Improved acoustics for semi-enclosed spaces in the proximity of residential buildings

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ABSTRACT

Continuous urban densification exacerbates acoustic challenges for residents of housing complexes. They are confronted with higher noise immission from railway, road traffic, construction, as well as louder neighborhood acoustic environments. Thereby, not only noise immission indoors is associated with stress, annoyance, and sleep disturbance, but also the immediate outdoor living environment (e.g., courtyards, private gardens and playgrounds, etc.) can be acoustically unpleasant and annoying. This non-exhaustive narrative review paper elaborates on the role of a number of design parameters on improving the quality of the outdoor soundscape of housing complexes: architectural and morphological design, facade material characteristics, balconies, greenery, ground, background sounds, and several factors concerning quality of sounds (e.g., multisensory perception, holistic design, the relevance of space, context, social factors, co-creation, etc.). It mainly covers literature including both acoustical (e.g., sound pressure level and room acoustical parameters) and human/perceptual (e.g., comfort and annoyance) factors. A series of recommendations are presented here as to how the semi-enclosed outdoor spaces in the proximity of residential complexes can be acoustically improved.

1. INTRODUCTION

Densification of urban living areas has been leading to acoustic challenges. It is well-established that noise control solutions alone do not yield to satisfactory results [1–7]. Implementation of too many noise abatement strategies might affect the perceived living space dramatically [6]. From a holistic point of view, it is necessary to improve the perception of the physical environment in a smart multimodal design, considering its aesthetic, social and acoustical dimensions [6–9].

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This paper focuses on the combined idea of "soundscape" and "sound of the city" in a small scale, namely for immediate outdoor environments of housing complexes (e.g., front, back or inner yards and gardens). It encompasses knowledge from conventional environmental and building acoustics, as well as soundscape research, since improving acoustic comfort not only depends on traditional noise abatement methods, but also on enabling a relatively pleasant acoustic environment [10].

So far, aspects related to acoustic quality in either indoor or outdoor spaces have been addressed mostly as independent issues. Specifically, for indoor contexts, efforts are focused on achieving acoustic comfort (room acoustics) and preventing noise intrusion from external sound sources (environmental and building acoustics). As for outdoor contexts, less is known about the acoustic quality in "buffer" areas in the proximity of buildings and/or residential complexes located at the interface between the public and private spheres.

A further goal of this paper is to list research gaps. That is, the authors would like to encourage the urban and environmental acoustic community to investigate open aspects of "outdoor" acoustic environment from a "subjective, perceptual" perspective, linking physical/acoustical measures to psychological constructs, such as acoustic comfort, pleasantness, noise annoyance, and so on. With this background, two main criteria have been adapted for the choice of the literature reviewed in this paper. Firstly, only points relevant to outdoor spaces in the immediate proximity of residential buildings are discussed here. Secondly, the main focus was on papers including perceptual variables (i.e., not solely based on sound pressure level, SPL, and other acoustic measures).

2. FACTORS AFFECTING THE ACOUSTIC ENVIRONMENT

2.1. Architectural and morphological design

As within indoor spaces, the shape and placement of elements and surfaces affect sound propagation in outdoor environments. This applies to elements at a smaller scale, such as the shape of facades or roofs and at a larger scale, considering the configuration and placement of buildings. Since no studies were found directly linking subjective perception of the acoustic environment to the input variables roof shape, facade shape design, street/district configuration, etc., this paper will not discuss this point in detail. Nevertheless, as noise SPL attenuation is considered to reduce indirectly and typically noise annoyance, the following exemplary results are presented here.

Many cities include a large network of street canyons, which have become an element of interest in various studies with regards to the acoustic environment. One of the parameters that has been found to have important influence on the noise propagation is the profile of the building facades along the canyon [11, 12]. The building height in relation to the width of the street canyon (H/W ratio) has been found to influence the noise attenuation along the canyon [13, 14]. In addition, an increase in both reverberation time (RT) and early decay time (EDT) was found at an increased H/W ratio [14]. In the same direction by means of in-situ measurements, a comparison of a street canyon (i.e., buildings on both side of the street) and a street with buildings on only one side – and an open area with greenery on the other side – showed higher RTs for the street canyon at all frequencies and distances with a maximum RT difference of 1.8 s at 500 Hz [15]. Moreover, in comparison to the one-sided building reflections, the street canyon exhibited lower values of the rapid speech transmission index, RASTI [15]. It should be noted that speech intelligibility measures, such as speech transmission index (STI), rapid speech transmission index (RASTI), speech intelligibility index (SII), and extended speech intelligibility index (ESII) can be useful in terms of the use of public address systems as well as soundscape applications and acoustic comfort evaluation [15–20]. Thereby, higher speech intelligibility is preferable [17–20]. Additionally, Yang et al. [15] showed that compared to simulated semi-free field, an SPL increase of up to 5 and 8 dB was observed for the one-sided building reflections and two-sided multiple reflections (i.e., street canyon), respectively [15].

Gaps between buildings can provide about 2–3 dB extra sound level attenuation, especially in the vicinity of the gap [13]. Furthermore, the effect of roof shape on traffic noise propagation from a street or a street canyon and to a nearby facade or courtyard has been investigated with the primary concern of minimizing noise levels at the shielded side of buildings. The shape of roofs and green roofs has been shown to have important influence on noise propagation [21–23]. Differences in noise shielding effect of various roof types were found to exceed 10 dBA, averaged over the whole facade [21].

2.2. Facade material characteristics

Due to the critical role that building facade performs in transmitting or reflecting of environmental noise, it seems to be one of the most investigated topics in the literature [24]. In the presence of multiple buildings in urban spaces – e.g., in the case of street canyons or inner yards of housing complexes – strong (and multiple) facade reflections can lead to increased reverberation time (RT) and SPL for noise sources from the environment, which in turn affects the spatial impression and noise annoyance [10, 15, 25].

In order to ameliorate the acoustic environment (indoor and outdoor), there are a number of noise reduction methods to employ in facade acoustics such as using facade absorptive material, scattering facade structure, adding control components, applying new designs, etc. Use of acoustic absorbing materials on building facades has been shown to have a significant effect on both reducing noise levels and annoyance ratings [24–28], even though in long-term, their durability could be problematic especially when exposed to the environment on a building facade surface [24].

Yang et al. [15] mentioned that the presence of buildings induces many complicating acoustic effects such as multiple reflections, diffraction, and diffusion, which depend, among others, on the material property of building facades. In general, buildings in urban spaces seem to contribute to increases in noise levels and RT due to multiple reflections which are influenced by various factors such as street width and acoustic characteristics of building facades and ground surfaces, including absorption, diffusion, and diffraction [15].

In a psychoacoustic laboratory experiment Calleri et al. [29] investigated effects of absorption and diffusion facade materials on the perceived wideness. In the course of the auralization, SPL and RT were calculated in the room acoustic simulation software ODEON. Three independent variables were considered: weighted sound absorption coefficient, α_w, changed in three steps (0.05, 0.35, and 0.70), scattering coefficient, changed in three steps (0.1, 0.5, and 0.9), and source–receiver distance, changed in two steps (25.5 and 51.0 m). The SPL was decreased consistently with increasing α_w [29]. For the longer source–receiver distance (i.e., 51.0 m), the SPL decreased with increasing scattering coefficient. The RT decreased with increasing α_w or increasing scattering. Furthermore, mean perceived wideness decreased with increasing absorption α_w. Use of diffusing materials did not have a significant effect on perceived wideness [29].

In a series of psychoacoustic laboratory experiments, Taghipour et al. [10] investigated effects of facade absorption on short-term acoustic comfort in presence of everyday life sounds in virtual inner yards. In one experiment, different portions of facade surfaces were covered with reflective or absorptive materials. In two other experiments, a unique portion of facade surfaces was covered with materials exhibiting different values of α_w from highly reflective to highly absorptive. The results of all three experiments showed consistently that reflective facades and moderate absorption were associated with the lowest and the highest acoustic comfort ratings, respectively. Two much absorption was not found to be more comfortable than moderate mid-range absorption. Taghipour et al. [10] concluded that using absorbing materials on the facade would improve acoustic comfort, but only up to a point, beyond which the effect on acoustic comfort would saturate or drop. That is, whereas some absorption is desirable, too much absorption – which also causes higher costs – might not yield further acoustic improvement, or may even decrease it, presumably because the inner yard would lose its room acoustic quality, i.e., its roominess [10].

In accord with findings by Yang and Kang [30] and Yang et al. [15], a further analysis of the experimental data with respect to L_{Aeq} showed that, in general, acoustic comfort decreased with increasing L_{Aeq} (associated with reflective facades) [10, 20]. This relationship was especially observed in the case of relatively unpleasant stimuli [10, 20], as also reported by [30].

Gisladottir et al. [25] showed a similar facade behavior with respect to annoyance from car pass-bys in front of or through housing complexes. Direct comparisons (three alternatives forced choices) led to a clear preference for sound absorptive facades (i.e., least annoying). While reflective facades were ranked as the most annoying case, sound diffusive facades were ranked in between [25].

Kang [31] showed that replacing diffuse reflective boundaries in street canyons with geometrical reflective (i.e., smooth) boundaries led to considerably less sound attenuation along the length, typically by 4–8 dB with a source–receiver distance of 60 m. Also, the RT was significantly longer, typically by 100%–200%. With moving traffic, about 2–4 dB extra attenuation could be obtained by using diffuse boundaries for observers not too close to the source [31]. Kang [13] showed that over 2–4 dB extra attenuation can be obtained either by increasing boundary absorption evenly or by adding absorbent patches on the facades. Furthermore, Hornikx and Forssén [32] have found that the use of absorptive facade materials in a shielded canyon could lead to SPL reduction for various observer positions within the canyon. Kang [31] suggested that not only the building facade, but also street furniture, such as trees, lampposts, fences, barriers, benches, telephone boxes, bus shelters, and so on, can be effective in reducing noise.

In summary, acoustically, reducing strong reflections by means of absorptive or diffusive facade materials is associated with decreased RT, EDT and SPL. Psychoacoustically, this was reported to decrease noise annoyance and increase acoustic comfort as well as speech intelligibility.

2.3. Balconies

Balcony design and material – typically in interaction with facade design and material – can be effective in mitigating noise immission [33]. Tang [34] reviewed complex behavior of facade balconies with a variety of designs, whereby acoustically absorbing balcony facades were found to be significant or insignificant based on their position and angle [34, 35]. For example, multiple rectangular balconies were found to be problematic reflectors [35]. With a noise source on the ground or from the roadway, generally, balconies on a building facade provide significant acoustic protection to the areas beyond them [34, 36]. This protective effect is, however, partially canceled by reflecting balcony ceilings [10, 37, 38]. In psychoacoustic laboratory experiments with virtual inner yards and in the presence of acoustically reflecting building facade materials, using acoustically absorbing materials on the balcony ceiling was found to be associated with increased acoustic comfort [10].

Alongside streets, building facade and balcony absorption was found to reduce immited SPLs from traffic noise [33,39] and leisure noise [40]. By combining the use of facade absorption and balcony geometrical design modification, building facades seem to be effective noise mitigators [33]. Badino et al. [40] have stated that adding sound absorbing materials on a geometrically optimized facade could achieve a noise reduction of up to 10 dB in the A-weighted SPL in street canyons. Furthermore, inclined parapet was found to provide equivalent reduction in SPL as insulation treatments [36].

2.4. Greenery

Greenery possesses some sound absorbing and diffusing characteristics. On the one hand, soil and trunk layer affect noise propagation at low frequencies. On the other hand, leaves affect noise propagation at high frequency [41, 42]. However, from a pure acoustic perspective, a belt of trees and shrubs cannot address noise screening aims unless by a rather high biomass density, limiting the spaces between trees, and enhancing the diameter of trunk [41, 43]. Significant reduction by greenery on the facade can only be achieved with a porous green wall (rather than only leafy Ivy) [42].

More importantly, greenery improves the environment aesthetically, as well as ecologically. In order to benefit from possible vegetation's advantages, it needs to be designed and applied thoughtfully [44]. From a perceptual perspective (of the dwellers), greenery has a special, first-line place among parameters effecting noise immission, even though the SPL reduction by greenery might not be as effective as by other parameters [44]. Attractiveness and acceptance of greenery among public is not only because of its visual aesthetics, but mainly because it provides an appropriate space of natural presence and pleasant – even partially masking – sounds, such as birds, moving leaves etc. [41]. This natural presence, not only improves the acoustic pleasantness, but also offers high restorative quality [41].

2.5. Ground

Since tire noise is one of the dominant noise sources in the urban environment, use of silent asphalt is considered to reduce noise emission. While road areas often cover a large part of the urban layout, also other ground surfaces influence sound propagation and, hence, the urban soundscape. This includes ground surfaces within courtyards, green spaces and other traffic free zones.

In traffic free urban areas, such as parks, corridors, and generally in the field of building acoustics, sound generated frequently by footsteps is widely considered as a source of irritation or discomfort. Aletta et al. [45] investigated possible solutions for the choice of ground material of footpaths in urban parks and their effect on people's soundscape. The application of four ground materials gravel, wood, stone, and grass was investigated in two laboratory experiments, where the use of different materials was found to have significant effect on perceived noise annoyance and soundscape quality. Use of grass was associated with the best soundscape quality while gravel was associated with the worst.

Several studies have been performed to investigate the influence of ground design on SPL. Although not directly shedding light on the subjective evaluations of diverse design actions for ground surfaces, SPL are a part of the overall acoustic experience. Kim et al. [42] investigated how the sound field within a courtyard with reflecting surfaces can be altered with landscape designs. Use of highly absorptive vegetation on ground alone was shown to be insignificant for the moderation of speech levels in courtyards [42]. Similarly, advantage of applying grass rather than asphalt on the ground in a shielded canyon has been investigated by Hornikx and Forssén [32]. The results indicate that changing to grass surface does not provide large further reduction compared to increasing facade absorption. A similar result is obtained by Magrini and Lisot [46] , who have investigated the influence of absorbent paving and green areas within street canyons instead of existing road and sidewalk areas. The design changes were not found to affect noise levels near the facade significantly. Despite these findings, from a multimodel perception perspective, it is to assume that use of vegetation on the ground might improve the experience in the environment considerably.

Ground effects should be exploited for noise reduction along larger roads [47]. While it might be difficult to achieve as much reduction as with traditional noise barriers, there are other advantages such as preventing impassible divisions and adding "green" to the urban environment. An insertion loss of up to 10.5 dB was found by replacing hard ground with soft ground near the road area. Although primarily focusing on model validation, a study by Van Renterghem and Botteldooren [48] pointed out the important advantage of considering terrain shape around highways for road traffic noise mitigation. This should be done in combination with controlling ground properties.

2.6. Background sounds

Introducing additional background sounds in the noise-polluted sound environment would lead to even higher SPL. Despite that, certain background sounds seem to have a positive influence on the perception of the soundscape [49–54]. Relatively pleasant background sounds are shown to be associated with increased acoustic comfort [10] and decreased noise annoyance [54]. More specifically, it has been suggested that sounds of water features, birds, or natural vegetation could improve the quality of the (acoustic) living environment [51, 52].

Background sounds might improve the acoustic quality of urban noisy soundscape [49, 50, 52, 53]. For example, natural water features in urban environments were reported to reduce the loudness of road traffic noise [50, 53] and of wind turbines [49]. They were further reported to reduce annoyance from the road traffic or wind turbines [49,52]. Jeon et al. [52] reported that among nine different background sounds, "water stream" and "waves of lake" were found to be more preferable than other sounds to be used as mixed background sounds for road traffic noise as well as for construction noise. Furthermore, Watts et al. [55] reported that water sound samples containing high low-frequency energy were judged as relatively unfavorable compared to water sounds at higher frequencies.

There are three positive aspects regarding the effect of pleasant background sounds on the soundscape: First, partial auditory masking of noise sources; second, attention distraction from the noise sources; third, overall improvement of the soundscape quality.

Auditory masking is defined as the process by which the threshold of audibility for one sound is raised by the presence of another (masking) sound [56]. The masker might either make the maskee inaudible or lead to its partial masking [57,58]. The masking ability depends on the temporal and spectral characteristics of the masker and maskee, as well as the signal-to-noise ratio (SNR) between them [57, 58]. There is an asymmetry in the masking ability of tonal and noise-like sounds, whereby noise-like sounds seem to be more effective maskers than tonal sounds [59–61]. The terminology "noise-like" refers to narrowband or broadband noise with rather flat spectra and low degree of tonality.

Sounds of water features or natural vegetation (in light wind) typically possess relative broadband spectra. This enables them to be effective maskers. For them to be effective auditory maskers of the environmental noise, however, they have to exhibit a certain SPL (or a certain SNR) [57, 58], in the case of which it might be inaccurate to label them as "background" sounds [54]. Luckily, in order to psychoacoustically reduce annoyance from environmental noise, it seems that a partial masking would be satisfactory [54, 62]. That is, they do not necessarily have to make unwanted sounds (i.e., environmental noise) completely inaudible.

Perhaps due to its temporal variation and tonal characteristics, sound of singing birds was found to be a less effective masker than broadband natural sounds of a water stream, deciduous vegetation, and coastal breaking waves [49]. Nonetheless, background bird sounds were found to improve pleasantness more strongly than background water features [50]. This brings us to the second positive aspect of pleasant background sounds: background sounds, their presence, and their varying temporal structure can play an important and positive role in attention distraction from noise [50, 54].

Yang et al. [15] suggested that further psychoacoustic parameters, namely fluctuation strength, sharpness, and loudness were the three key indicators for characterization of sounds in soundscape. Taghipour et al. [54] hence argued that not only different background sources (water, birds, vegetation, etc.) might influence the perception of the foreground environmental noise differently, but also the temporal structure [49, 63], spectral structure [49, 59, 61], and the level [49, 52, 53, 64] of the background sound could be important parameters for the altered perception of noise.

When considering a holistic approach [65], also including aesthetics (i.e., audiovisual perception), a third argument is to be made that those pleasant sounds associated with nature are likely to generally improve the soundscape [8, 66]. Up to a certain noise level (i.e., below the levels causing direct auditory or other health issues), the content and context of the sound environment are at least as important as its SPL. Thus, recommended noise limits could potentially be relaxed in the case of the presense of positive or pleasant sounds that lessen annoyance [8].

Enabling pleasant human interactions or music can improve the liveliness of the acoustic scenery [10,30,51]. While music from cars does not seem to be favorable, presence of live music tends to have a positive/pleasant effect on the judgment of the acoustic environment [30, 51]. Sounds of joyfully playing children in a virtual inner yard were reported to be associated with higher acoustic comfort ratings than a bouncing basketball, a crying baby, a moving doll's pram or even everyday conversations (which were rated as second favorite) [10].

It has been argued above that adding pleasant sounds can improve the soundscape in outdoor living environments. While natural sounds of particular water features, singing birds and vegetation seem to be typically calming and helpful, pleasant music and human interactions can improve the degree of liveliness. Considering the fact that any addition of sounds would increase the SPL, the background sound mixture added to a particular acoustic environment should be chosen wisely.

3. NON-ACOUSTICAL FACTORS AFFECTING THE SOUNDSCAPE

3.1. Holistic discussion

From a holistic point of view, the overall residential satisfaction influenced by the design quality of residential outdoor environments would, in turn, influence the perception of the acoustic environment (e.g., noise annoyance) [67,68]. Hereby the idea of soundscape is not to be mistaken with the "acoustic environment" (i.e., the sound mixture surrounding and received by the observer, including any acoustically modifying effects of the environment) [69]. The soundscape considers the acoustic environment, but also non-acoustic elements, such as the listener's context, preference, control, the visual setting, and social factors, as well as how these elements interact with the acoustic environment to influence the listener's multisensory perception [8, 69].

The soundscape approach has generally been successful in shifting the discourse about the quality of the acoustic environments from a source-oriented to a listener-oriented paradigm for public spaces [70]. The research field as a whole is going through a standardization process, seeking consensus on frameworks, definitions and methodologies [71, 72]. Such efforts by the international research community resulted in the ISO 12913 series [2, 3, 73] on soundscape, developed by the ISO/TC 43/SC 1/WG 54 – "Perceptual assessment of soundscape quality". The first document of the series, ISO 12913-1 [2], recognizes the importance of "context" for how people experience and perceive acoustic environments. Context itself is seen as embedding "the interrelationships between person and activity and place, in space and time" and has the potential to "influence soundscape through (1) the auditory sensation, (2) the interpretation of auditory sensation, and (3) the responses to the acoustic environment" [2]. Context thus includes both tangible and intangible aspects and implies that non-acoustic factors are just as important as acoustic ones in shaping the soundscape of a place.

3.2. The Relevance of Space – "the listener's space"

Analyzing sound in the context of built environment implies an understanding of space. Spatial concepts referred to in spatial sciences and spatial planning go back to the so-called "spatial turn" in social and cultural sciences [74]. The French sociologist Lefebvre [75] was thereby a highly influential figure. He understood the space as social process shaped by individuals, conceptualisations, perceptions, and everyday lives [76].

Speaking of le perçu (perceived space), le conçu (conceived space) and le vécu (lived space) [75], he introduced a threefold understanding of space in physical, mental and social terms. In this model, space is a category exploring the relation between physical-material, psychological-individual and social-common elements, leading to differentiated as well as changeable interpretations [76].

Among many other further developments Lefebvre's concept of space was applied in the context of empirical cultural science to different fields. Rolshoven [77] gave it an often-cited form, which is operationalized for empirical research. In her "space triad" concept Rolshoven refers to physical-measurable, perceived-lived, and representational dimensions of space (*gebaute, erlebter und Repräsentationsraum*). This can be exemplified with Müske's empirical study on the sounds of Flensburg harbour [78] which showed that people living at the harbour experienced its soundscape as maritime, picking up seagull cries and ship horns, although the (physically) dominant sound derived from car and truck traffic (noise) [78]. Here the representational dimension, a certain interpretation of "maritime space" overrides the physical "reality" of SPLs. This characterizes the specific "lived space" of Flensburg Harbour.

3.3. Context: Sonic effects and listening (Quality of sounds)

The quality of sounds that reach people in an urban environment and the way they affect them have been described in numerous publications [78]. As particularly influential the comprehensive account by Augoyard and Torgue [79] and their interdisciplinary team at CRESSON is described here in more detail. Augoyard's work focuses on the ordinary situated sound experience and understands the sounds of a city as urban sound environment that produces "sonic effects." The term "sonic effect" was first developed in social sciences to understand the interaction of environment, milieu, and soundscape and to apply it to constructed space. The motive of the modal approach of the research at CRESSON was to provide answers to the question "how things occur" [79].

The work not only offers an in-depth theoretical exploration, but in particular a systematic description of more than 80 sonic effects, divided into elementary, compositional, mnemo-perceptive, semantic, psychomotor, and electroacoustic effects. The effects listed are described on the level of physics and applied acoustics, as well as from the perspective of architecture, physiology of perception, sociology, musical and textual aesthetics, and idioms. As an example, the "cut out" effect as compositional effect describes an abrupt change from one sonic state into another, a drop of intensity, leading to an obvious change in the surrounding sound ambience [79, 80].

From the described knowledge of sonic effects, both negative and positive influences of sound sources and their propagation characteristics can be gathered and should be taken into account.

3.4. Individual preferences and control

Individual dispositions and personal traits can play a role in how acoustic environments are perceived, especially when these are considered in the context of residential spaces. Some basic demographic factors such as age and gender have previously been shown to affect responses to different sound sources. For instance, it was reported that different age groups being interviewed resulted in differences in evaluating sounds; namely, with increasing age, people tended to be more favourable towards natural sounds, and sounds related to human activities, whilst younger people tended to be more tolerant towards music and mechanical sounds [30].

Regarding presence vs. lack of music, Aletta et al. [9] reported no significant difference in the number of subjects stopping in an open public space, while music could positively affect length of people's stay. Considering more specific soundscape dimensions such as pleasantness and eventfulness (see: Axelsson et al. [81]), Erfanian et al. [82] reported about a large-scale soundscape survey that included data related to psychological well-being, age, and gender. Preliminary results indicated that a positive psychological state was often associated with increased soundscape perceived pleasantness, and even if to different extents, age and gender could also modulate pleasantness and eventfulness, depending on urban locations and types of sound sources. Besides demographic factors, personal attitudes towards a specific sound source or soundscape as a whole, will have an effect on how people respond to environmental sounds [62, 83–85]. This has been showed to be particularly the case when the private and domestic/residential domain is affected [86, 87]. Furtheremore, Aletta et al. [9] have suggested adding music could enhance capability of the liveability and the pleasantness, as well as positively impact the psychological and physiological well-being in a transit or waiting place.

Previous experiences and/or preconceptions can also moderate people's responses to environmental sounds; this has been approached in soundscape studies in terms of familiarity and expectation dimensions. Bruce and

Davies [83] showed that in public spaces, participants expected certain sound sources to be present. Instead, considering soundscape as a whole, such perception was found to be mostly driven by prior experiences of similar spaces by users.

The degree of control people have over their own exposure to environmental sound can lead to more positive or negative soundscape outcomes, accordingly. Once again, this becomes even more relevant if the exposure is taking place in residential contexts where intrusion indoor from outdoor noises is by default less accepted [8].

3.5. Visual settings and multisensory perception of sounds

It has been shown that multisensory perception affects the acoustic perception of sounds and environmental noise [88–90]. That is, the multimodal (e.g., audio-visual) setting is crucial. A helpful visual design can reduce annoyance ratings and stress ratings associated with noise sources [67, 91]. Furthermore, pleasant sounds associated with nature/vegetation are likely to generally improve the soundscape [66].

3.6. Social factors and co-creation

All themes mentioned so far converge towards asserting that management and design for the soundscape of outdoor living environments should be approached holistically; this implies both different perspectives (e.g., source-oriented vs. listener-oriented) and different scales of design and intervention (e.g., building-, urban-, and planning-scale). For such processes/changes in the built environment to succeed, participation of all stakeholders is crucial [92–95]. In this relation, not only participation but also a mutual language and understanding of the decision making and thought processes in play are important [10, 96]. From the designers point of view, it is highly valued if the experts involved can adjust and filter their knowledge to fit practice at different design stages [97].

Noise control and soundscape studies alike have been advocating for implementing a co-creation philosophy in urban sound planning, however, empirical evidence of its benefits in this specific field of application is still scarce. A recent case study by Van Renterghem et al. [98] applied a methodology to embed sound-related considerations in an urban planning process related to a major infrastructural project of the city ring road in Antwerp (Belgium). The co-creation approach led to noise experts collaborating with the spatial planning teams and residents of the neighbouring areas [98].

4. CONCLUSIONS

This paper reviewed a non-exhaustive list of reports dealing with acoustical and non-acoustical factors affecting soundscape in outdoor living environments. The authors found a partial disconnect between pure physical/acoustical reports and reports including human perception data. A lack of perceptual data was especially found for the effects of “ground”, “balconies” as well as “architectural and morphological design.” A pure acoustical approach has the disadvantage that only an indirect effect of the parameter under review on human perception can be derived through SPL or RT60 and so on. As auralization techniques make it possible to run psychoacoustic experiments, the authors suggest that such indirect inferences can be compared to the results of direct investigations in laboratory psychoacoustic experiments. An alternative approach would be in-site acoustic investigations accompanied by perceptual questionnaires [3].

This review laid out clues as to how different factors individually influence the soundscape of outdoor spaces in proximity of residential buildings. One of the major areas for future studies is to investigate the combined effects of the above-mentioned factors on the soundscape quality. That is, it is crucial for soundscape evaluation and design to gain more insight into the weighted effects of these factors, when interacting with each others.

The authors would like to emphasize that higher qualities for shared outdoor spaces are necessary to create acceptance for further inward urban development. An improvement of the noise situation is an essential factor to increase the acceptance of densification [99]. Complex public spaces require complex approaches that incorporate interdisciplinary local knowledge. In order to obtain better acoustic qualities it is crucial not only to consult analyses and measures of acoustic disciplines, but to consider synoptically the interplay and mutual dependencies and relationships between a variety of disciplines, encompassing architectural, social, and landscaping insights. This helps to judge design measures as compatible, aggravating, incompatible, conditional or even supportive to good sound quality of outdoor spaces. This should lead to practical recommendations, such as in [7, 100, 101].

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