observation is in accordance with current literature on the limiations of the PSI for use in different urban contexts (Evans et al. 2019).

Secondly, the correlation values vary depending on which dataset is compared. The least correlated dataset is the use of "Audio and Visual" attributes, with mean distances of 18.89 and 15.22, for the market and the Park respectively. Using "Audiovisual" attributes decreases significantly the means, especially for the Park (10.50). However, the lowest mean distance is achieved by the combination of "Audio+Visual+Audiovisual" attributes in the Park. A mean distance of 7.68 is achived, but with a high variance between the five dimensions. For this reason, the use of the separate datasets of "Audio" and "Visual" attributes might be more suitable to achieve low mean distances and low variance over the dimensions. This is especially the case of the "Audio" attributes rated in the Park, which mean distance is 8.71 and a lower variance than before.

Conclusion

This research explores the role of the soundscapes when evaluating public space and performs a quasi-experimental comparison between the PSI and IVP to extract which dimensions correlate best between both approaches. The results show that the PSI evaluations differ to what people rate using PSI methods if the attributes used for the rating are referring to acoustic properties, to visual properties or combinations of them. In particular, the clear separation between acoustic and visual attributes shows a better correlation between both PSI and IVP. Finally, this urges the development of more robust and reproducible representation tools of urban spaces which include not only visual properties of urban spaces, but also soundscape characteristics of them.

As a limiting factor, the research was conducted with a limited number of people. This fact did not allow for the extraction of relevant information from different groups of people, users and not users of spaces, diversity in age, education, and

to the dataset, as it can be seen in Table 4. Data is shown for each IVP dataset (Audio, visual, Audio + visual, Audiovisual, and Audio + visual + Audiovisual). It can be observed that PSI and IVP differ most when people use multimodal "Audiovisual" attributes, rather than "Audio" and "visual" attributes.

language backgrounds, etc. Therefore, the present study opens the door to investigate on this direction. Additionally, objective metrics could be included to complement the description of the public space and relate them to the descriptive clusters, such as connectivity indexes, visual integration or other parameters from urban network disciplines. Finally, the physiological impacts of the spatial soundscapes and the role of multisensory integration is important, as highlighted in the presented results. The study of those will require additional hardware and methodological implementations.

Acoustic virtual reality might play an important role when applying this method to future urban plans. The auralization tools, in combination with visual rendering tools, provide plausible audio-visual stimuli which might be used as new input for judgements and evaluations. Further research on the levels of plausibility required would provide helpful insights to which extent those technologies might be used.

Note

1. https://youtube.com/playlist?list=PLjVMT5BkCe80bcKqUQ7FTYJLFb5Ibt1Kl.

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