Research Article

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Conscious walk assessment for the joint evaluation of the soundscape, air quality, biodiversity, and comfort in Barcelona

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Abstract: High environmental noise as well as poor biodiversity and air pollution pose significant challenges for the European population, particularly those residing in urban areas, impacting clearly on citizens' health. The Conscious Walk initiative stands for an innovative hybrid approach to analyse citizens' perception of their environment. Being a citizen science participative project, Conscious Walks involves both citizens and scientists collecting high-quality acoustic, chemical, biodiversity, and comfort data while walking in pre-analysed urban environments. The main objective of this proposal is to obtain comprehensive data encompassing both subjective and objective aspects related to soundscape, air quality, biodiversity, and urban comfort. All these elements are closely tied to the overall acoustic environmental quality of the places under study. The effectiveness of this methodology has been tested in various locations in Catalonia, including Sabadell and Barcelona. This contribution focuses on the evaluation of the soundscape in the urban centre of Barcelona, with a comprehensive analysis that integrates data collected by both citizens and scientists during Conscious Walks, air quality metrics, biodiversity, and human comfort information.

Keywords: acoustic pollution, air pollution, urban biodiversity, human comfort, citizen science, sensors, soundwalk

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1 Introduction

More than half of the world's population resides in urban areas, underscoring the critical role of addressing urban environmental challenges in achieving sustainable development. This significance is exemplified by the inclusion of sustainable cities in the 17 sustainable development goals outlined in the 2030 Agenda for Sustainable Development [1], adopted in 2015. Moreover, human well-being is related, among other issues, to city urbanism [2]. The city is the sum of several components, including not only its infrastructures but also its noises, the quality of the air, or its biodiversity.

From the point of view of acoustics, the quality of the city can be studied through its soundscape. Defined by Southwork in 1967 [3], this term is related to the acoustic environment perceived by the human being and takes into account all the sound sources that form the acoustic environment of the city. In an urban environment, we usually think of sound sources (or directly noise sources) that annoy us, either because they have high sound pressure levels (decibels) that can harm people or because we simply do not like them. But there are also other sound sources that can relax us, such as a waterfall, which often generates this effect despite the high sound pressure levels it generates. The public's perception of the quality of the soundscape is undoubtedly decisive.

Much research work states that several pollutants that exist in urban environments do have direct effects on citizens' health [4]. Noise, air pollution, and lack of biodiversity

severely affect citizen's perception of the quality of the urban environment. A recent study by Institut de Salut Global de Barcelona (ISGlobal) states that, only in Spain, NO_2 is responsible for more than 9,000 premature deaths per year [5], with a special focus on pollution and traffic noise, which by the way, citizens are not really aware of its impact on their lives.

On the other hand, a rich biodiversity has great benefits. Vegetation decreases air pollution, which has an impact on breathing illnesses, and the probability of having serious diseases [6], heart conditions, endocrine disorders, or mental disorders (among others). It helps to regulate temperature and humidity and improves people's comfort and health without any additional cost. Even there is evidence that being surrounded by blue and green decreases stress and improves cognitive development, especially in children.

The city is a "device for happiness," as Montgomery [2] passionately argues. But for the city to be a tool for happiness it should be comfortable. Spaces can be designed with different priorities, commutation areas, commercial areas, leisure areas, etc. In any case, all those spaces should have inherent human comfort, if not, they would lead to stress, discomfort, and in the end, unhappiness.

Several months ago, the authors developed an initiative aimed at improving the public awareness and acquiring a blend of objective and subjective measurements in quiet urban environments. Named as Conscious Walks, this approach strives to comprehensively address acoustic and air pollution, biodiversity, and human comfort within city environments. Walking has been systematically employed as a methodology [7] closely aligned with citizen participation processes, incorporating the act of walking as a means of obtaining a natural view of the space [8], as well as a way of collecting data. The proposed methodology involves engaging citizens in active walks along predefined routes in the city. The implementation of the Conscious Walks methodology has started in various cities, including Barcelona and Sabadell, and this article seeks to summarize the experiences and findings from Barcelona activities.

This article is structured as follows. Section 2 gives an overview of the state of the art of the several disciplines involved in this article, and Section 3 gives a brief explanation of what a Conscious Walk is. Section 4 gives the concept validation in Barcelona of the Conscious Walk. Section 5 presents the Discussions, and Section 6 gives the Conclusions and Future Work for this interdisciplinary team.

2 State of the art

In this section, we briefly review some relevant methodologies for characterizing Environmental Noise and Soundscape, Air quality, Urban Biodiversity, and Human Comfort. The state-of-the-art is limited to parameter-based citizen science approaches.

2.1 Walking as an experiential methodology

In the pursuit of sustainable urban development, several articles in the literature contribute valuable insights, mainly focused on the exercise of walking in community as a methodology. The work [9] addresses the challenges of noise and light pollution, advocating for a novel approach, the combined sound- and lightwalks. This mixed method, exemplified in a case study in East Berlin, integrates perceptual responses and quantitative measurements to comprehensively assess the impact of these pollutants, emphasizing the importance of human perception in urban sustainability. In the case of the study by Shamova [10], the article explores collective walks in artistic projects, aiming to understand the formation of a "common movement." Investigating the transition from individual experience to shared group experiences during walks as a main collective exercise, the study delves into sensory, bodily, and kinaesthetic aspects, offering a perspective on the establishment of a collective presence in urban spaces.

Piga [8] introduced the experiential-walk method, an experimental approach for sensing and communicating the city in urban design. This method emphasizes multisensory and dynamic environmental conditions, promoting a designer's early consideration of sensory experiences to be collected and to enhance urban design processes and increase sensory awareness. Petit *et al.* [11] proposed the concept of "sensory chromatic effects" to understand the variations in coloured architecture under different environmental conditions, introducing the visual component at its maximum. Utilizing experiential walks in Nantes, France, participants recorded visual and auditory aspects to identify and categorize chromatic effects. The results contribute to graphical representations for urban and architectural projects, enhancing the understanding of the ordinary perception of coloured architecture in everyday situations.

Oberman *et al.* [12] investigated the influence of space syntax tools on soundscape assessments in urban planning by means of walking. The study, set in the historical centre of Zagreb, Croatia, explores the integration of space syntax analysis into soundscape assessments, demonstrating the potential of planning-related configurational factors in soundscape studies. Andersen and Balbontin [7] used the expression "commented walks" to describe a method to analyse the use and value of open spaces on a university

campus. As part of a citizen participation process, this method integrates walking as a natural observational tool, enriching the comprehension of urban spaces and contributing to the development of a University Campus Master Plan in Punta Arenas, Chile.

These studies collectively underscore the importance of considering human perception, sensory experiences, and participatory methods in urban research, planning and design, aligning with the broader goals of sustainable urban development by means of a collective exercise as walking. The following section will put more focus on the soundwalks as a methodology to work and analyse soundscape, but this first piece of state-of-the-art pretends to state that walking has been proposed for multipurpose data collections and design proposals.

2.2 Environmental noise and soundscape

The urban soundscape plays a significant role in shaping the identity of a city. It contains different sound sources, some of which are annoying and should be avoided, either because of their intensity or because of their interference with the perception of the most characteristic sounds of the city [13]. The well-being of a city's population is closely linked to mental health, and a thriving city depends on the positive mental health of its residents [14]. With nearly 50% of the global population residing in urban areas, urban planners, architects, and other city stakeholders play a crucial role in city design [15], with some incorporating noise mapping techniques to enhance urban environments [16]. It is noteworthy that individuals residing in tranquil environments do not experience the adverse health effects associated with noise [17]. Similarly, such peaceful areas tend to positively impact the health of individuals who regularly visit them.

The assessment of acoustic comfort in open urban public spaces is a crucial aspect in promoting the design of a healthy city [18]. Notably, substantial distinctions exist between subjective evaluations of sound levels and assessments of acoustic comfort. The latter is inherently more intricate, with individuals demonstrating varying degrees of tolerance for acoustic comfort based on the type of sound source. Moreover, it is essential to recognize that the social context in which noise exposure occurs serves as a co-determinant of noise annoyance [19].

According to Schafer [20], the contemporary condition involves suffering from acoustical overload, diminishing our ability to discern the nuances and subtleties of sound. He contends that our challenge is to actively engage in listening, analysis, and differentiation despite the prevalence of sound pollution. In a similar vein, Westerkamp [21] defines a soundwalk as an excursion primarily dedicated to environmental listening, involving the deliberate exposure of our ears to all surrounding sounds, regardless of our location. It is noteworthy that both Schafer [20] and Westerkamp [21] played pioneering roles in the field of soundscape research.

Conducting a systematic soundwalk offers notable advantages in the quantitative and qualitative assessment of soundscapes as multimodal experiences, particularly in compensating for the limitations of laboratory-based experiences [13,15]. This approach facilitates the collection of both subjective responses and objective measurements for soundscapes, providing a valuable tool for soundscape interpretation. It must be taken into account, though, that the soundwalk path directly affects the soundscape perception[22], and therefore, the soundscape circuit must be carefully planned in advance. Besides the path, there are other landscape variables [23] such as the season of the year, illumination of the path, wind speed, or temperature [22] that contribute to the contention of different perception responses from the users.

The use of smartphones, considered a cost-effective device, enables audio measurements and the recording of a location's soundscape [24,25]. Numerous mobile apps, such as Hush City, City Soundscape, MoSart, Audiospook, and others, are available in the market for this purpose [26].

The individual soundwalk is advantageous for capturing diverse subjective responses [27]. However, engaging in group soundwalks represents an active mode of participation in soundscape evaluation, emphasizing the encouragement of participants to engage in discerning listening and critical assessments of the sounds encountered, along with their impact on the sonic environment's balance or imbalance [28]. Even children under supervision [29] or impaired people [30] can enrol on these types of activities and provide information about their perception of the sonic environment. Typically, participants are requested to complete questionnaires at the conclusion of the soundwalks, providing insights into the location, characteristics of stops and stations, and evaluations of the spaces between stops. The feedback collected through these questionnaires can be analysed and processed in different ways [31] and serves as a qualitative descriptor for designing urban places and should be considered in the holistic understanding of the soundscape. This comprehensive approach involves merging both quantitative and qualitative data from the soundwalk, with the results utilized to enhance acoustic environments [32].

2.3 Air quality

Air pollution is becoming one of the main threats to urban societies [33] due to its high impact on the public health [34].

In response to the challenge of addressing air quality issues, citizen science, and community engagement [35] have emerged as pivotal components in air quality monitoring. The field of citizen science has rapidly evolved, leading to the implementation of projects focused on air quality monitoring by citizens. These initiatives aim to establish alliances, knowledge-sharing platforms, and increased awareness, ultimately fostering resilience against air quality-related challenges [36].

A notable example occurred on 21 June, 2018, when Global Action Plan organized the inaugural Clean Air Day in the United Kingdom [37]. A follow-up survey conducted 1 month later revealed that over 10.5 million individuals in the UK were aware of Clean Air Day. Significant outcomes from these initiatives manifested in an increase of individuals choosing cycling or walking routes over driving, which could avoid the annual emission of 27,000 tonnes of CO_2, 13 tonnes of NO_x, and 2 tonnes of PM_{10}. This underlines the considerable potential for engaging individuals throughout Europe as well as the subjective perception, as measured by the environmental impact of cities, becomes a valuable component for understanding and addressing the complexity of air pollution in urban environments.

Furthermore, recognizing the subjective perception [38], as measured by the environmental impact of cities, becomes a valuable component for understanding and addressing the complexity of air pollution in urban environments.

2.4 Biodiversity

The concept of urban green infrastructure can be interpreted in various ways. In this study, we adopt the definition provided by Cole viewing it as a network comprising both human-managed and natural ecosystems [39]. Together, these elements enhance ecosystem health and resilience, contribute to biodiversity, and provide benefits to human populations through the maintenance and improvement of ecosystem services. Urban green infrastructure plays a crucial role in delivering essential ecosystem services, including air purification [40], temperature regulation [41], noise reduction [42], carbon storage [43], recreational flood services [44], and biodiversity conservation [45]. Therefore, any reduction in urban green infrastructure could have significant adverse effects on the environment, human populations, and biodiversity.

Bedessem's research on biodiversity citizen science projects underscores the value of public engagement in monitoring and understanding biodiversity, positively impacting participants' learning and environmental awareness [46].

Furthermore, citizen science projects contribute significantly to our understanding of biodiversity distribution [47,48]. Thompson *et al.* [47] highlights the importance of participant behaviour in optimizing data quality, while Chowdhury introduces a novel approach using online platforms and citizen science to bridge data gaps in the distribution of species in urban areas [48].

2.5 Human comfort

When talking about urban infrastructure from the architectural and design point of view we find a wide range of approaches. We would like to highlight here the ones that design the city as the pillar to build a community. Those projects are usually defined by a set of parameters where the health and the well-being of the community are at the centre. Thus, for example, in *Project for the public spaces* [49], their "groundbreaking placemaking approach helps communities transform their public spaces into virtual places that highlight local assets, spur rejuvenation and serve common needs. All is done by some values that guide them every day: participation, collaboration, local leadership, pragmatism, and integrity." Within the project, they use 24 parameters to characterize four descriptors of quality of life. In a similar approach, in 2006, Gehl *et al.* [50] summarized 12 basic design criteria that help to evaluate the quality of a public space. With the evaluation of all these criteria, the quality of the space and the comfort and livability it has for citizens is determined.

2.6 Joint evaluation

A city is a complex system. A sustainable city encompasses various facets influenced by environmental, economic, and social considerations. The environmental dimension of urban sustainability is shaped by interacting factors, including air quality, noise pollution, sustainable land use, waste generation and management, and biodiversity [51]. Several research studies have been carried out, which include, tranquility studies, ecological soundscape studies, or environmental impact assessments. In this

sense, specially tranquility studies [52] and mapping [53] offer a valuable lens to understand urban environments, emphasizing the importance of subjective experiences alongside objective descriptors.

A comparison with an objective measure of urban inhabitants' exposure to noise and air pollution supports the intuition that subjective perceptions when combined with objective descriptors offer a comprehensive understanding of urban environmental quality [38]. Historically, existing descriptors have predominantly relied on physical, chemical, or ecological measures, encompassing factors such as energy, air and noise pollution, and biodiversity [54,55]. Integrating the concept of tranquillity, such as those considering soundscape methodologies (ISO12913-2:2018), contribute to the holistic evaluation of urban environments, and providing insights into the perceptual aspects of tranquility also contributes to these descriptors introducing a more nuanced understanding of the urban environment, considering the psychological and emotional dimensions associated with tranquility [56].

The impact of traffic-related pollution on residential urban landscapes extends beyond negative effects on biodiversity; it also has implications for human well-being [57]. As discussed in the related study [58], the joint evaluation allows us to detect hot spots where transformations are needed to improve biodiversity, the daily quality of life of people as a whole, and health. The interplay of air pollution and noise pollution in urban settings further influences the overall urban experience [38]. Successfully implementing urban policies that prioritize the promotion of green spaces for a more sustainable and healthy urban lifestyle depends on heightened public awareness of the consequences of air and noise pollution [59]. Therefore, understanding the subjective perception of both environmental impacts in cities is crucial for navigating the intricate challenges of maintaining a healthy and harmonious urban environment [38]. Although, as it has been proved, there are several initiatives analysing some of the target spaces together, to the best knowledge of the authors, not a single one has jointly analysed the soundscape, air quality, biodiversity, and comfort. In our research, we aim to combine those different approaches (soundwalk, descriptors, citizen science) to develop a new methodology to (1) rise citizen's awareness and (2) have a new method to evaluate urban environment.

3 Conscious walk description

The aim of the work is twofold, on one hand, we aim to work with citizens to raise awareness about the city's infrastructure and its challenges. On the other hand, we aim to validate a set of descriptors (objective and subjective) that would allow us to properly characterize the city. Those descriptors should be helpful lately to follow-up and evaluate the actions taken by the city to improve it.

3.1 Conscious walk

The conscious walk was crafted to confront various urban environments based on the four issues identified in the preceding section: (i) soundscape, (ii) air quality, (iii) biodiversity, and (iv) human comfort. This directly influences the design of the route and the selected locations for volunteers to traverse, including all stops, the starting point, and the conclusion. The soundscape perspective introduced the method of soundwalking in the 1970s, as previously stated, through Murray Schafer as part of the World Soundscape Project [20]. Schafer aimed to investigate the connection between humans and the sounds in their environment, exploring the impact on human perception as sounds undergo changes. According to Schafer [20], a soundwalk is characterized as "any excursion whose main purpose is listening to the environment" [21,56].

A distinction between a soundwalk and a conscious walk lies in their respective scopes: while the former evaluates the acoustic environment exclusively, the latter delves into the four axes outlined above [60]. Participants are anticipated to evaluate the acoustic surroundings and articulate their perceptions. Detecting air pollution proves challenging for citizens, given its nearly invisible nature, only becoming observable when a cloud of pollution is present.

In considering biodiversity and human comfort, citizens often possess a general awareness of the greener streets or squares. However, there remains an analysis to be conducted regarding the significance of the trees, plants, and the overall habitat (or microhabitat) in these areas [60]. The conscious walk aids volunteers in identifying tree species and determining whether they are indigenous. A parallel process occurs for bird species. This approach is extended to the evaluation of comfort and amenities for citizens, including considerations such as seating, accessibility, playgrounds, and more. The aim is to create spaces that are equitable for all individuals and groups.

3.2 Descriptor definition

To assess the performance of urban sustainability, descriptors, frameworks, and evaluation tools have been

developed. These are essential for setting goals, reviewing performance, and facilitating communication among policymakers, experts, and the public [51]. However, it is important to note that descriptors used to be defined according to the specific needs and goals of each city.

This section delves into the intricate assessment of the various dimensions that shape the design and quality of Barcelona's urban squares, with a specific focus on those visited during the conscious walk conducted as part of the "Setmana de la Ciència 2022" – a regional initiative dedicated to promoting science to citizens throughout an entire week. Four fundamental aspects that directly influence the experience and sustainability of these spaces are as follows: Environmental Noise and Soundscape, Air Quality, Biodiversity, and Human Comfort [38,61–63]. Each of these facets is analysed using specific descriptors (Table 1), providing a comprehensive framework for the thorough evaluation and improvement of urban squares. It is important to highlight here the relevance of using the same descriptors for several spaces. This is exactly the keystone of the project, since this relation is the reason for performing a joint evaluation and not four separate ones. Hereafter, a general definition of each descriptor is provided, followed by a more detailed definition for each space. Please note that in this work we focus on the descriptors used in parks and squares, not on streets.

- **Intensity of use:** This descriptor assesses the frequency, extent, and diversity of activities and events in a given space. It aims to encompass various aspects, such as the number of people present and the variety of activities undertaken, seeking to provide a comprehensive understanding of human utilization and impact in a specific area. This allows for the evaluation of its dynamics and levels of activity.
- **Habitability:** Habitability refers to the ability of an environment to provide suitable and satisfactory conditions for human life or other forms of life. This descriptor assesses the suitability of the environment in terms of comfort, safety, and quality of life.
- **Activity:** The activity descriptor measures the intensity and diversity of actions and events occurring in a specific area over a defined period. It evaluates the vitality and dynamism of the environment based on human and natural activities.
- **Habitat complexity:** Habitat complexity refers to the type of environment or place where a species or a community of organisms lives. It encompasses both the physical and biological features of an area, including the climate, soil, vegetation, and other abiotic and biotic factors. The habitat provides the necessary conditions and resources for the survival, growth, and reproduction of the organisms that inhabit it.
- **Resources:** The resources descriptor evaluates the availability/presence of different substances or objects in the environment required by organisms for their normal growth, maintenance, or reproduction. It can encompass flowering plants, water elements, presence of pollinable trees, etc.
- **Extension:** Extension refers to the breadth or size of a geographical or environmental area under consideration. This descriptor assesses the spatial scale of an environment, offering information about its physical size and scope.
- **Contextual:** The contextual descriptor focuses on understanding an environment in relation to its surrounding context. It evaluates how the characteristics and dynamics of the area under study integrate and are influenced by the broader context, providing a holistic perspective on its position and function within a larger context.

Table 1: Descriptors for urban evaluation

Descriptor	Noise	Air quality	Biodiversity	Human comfort
Intensity of use	X	X	X	X
Habitability	X	X		X
Activity	X			X
Habitat complexity			X	
Resources			X	
Extension			X	
Contextual				X

3.2.1 Environmental noise and soundscape

The general descriptors for Environmental Noise and Soundscape are focused on the intensity of use of the spaces, and overall, the type of use of the spaces. A graphical view of the descriptors is shown in Figure 1. Hereafter a short description of them is presented:

- **Intensity of use:** the frequency of use by means of people, gathering people talking, dogs barking, or even music, together with the frequency of use of vehicles, considering both cars, bicycles, motorbikes, trucks, etc.
- **Habitability:** also taking into account the several agents that can cause noise in the public space, such as children and adults in the playing zone, the presence of water (especially if it is running water), and the diversity of the space, which can allocate several types of activities.

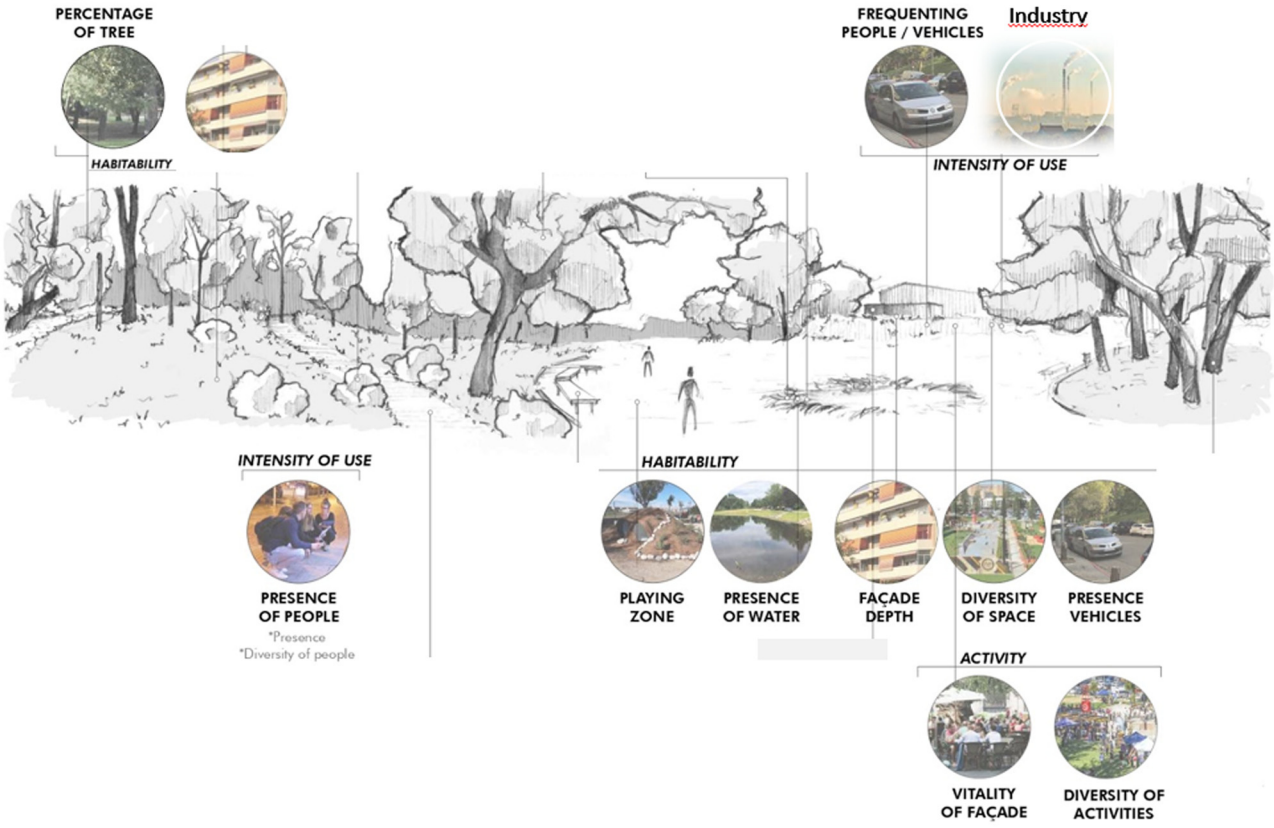

Figure 1: Graphical representation of parameters to build environmental noise and soundscape (bottom) and air quality (top) descriptors.

– **Activity:** both the vitality of the places, façades and parks and the diversity of activities that can be allocated in the different environments affect the environmental noise soundscape.

After these descriptions of the general issues to consider from the environmental noise and soundscape point of view, a taxonomy of types of events and sounds should be described.

– **Human events:** they include cough, movement (steps), music, and voice.
– **Nature events:** they include animals (birds, cat, cricket, dog, sheep), elements (thunder, water, wind), and vegetation.
– **Things:** the list is ball, blind, door, movement, and trolley.
– **Industrial:** sounds of construction, industry, vacuum, and ventilation.
– **Signals:** listing sounds of alarm, bells, car horn and sirens.
– **Transport:** dividing into motorized (air, rail, road), and non-motorized.

The combination of identified sounds detailed in the taxonomy is used to describe the former general descriptors, with the three main axis highlighted.

3.2.2 Air quality

The descriptors for air quality are designed to explore various aspects related to the source and quantity of pollutants, as well as environmental factors that influence the air quality of squares and parks. Figure 1 provides a visual representation of these descriptors.

– **Intensity of use:** this descriptor focuses on the identification and measurement of various pollutants present in the air and their respective emission sources, such as *background emissions*. Example: A festival or market in an urban square with high intensity of use may result in increased *vehicular traffic* and, consequently, higher levels of pollutants in the air.
– **Habitability:** factors like the *layout of streets and squares*, the presence of *green areas*, and the *height of buildings*

can influence pollutant concentration by affecting air circulation and *emission dispersion*. Example: the quantity and type of *tree coverage* can impact air quality by filtering pollutants and providing carbon sinks.

3.2.3 Biodiversity

The general descriptors for biodiversity quality description used in this work are properly described in the study. A graphical view of the descriptors is given in Figure 2. A summary of the descriptors is presented here.

- **Habitat complexity:** the *tree cover* (i.e. percentage of an area that is covered by the canopy of trees when viewed from above), *shrub cover*, and *herbaceous cover* are important, especially for avifauna. Often because they find shelter and food depending on the planted species. There may be insects or fruit. The *presence of grass* is positively related to the diversity and abundance of arthropods.
- **Resources:** The importance of *flowering plants* and *pollinable trees* is vital to accommodate different pollinators. It is also important for species to have access to *water elements* for survival.
- **Intensity of use:** The chances of animal species to live in an area decrease with noise and the presence of vehicles or people.
- **Resources:** The importance of *flowering plants* and *pollinable trees* is vital to accommodate different pollinators. It is also important for species to have access to *water elements* for surviving.
- **Extension:** Bird species richness and species temporal persistence are positively influenced by squares size. The minimum recommended *surface area* is 0.5 Ha.

3.2.4 Human comfort

The general descriptors for human comfort are the following ones. A graphical view of the descriptors can be seen in Figure 2. Hereafter, a short description of them can be found.

- **Intensity of use**: it is related to the capability of the space to be used by several types of citizens: from

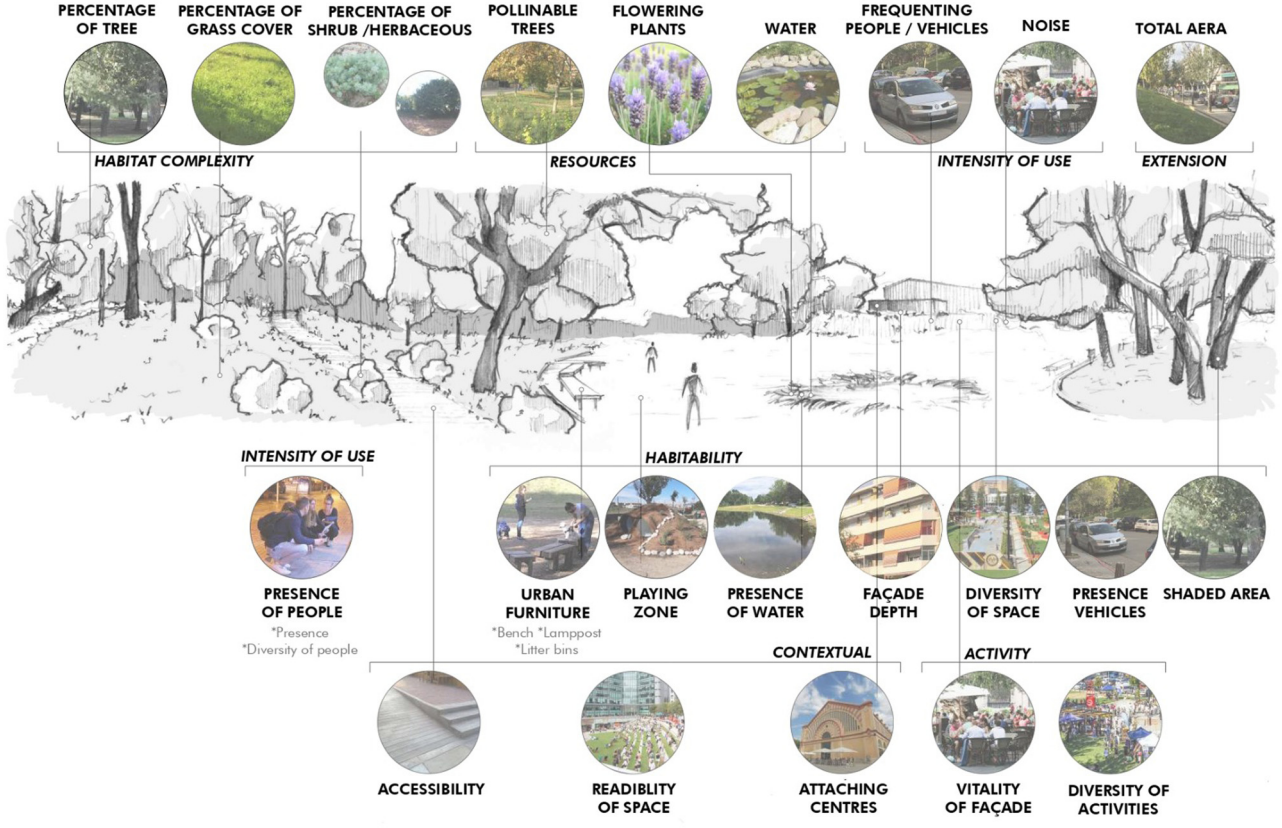

Figure 2: Graphical representation of parameters to build biodiversity (top) and human comfort (down) descriptors.

children to elderly people; and by several types of activities: from concerts to markets to play areas.
- **Habitability**: degree of comfort and variability of the space depends on several items like the presence of *Urban furniture* that allow comfort, like seating areas or shaded areas, trash cans (cleaning), lightning (security), or game spaces. It depends also on the presence of *Natural elements* that connect people with well-being.
- **Contextual**: related to the attractiveness of the area. It includes among others the space *accessibility*, that is, the degree of autonomy of all citizens. It includes the presence of paved areas that connect the different parts of squares or the gradients that allow access to different types of users (strollers, wheelchairs, elderly people, etc.).
- **Activity**: spaces designed to be populated and used. The items to measure this parameter includes the *Surroundings*, that is, the facades of the nearby buildings. If they are residential or commercial, the degree of isolation is from cars, etc. Other items are the *diversity of activities* that can be carried out in the space or the *diversity of users*.

3.3 Descriptor evaluation

3.3.1 Objective evaluation

In order to objectively evaluate the soundscape, a handy recorder Zoom H5 and a tripod is used to collect a piece of audio of each of the stops of the Conscious Walk. The audio files are manually labelled by an expert annotator using the taxonomy explained in the study of Bonet-Sola *et al.* [64]. The annotated acoustic events are analysed to obtain their duration, their Signal-to-Noise ratio (SNR), and its impact on the A-weighted equivalent Level ΔL_{Aeq}. The SNR calculates the ratio between the signal and the noise, which means that it evaluates the salience of the event relative to its surrounding sound. The impact on the L_{Aeq} value is determined by computing the difference between the equivalent level at a specific time frame and the corresponding value when excluding the event under study. Both the evaluation of SNR and the impact have been detailed in our preliminary work [65].

Regarding air quality descriptors, we set the following values: Bad, Poor, Fair, or Good according to the next rules. In order to set the values for the *intensity of use* the measurements of the air quality measurement official stations are used. The metropolitan area of Barcelona counts with several stations that allow us to know both the background pollution and the traffic-related pollution. The values for *habitability* are set by means of the analysis of a data collection on the field.

For biodiversity, we also set the values Bad, Poor, Fair, or Good. The rules to assign a value are as follows. Regarding habitat complexity, we assign it as Good when the square has the presence of at least 10% of coverage in each of the highlighted elements (trees, shrub, and herbaceous) and there is grass. Regarding resources, we assign it as Good when the square has the presence of pollinable trees, flowering plants, and water elements; as Fair if there are two of the three elements; Poor if there is only one element; and Bad if there are any of these elements. Regarding the intensity of use, we assign it as Good when there is a few presence of people and vehicles. Finally, for the extension, we assign it as Good when the square has more than 0.5 Ha.

Again, for urban comfort, we set the values Bad, Poor, Fair, or Good. In order to obtain the data of the human comfort, an *in situ* work has been carried out on the ground. We visited the spaces that we wanted to analyse in order to obtain data on the "physical capacity of the space" (which takes into account the elements that make it up, both within the spaces and around them) and those of "social use" (which take into account the activities carried out there and the frequency of people).

3.3.2 Subjective evaluation

At all stops the participants were asked to evaluate the soundscape, air pollution, and biodiversity with the help of a guided online survey. Also, they are requested to record a 30-s video with their smartphones and to provide some feedback about it. The collected videos can be used in the future to automate the objective evaluation of the soundscape and to obtain additional visual information from the stops.

By the end of the conscious walk evolves, when the participants are explained about the different topics, we aim to see how the subjective evaluation is more similar to the objective one. In case that objective and subjective evaluations are really far away, this would mean the descriptors are not appropriate.

4 Concept validation

4.1 Test site

The Barcelona's conscious walk was done in the framework of the "Setmana de la Ciència 2022" held in Barcelona.

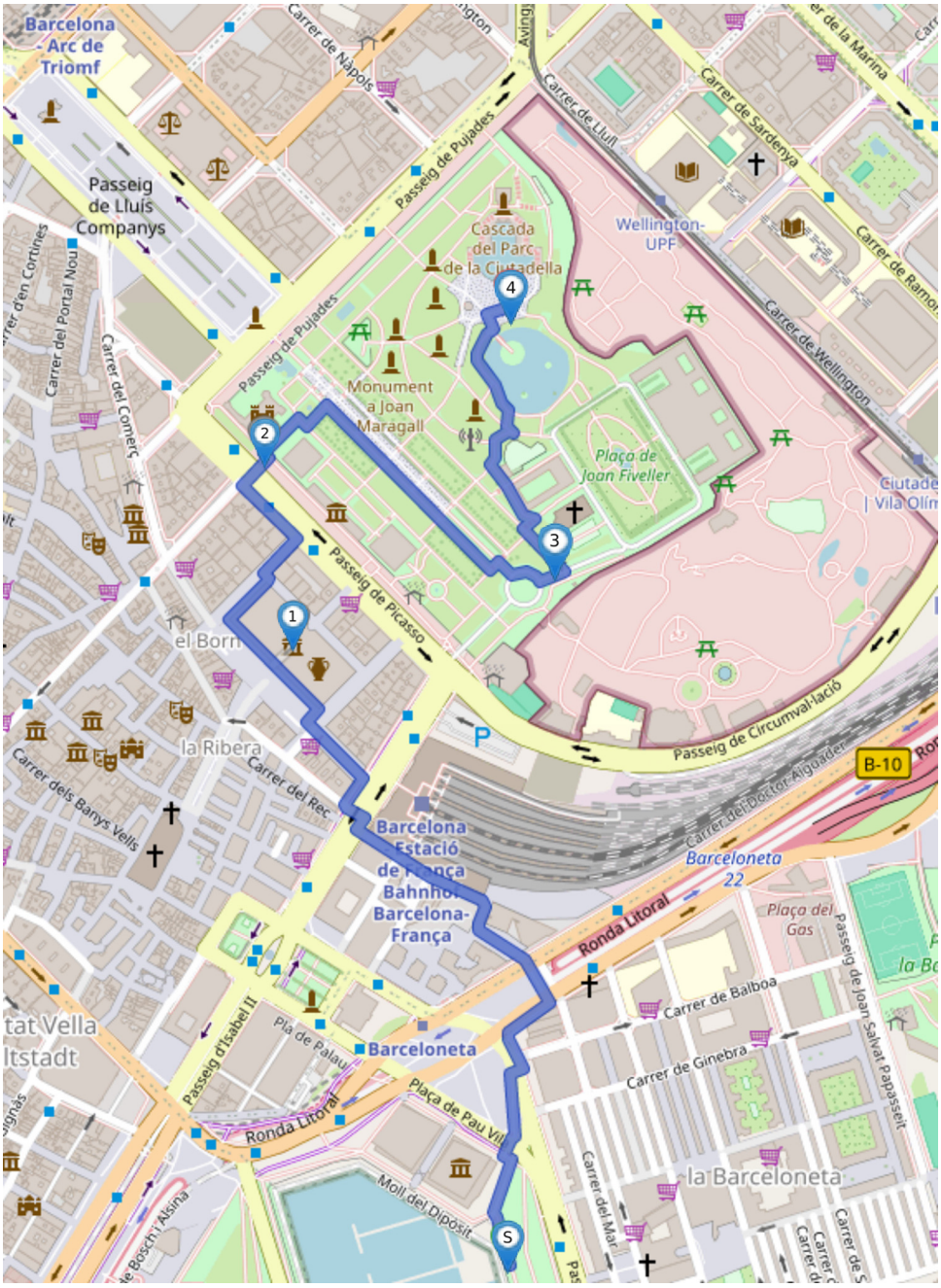

Figure 3: Conscious walk route map in Barcelona.

The walk was done on 17 November, 2022, starting at 5:30 pm. There were ten participants. The conscious walk path has been designed in a way that very different scenarios of the city were visited. Starting from the harbour, one of the main noisy and polluted areas of the city, the walkers move through wide avenues, isolated squares and two green parks. The evident contrasts in biodiversity and city uses in that spots allow the participants to easily be aware of their daily noisy and polluted surroundings. The route is detailed in Figure 3, containing also the starting and the four selected stop points. Figure 4 shows some images captured.

The main goals of the Conscious Walk were detailed to the participants in the starting point: the Harbour. Next, we walked to reach the following measuring point stop at Plaça Comercial, a pedestrian square in front of Mercat del Born (Figure 4(ii)). This place is characterized by being a very big and open space made mainly of concrete. No traffic inside, with few vegetation and very sparse urban

Figure 4: Images of all the points in the conscious walk: starting point, first stop, second stop, third stop, and fourth stop.

furniture. At the moment this is a very touristic place due to because of the archaeological remains of the area. The second stop was inside Parc de la Ciutadella, in the side of the entrance from Passeig Picasso (Figure 4(iii)). This place is characterized by being also a very big and open space but with a soil ground. No traffic neither inside, with quite a lot of vegetation and urban furniture. Here, we focused on the soundscape and biodiversity. The third stop was next performed in another location of the same park, close to a meteorological station used by the city council to measure air pollution (Figure 4(iv)). This place is characterized by being also a very big and open space but with mixed concrete and soil ground. There is a small road in this place. Some occasional traffic in the spot, with quite a lot of vegetation and urban furniture. This gave the whole team of participants a perfect scenario to discuss about background air pollution in the city and its dynamics. The fourth and final stop was next to a waterfall inside the park, which is known to be pleasant from a soundscape point of view despite presenting loud noise (Figure 4(v)). This place is characterized by being also a very big and open space with a soil ground. No traffic neither inside, with a big fountain, a lot of vegetation, and urban furniture. A meeting place for Barcelona citizens. Sound, biodiversity, and urbanism were again topics of discussion. At this stop, participants were again asked to record a short video and complete a questionnaire. Finally, a summary of the conscious walk was also made, sharing conclusions and impressions among the participants.

4.2 Preliminary results

In this section, an approximation to the preliminary results gathered both by citizens and by scientists are detailed.

4.2.1 Soundscape analysis

4.2.1.1 Objective analysis of acoustic events

In order to perform an acoustic event analysis, four audio recordings were captured to examine the acoustic events during each stop and correlate the findings with participants' questionnaire responses. The duration of the audio files varied at each stop, contingent upon the length of time spent after concluding the technical explanations. The maximum duration is about 6 min at the first stop, and the minimum duration is about 2.5 min at the second stop.

The event analysis of the manually annotated audio files is presented in Figure 5. The figure shows a longitudinal event analysis of the four stops, even though they can be checked individually as they were not recorded simultaneously. Every event type is shown with a different colour, and the width of the bars represents the event duration. The height of the bars shows the impact of the event with regard to the background noise.

Observing the figure, it can be seen that the most predominant sound categories detected at the first stop were Voice and Non-motorized vehicles (bicycles). The Voice category is present in the three remaining stops, specially in the third one, and with a significant decrease both in terms of occurrences and impact in the fourth stop. It is worth noting that, even if there are almost no Voice occurrences at the last stop, the steps of people walking were detected, revealing the presence of humans but in a quieter environment.

In contrast to the first predominant category (voice), almost no Non-motorized vehicles were detected in the three remaining stops. Another interesting analysis that can be obtained from Figure 5 is that the event that presents the highest impact is the Wind category in the last two stops; however, this event is not expected to be written as an annoying source from the users in the questionnaires that they filled in the first and last stop. This analysis enables a better comprehension of the answers to the surveys given by the participants, as it gives an overview of the soundscape at the time while the participants were completing the questionnaire.

4.2.1.2 Participant questionnaire answers

The manual labelled process can be compared to the answers of one of the questions of the survey. In one question, participants were asked to identify the sound sources present in their recordings from a set of categories: Road Traffic, Train, Place, Industry, Works, Commercial Activities, Leisure Activities, Neighbours, Pets, Birds, Water, and Vegetation. The results, segregated by stop, are shown in Figure 6.

Contrarily, to the manually labelled events, Road Traffic noise has been identified both in Stop 1 and Stop 4, with a higher presence in the last stop. Also, Commercial

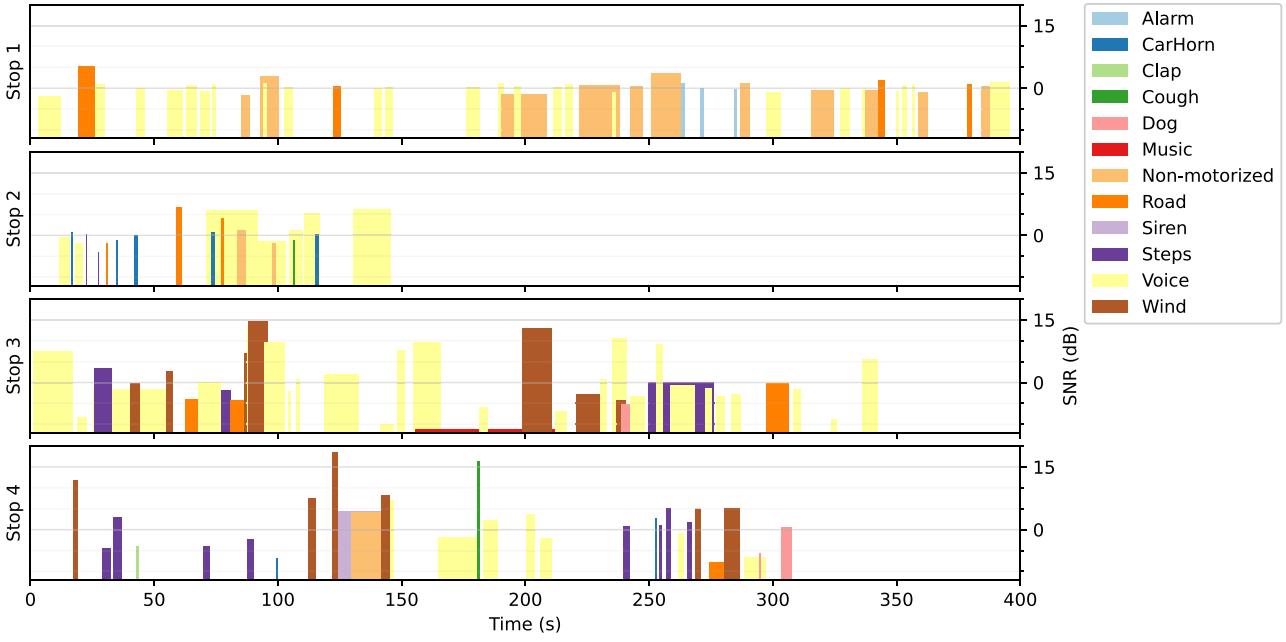

Figure 5: Distribution of acoustic events detected in the different stops. Different colours represent different events, and the amplitude of each event represents its impact on the sound environment.

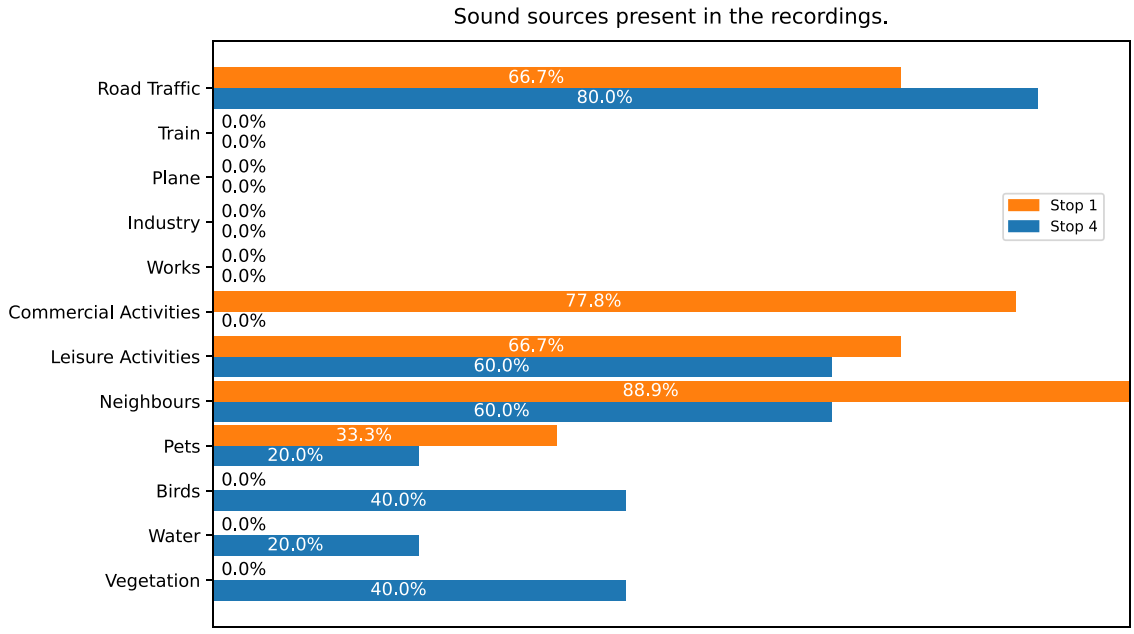

Figure 6: Comparison of appearance of the different sound sources in the taxonomy.

Activities were detected in the first stop but not in the last one, which makes sense as the first stop occurred in front of a market while the last stop occurred in a park. In this respect, at the last stop, some participants reported the audible presence of Vegetation. This observation may be attributed to the detected Wind, causing the movement of leaves from trees.

Another question that the participants were asked to answer *How well do the following adjectives describe the sound environment they had recorded?*, and were given a few adjectives and a Likert scale [66] with five possible answers (*Strongly disagree, Disagree, Neither agree nor disagree, Agree, Strongly agree*)[1] [56]. The results of these question have been aggregated and shown in Figure 7.

The correlation between the participants' responses and the adjective "Eventful" aligns with the events manually labelled in Figure 5. Specifically, there is a notable contrast in the number of events between Stop 1 and Stop 4, with Stop 1 exhibiting a higher frequency of events. It is conceivable that the relative scarcity of events in the last stop contributes to participants perceiving it as more "Pleasant" compared to the first stop.

Interestingly, although the last stop is characterized by fewer events, it has not been universally perceived as "Calm." This variance in perception might be attributed to the on-going movement of people walking, as evidenced by the numerous steps detected in the audio recordings. The presence of human activity, albeit in a quieter environment, may contribute to a nuanced perception of tranquility.

Furthermore, it is noteworthy that none of the stops have been reported as "Annoying" or "Chaotic" by the participants. This suggests a generally positive experience during the conscious walk, with participants not associating any of the locations with discomfort or disorder.

4.2.2 Air quality analysis

At this point, we present the preliminary results of the air quality perception analysis during the walk. On the one hand, the scientists determine the values of the descriptors according to their formal definition as described in Section 3.3.1. The evaluation is presented in Table 2. On the other hand, in Table 3, the results of subjective evaluation after analysing the survey are presented. Note that in the first stop, they evaluate according to their previous knowledge and at the last stop they evaluate taking into account all the explanations received during the conscious walk. Thus, at the beginning of the walk, some users are not aware of the background pollution and describe the intensity of use parameter as good, because they believe being far for cars is good enough. After the walk, they their impression and became aware of the background pollution. Although it is not conclusive, we can see in the results that the subjective and objective descriptors at the first stop are

1 https://www.iso.org/standard/75267.html Last accessed on 14/01/2024.

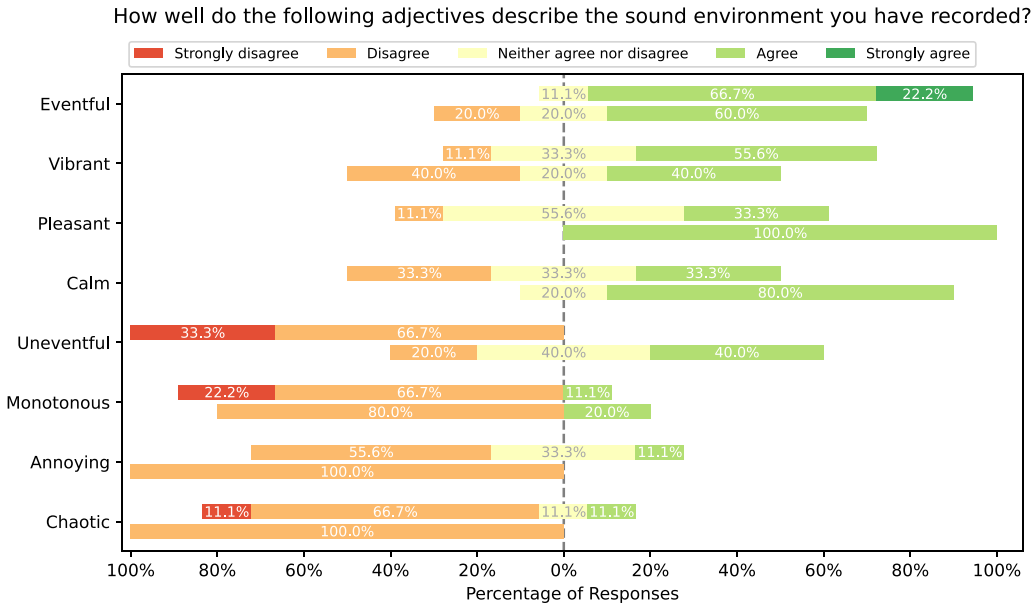

Figure 7: Adjectives given by the participants to the soundscape of the first and fourth stop. Every adjective has horizontal bar for the answers of the first stop and, under it, a horizontal line for the answers of the fourth stop.

Table 2: Objective air quality perception descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Intensity of use	Fair	Fair	Fair	Fair
Habitability	Good	Good	Good	Good

Table 3: Subjective air quality perception descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Intensity of use	Good	Good	Fair	Fair
Habitability	Good	Good	Good	Good

slightly different but by the end of the walk, they are fully coincident.

4.2.3 Biodiversity analysis

At this point, we present the preliminary results of the biodiversity analysis during the walk. The scientists determine the values of the descriptors according to their formal definition (Table 4), while the participants of the session assign their values according to their impressions (Table 5). It is important to note that at the first stop they evaluate according to their previous knowledge and at the last stop they evaluate taking into account all the explanations received during the conscious walk. We can see in the

Table 4: Objective biodiversity descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Habitat complexity	Poor	Fair	Good	Fair
Resources	Poor	Good	Good	Good
Intensity of use	Bad	Fair	Fair	Good
Area	Poor	Good	Good	Good

Table 5: Subjective biodiversity descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Habitat complexity	Poor	Good	Good	Fair
Resources	Poor	Good	Fair	Good
Intensity of use	Bad	Good	Fair	Good
Area	Fair	Good	Good	Good

results that the subjective and objective descriptors are slightly different, more at the beginning of the walk. Those descriptors are more complex and depends on more indices than the air ones for example. This could be an explanation of the difference. In any case, more tests need to be done, to validate this approach.

4.2.4 Human comfort

As in the previous subsections, the scientists determine the values of the descriptors according to their formal

Table 6: Objective human comfort descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Intensity of use	Fair	Good	Fair	Good
Habitability	Fair	Good	Fair	Good
Contextual	Good	Good	Good	Good
Activity	Fair	Good	Good	Good

Table 7: Subjective human comfort descriptors

Descriptor	Stop 1	Stop 2	Stop 3	Stop 4
Intensity of use	Good	Good	Fair	Good
Habitability	Good	Good	Fair	Good
Contextual	Good	Good	Good	Good
Activity	Fair	Good	Good	Good

definition (Table 6) while the participants of the session assign their values according to their impressions (Table 7). Although it is not conclusive, we can see in the results that the subjective and objective descriptors are generally consistent, with an exception at the first stop. This may be due to the nature of the place, a big square with monumental buildings that at first sight look good but do not fulfill all requirements of comfort. The authors believe the human comfort descriptors are really close to the subjective feelings of citizens.

5 Discussion

The development of conscious walks in Barcelona as part of the "Setmana de la Ciència 2022" has yielded promising results, particularly in understanding and addressing environmental sound within urban spaces. These walks aimed to achieve dual objectives: raising citizens' awareness about the city's infrastructure and challenges, and validating a set of descriptors for comprehensive city characterization.

The conscious walk, crafted to address various urban issues, especially soundscape, allowed participants to actively engage in identifying and evaluating acoustic environments. Murray Schafer's concept of soundwalking, introduced in the 1970s, served as a foundation, emphasizing the importance of listening to the environment during excursions. Unlike traditional soundwalks, our conscious walks extended beyond the acoustic domain, encompassing four axes: soundscape, air quality, biodiversity, and human comfort.

The descriptors proposed for Environmental Noise and Soundscape provided a nuanced understanding of the urban auditory experience. Intensity of Use, Habitability, and Activity were key factors influencing participants' perceptions. The distinction between Motorized and Non-Motorized events further enriched the evaluation, offering insights into the diverse sound sources within urban spaces.

Preliminary results from the air quality analysis demonstrated the dynamic nature of participants' perceptions. The initial subjective evaluations, often influenced by preconceived notions, evolved as participants progressed through the conscious walk. The alignment of subjective and objective descriptors toward the end of the walk highlighted the role of environmental awareness in shaping perceptions.

The analysis of biodiversity, a complex and multifaceted aspect, revealed interesting patterns in subjective and objective assessments. While some disparities existed initially, they tended to converge as participants gained insights during the walk. Habitat complexity, resource availability, and the impact of human activities emerged as critical factors influencing biodiversity perceptions.

Human comfort, as assessed through both subjective impressions and objective descriptors, displayed overall consistency. The focus on Intensity of use, habitability, contextual factors, and activity provided a comprehensive framework for evaluating the comfort of urban spaces. The minor discrepancies observed, particularly in the first stop, underscored the importance of considering the specific nature of each location.

6 Conclusions

In conclusion, the preliminary outcomes of conscious walks underscore the effectiveness of this methodology, particularly in the realm of environmental sound assessment. Participants' active engagement in identifying and categorizing sounds, coupled with discussions on the acoustic environment, contributed significantly to a more profound understanding of urban soundscapes.

The discussions at each stop demonstrated the utility of a collaborative approach, where citizens not only became more aware of their surroundings but also actively contributed to the generation of subjective environmental indices. As we refine our methods and conduct further conscious walks, we anticipate an even closer alignment between subjective perceptions and objective measurements, especially in the domain of environmental sound.

These findings highlight the potential of conscious walks not only as a tool for comprehensive urban sustainability assessment but also as a means to foster citizen participation and strengthen the link between scientific research and everyday urban life. The emphasis on environmental sound within this framework signifies a promising avenue for future research and community engagement in shaping more harmonious and sustainable urban environments.

The data collected by the audio recorder were correlated with participant comments and responses. Participants' observations align notably well with the recorded events and subsequent data analyses, which included manual labelling. It is noteworthy that, despite no stop being reported as "annoying" or "chaotic," the wind category exhibited a significant impact in the last two stops, although it was not perceived as a bothersome source by the participants.

Regarding air quality, the correlation between objective and subjective data reveals a progressive increase in participants' awareness of air quality throughout the activity. The alignment of subjective descriptors in stops 3 and 4, compared to the objective ones, is remarkable. Concerning biodiversity analysis, the correlation between objective data and subjective perceptions highlights complete alignment only in the last stop, demonstrating the complex and multifaceted nature of perceptions regarding biodiversity. However, the correlation between human comfort descriptors reveals overall coherence, emphasizing the importance of considering the specific nature of each location in comfort assessment.

At this stage of our project, a pending task is the development of a procedure to extract correlations between descriptors. These identified correlations will serve as valuable tools for city managers, enabling them to assess the multifaceted and holistic impact of their actions on various frameworks; this analysis is scheduled for completion in the coming months. Furthermore, videos uploaded by citizens have the potential to offer valuable insights through the analysis of acoustic events detected by an automatic acoustic event detection algorithm, as well as from the visual information obtained through automatic video segmentation.

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