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Urban space and the sound environment: transport system, urban morphology, quiet side and space users in the SONORUS project

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ABSTRACT

Awareness on urban environmental quality is leading the built environment resilience and sustainability vision, highlighting the importance of a multidisciplinary framework on urbanization processes. A main concern is the negative impact of outdoor noise due to road traffic, determined largely by the source strength, i.e. the vehicles. This paper summarizes the work within the optimization of urban areas inside the SONORUS Urban sound planning project. The purpose is to provide urban planning tools focusing on interacting approaches through the traffic planning and buildings as instruments supporting a better urban environment, with noise as the main indicator. First, the prediction modelling for quiet sides based on the *Qside* model is implemented and tested on cases measured in situ. Second, a microscopic road traffic modelling tool gives useful output for noise level predictions as function of time, opening the possibility to calculate noise indicators and test traffic configurations. Discussion extends towards the study of urban morphology diversification, considered a key strategy to increase liveability of spaces, its interaction with the transport system and the impact on the sound environment. Finally, interest focuses on space users modelling their environment beyond noise control, using the soundwalk as a tool to study urban sound experience.

Keywords: urban sound planning, road traffic noise, urban space.
I-INCE Classification of Subjects Number(s): 52.3, 52.9, 68.2, 68.7

1. INTRODUCTION

In recent years, ideas around how the urbanization process is influencing the environmental conditions in cities are becoming stronger. The main drivers for the quality vision are colliding with each other, where projects are envisioned as having an enormous capacity to improve the quality of urban spaces, while the current practice is sometimes still far away from achieving those plans. Performance, resilience, cohesion, speed, compactness, densification, quality, liveability, sustainability, efficiency, etc. are looking in general through disconnected prisms. All of these aspects have a great impact on the environmental conditions. An overlooked problem is related to the acoustic environment, which may be seen as the invisible threat, and practically, it is never seen as an opportunity for improving the urban space. However, allowing room for urban sound planning in the urbanization process has not only the capacity to prevent hazardous situations related to noise exposure and annoyance, but moreover, it has the opportunity to improve the urban environment through the rethinking of different urban system variables converging in city planning and design.

By acknowledging these aspects, the study tries to grasp some of the many built environment variables that are interesting for the sound environment, mainly in the micro-scale design process. The following sections are mainly related to the unavoidable densification process in cities and the importance of the transport management and traffic design in the improvement of the acoustic qualities and the perception thereof.

The study goes through the concept and importance of the quiet side and the implementation of an engineering method. The study moves towards the influence of the transport management and the traffic strategies for the noise emission and the acoustic environment, which is strongly linked to the dynamics of vehicles (e.g. acceleration) then to a broader terrain, discussing about the relations

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between spatial heterogeneity and the performance and resilience capacities of the transportation system and the consequences on the sound environment, and finally, to the space users and the sound experience. Figure 1 shows the relation between the studied urban space and sound environment.

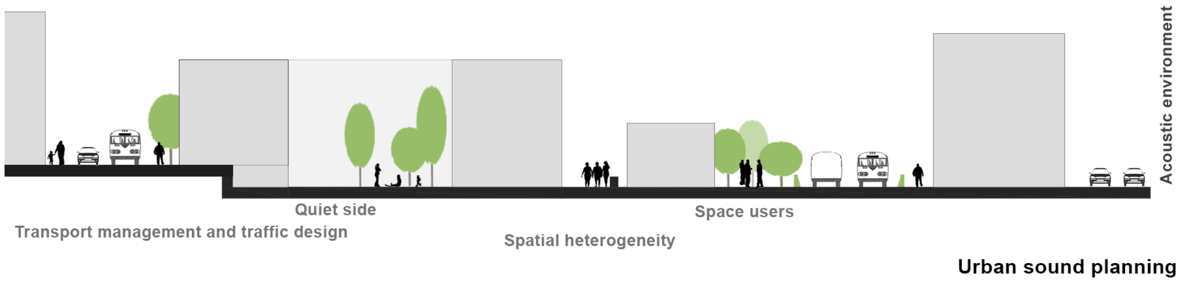


Figure 1 – Urban space and the sound environment

2. URBAN SPACE AND THE SOUND ENVIRONMENT

2.1 Quiet side

The concept of quiet side has become more popular, since it has been classified as a common restorative place to moderate the adverse effects of road traffic noise (1). These areas are identified as the ones not exposed to sound-pressure levels above a certain magnitude (2).

However, a major concern with is the capacity this concept has in the decision-making process. For example in Sweden (3) the guideline value on $L_{AEq,24h}$ is 55 dB. However, since 2015, a new rule came out and this value is now raised to 60 dB in the case small flats are built (up to 35 m^2). Moreover, for any other size of flats, there is no limit on the level, as long as 55 dB is achieved on the quiet side, at least in half of the rooms considered as living room or bedroom. These conditions are making the *quiet side* an incredibly powerful tool in the development of new urban areas, especially when it is argued from the desirable densification of consolidated cities.

In this sense, noise mapping has been the main tool to obtain the noise levels at the quiet areas. However, noise mapping prediction software are regularly underestimating the noise levels in quiet areas, as the inner yards (4). This is mainly due to the fact that they were developed for the exposed case.

The *Qside* engineering model was born with the idea to get reliable noise level values on the shielded façade (5,6). For our purposes, the model has been modified and corrected to enable its implementation. This paper presents a brief summary implementation in real case scenarios and its comparison with noise mapping prediction software, as SoundPLAN. To agree with the noise mapping software, the *Qside model* has been extended. The extension includes the explicit inclusion of ground reflection, development of geometrical parameters at complex situations, inclusion of air attenuation, decorrelation and scattering as well as the implementation of the road traffic source model Nord2000. The main focus is on the diffraction over the buildings due to reflections in both the street canyon and the yard. More information about the implementation model may be found in (7).

Qside implementation calculations were compared with noise mapping prediction calculations through the SoundPLAN software (Fig. 2). The calculations are made for hard ground and both soft (20% absorption) and hard façade (3% absorption). In case the calculations are compared with the first reflection order, differences are around 10 dB for low frequencies, increasing, as the frequencies get higher. Results get closer to each other when the SoundPLAN calculations include a higher order of reflections (20 in this case). However, minor deviations are present at frequencies below 125 Hz and above 4 kHz, mainly due to the differences air attenuation modelling at high frequencies and the diffraction at low ones. The large number of reflections needed is making almost impossible to calculate urban areas through the current noise mapping software techniques.

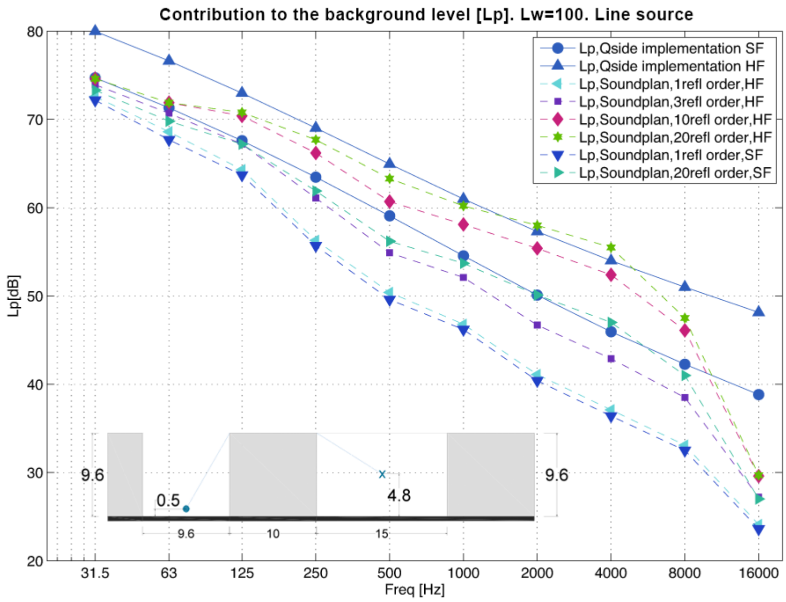


Figure 2 – Contribution to background noise level. Corrections were done after publication (7) in the attenuation calculation by the canyon effect. Façade absorption was set to ρ^6 instead of ρ^2

Results were compared with noise measurements at an inner yard in the city of Gothenburg (Fig. 3). Similar spectra were found for the Qside implementation and the measurements. The total deviation in sound pressure difference was about 3 dBA. Contrary, noise mapping prediction software showed a deviation of 15 dBA, in the case of including one reflection order. In order to apply the *Qside* implementation, geometry of the selected scenario was simplified. Discrepancies between the implementation and the measurements may be due to the simplification and the static traffic flow modelling.

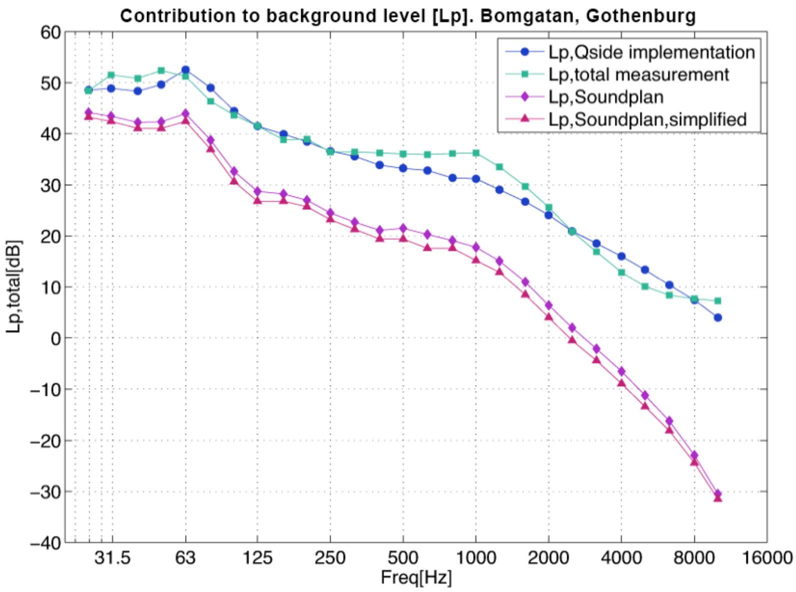


Figure 3 – Sound pressure level (dB) at an inner yard in Gothenburg

Normally, static traffic flow considering average speed and constant density is the input to calculate noise levels through noise mapping software. This is sometimes leading to underestimations (8,9,10), since vehicle kinematics are strongly determining single-vehicle noise emissions and hence, the urban sound environment.

2.2 Transport strategies and noise emission

Time patterns of road traffic flow have been suggested to have an effect on annoyance (11).

Annoyance seems to relate to the number of noise events, however, after a certain threshold, this number is no longer important (12). Medical studies have also highlighted that sudden noise (30 dB above the background noise) has more startling and stress-producing effects on patients than if they were submitted to a high continuous background noise (13).

To study the time patterns of the sound pressure level, single-vehicle noise emissions are needed, including its position, acceleration, speed and vehicle type. Microscopic traffic simulation allows the analysis of road transport noise emission under several strategies, giving as output the aboved described needed data. In order to calculate vehicle noise emissions, a series of in-house Matlab scripts were developed.

The study was made through a real case scenario located in Gothenburg, Sweden. The area, which is called Frihamnen (freeport), has around 1 km^2 area and will become a dense-mixed urban space with around 15000 inhabitants. Several challenges are present in terms of environmental conditions, especially in terms of noise, were the area is submitted to noise levels above 65 dB (Lden), with road traffic as the main source. In order to improve its sound environment, several traffic strategies were studied. More information about the noise emission model, the microscopic simulations, the dynamic maps and the time patterns can be found in (14). As an example, the noise map ($L_{AEq,900s}$) of a simplified base situation is shown with 11 study points (Fig. 4), for which effects of 9 traffic scenarios were studied: 1) Base scenario with modifications; 2) Remove parallel road to motorway located between study points 1 and 9; 3) Remove road close to piers positioned next to study points 3 and 4; 4) Transform intersection into a roundabout next to study point 6; 5) Reduce speed on motorway to 50 km/h; 6) Reduce speed on bridge near study point 11; 7) Reduce speed on road close to piers to 30 km/h; 8) Remove medium-heavy and heavy vehicles; 9) Set acceleration to 0.

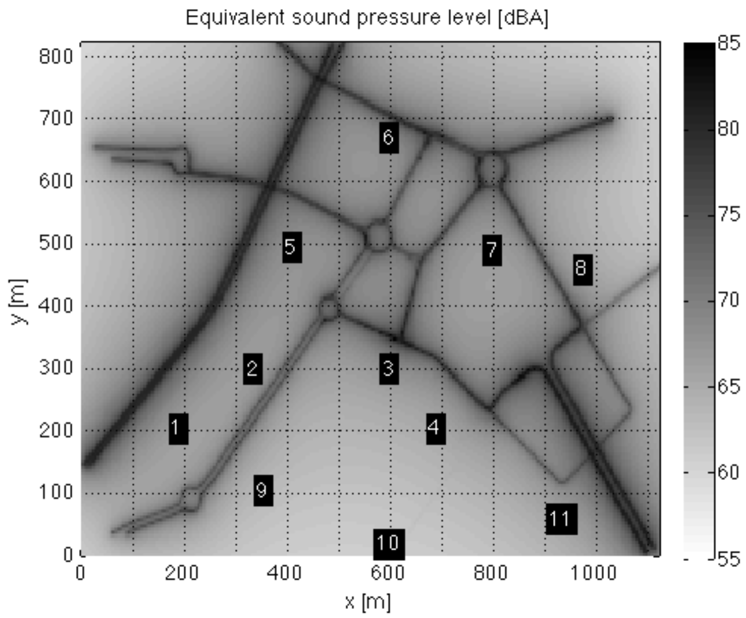


Figure 4 – $L_{AEq,900s}$ for the first scenario

In the temporal variation represented by the difference between the percentile L_{A10} (peak) and L_{A90} (background) levels, study point 6 presents the highest value of all scenarios (Fig. 5). This point is located close to a crossing intersection, replaced by a roundabout in scenario 4, which gets a significantly reduced value, as traffic flow becomes more constant. Scenario 8 scores as the lowest value in almost all study points, since in those ones acceleration is removed from the calculations, highlighting the importance of considering vehicles kinematics in every kind of sound assessment related to traffic.

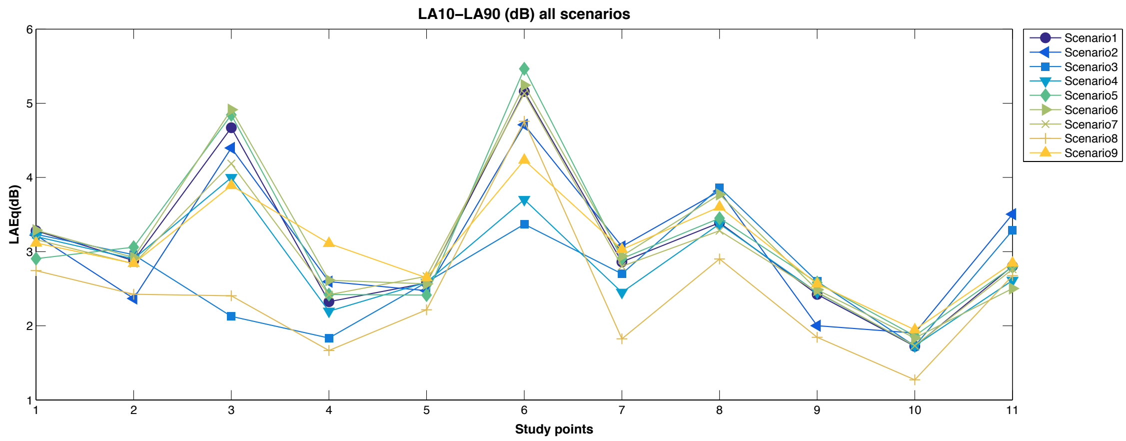


Figure 5 – L_{A10} - L_{A90} (dB) for all scenarios and all study points

2.2.1 Noise emission key features in intersection transport dynamics

To understand deeply the mechanisms behind micro-scale changes in the urban traffic layout, we attempt to study the vehicle dynamics at intersections. In the last decades, urban transport intersections have been suffering from transformations, especially through the replacement of crossings with roundabouts. These have been pointed out as a safer traffic layout. Crossings are based on a stop-controlled situation while roundabouts rely on drivers' capacity to gap management (15). Intersections are maybe the most controversial traffic designs. Here, vehicle kinematics becomes even more important (8,9,10), since they display the perfect situation for a large amount of braking and acceleration with rapid changes of speed.

As a continuation of the research carried out in the previous point, we attempt to isolate key features of these intersections' behaviour, gaining knowledge about the conditions that make them more suitable to a specific urban environment, attending to its characteristics, functions and activities performed. More information about this work can be found in (16). Here, a signalized crossing and a roundabout were compared, holding the same vehicle flow. Three variations of each intersection were included, where the first scenario contains light vehicles (92 %), medium heavy vehicles (4 %) and heavy vehicles (4 %). The second scenario has light vehicles (96 %) and medium-heavy vehicles (4 %). Scenario 3 has only light vehicles.

To study the sound pressure level as a consequence of these intersections, 12 study points were chosen. Four of them (1-4) are positioned near to the intersection (Fig. 6 left), 5-8 located around 100 m from the intersection (Fig. 6 centre) and 9-12 at the sidewalks of the lanes (Fig. 6 right). Closer to the intersections, the signalized crossing gives higher sound pressure levels than the roundabout. For the points located at the sidewalks, the situation varies depending on the traffic flow and the vehicle composition. In the further points, two of them showed higher levels for the roundabout and the other two for the signalized crossing, mainly due to the varying traffic flows around them.

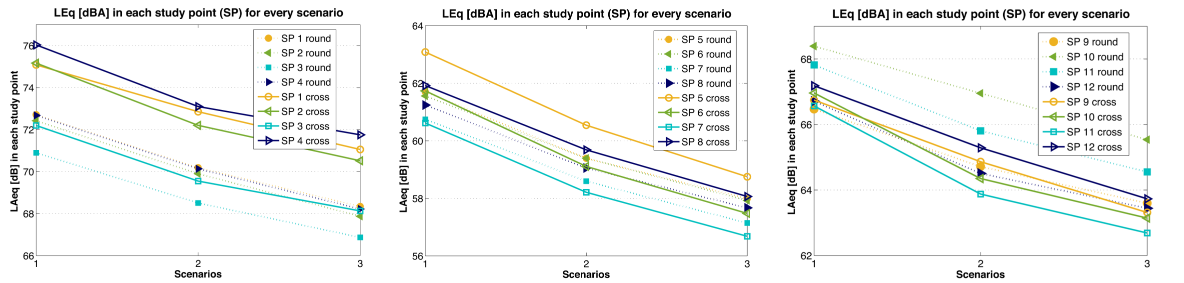


Figure 6 – L_{AEq} (dB) in each study point for the singalised intersection and the roundabout cases

The previous results are related to a flat-city model including geometric attenuation and energy doubling due to the ground. This type of assessment enables a comparative study of traffic strategies and layout configurations. However, the introduction of buildings as one of the main urban systems for determining the city model, will allow a major evaluation of the acoustic impact of the traffic strategies.

2.3 Spatial heterogeneity and the transport system, performance and resilience

The increasing awareness of climate change has lead the focus of urbanization processes towards an improvement of social, technical, economical and environmental performance of cities. However, due to the large amount of systems involved in cities, the resulting urban environmental quality is largely conditioned by understanding it from a multidisciplinary point of view. This type of framework involves an interaction of the different parties within the urbanization process. Disconnected urban systems and divided pronouncements about the decision-making planning process may overlook the complexity for retrofit, which increases the cost as a result. Additionally, it raises the pressure on the environmental quality, risking people's health and wellbeing, and hence, its quality of life.

In this sense, thinking on resilience needs to be linked to sustainability (17) as resilience helping to move towards a good built environment. Here, the urban environment is illustrated by two main characteristics, performance and resilience. Performance is understood as system effectiveness and resilience as the capacity to adapt, absorb and/or restore after a disruption. Finding appropriate balance between them demands a holistic thinking through the influencing variables. Spatial heterogeneity is seen as a fundamental variable of urban form and resilience (18). It interacts with the performance and resilience of systems, enhancing or hindering the liveability of spaces.

In this regard, environmental quality is under constant pressure, balancing between these two characteristics, allowing a high performance of the involved systems, while leading to a resilient behaviour. Two of the main systems under this vision are the energy and the transport. Both of them have an enormous impact on the air and acoustic quality of cities. In this sense, the major contributor to environmental noise in urban areas is road traffic (19). It is also one of the main contributors to greenhouse gas emissions (20). Transport is seen then as the main agent of the low environmental quality in cities. However, transport belongs to this complex systems universe that forms the city, and it cannot be understood without a context. In this sense, transport management and traffic design is largely answering to the desired model of city. Spatial heterogeneity results as a dependent variable of the transport urban system, which may constrain the efficiency of the traffic management and the complexity of the traffic design. Moreover, it may constrain the system capacity to adopt resilience behaviour.

A case study was used to review these concepts and study the spatial heterogeneity and its impact in the acoustic environment as a result of the transport system. More information about this is submitted for publication (21).

Some of the results showed that the diversity of land uses (LUMI, as land use mix index) does not have a clear effect on the performance of the acoustic environment due to road transport. More concrete, it seems that the percentage of users and residents in each area exposed to high noise levels is not directly related to noise emission, since other factors may be involved e.g. the disposition of dwellings, the urban form, and the activities and functions performed. This may be related as well with the possible existence of a threshold in the amount of urban alternatives, leading to a reduction in their resilience behaviour, their adaptive capacity related to how well they perform and the system components amount (22).

If the analysis relates to the density of inhabitants and users, the trend is still the same, where having higher densities does not directly link with a percentage of people exposed to high noise levels (Ld). The highest density of residents is found in scenario 5. In this scenario, the percentage of residents exposed to high noise levels is about the same value as for the rest of the scenarios. For the density of users, the scenario 3 is the one holding the highest number of people exposed to high noise levels together with the first one, with the lowest density of users (Fig. 7).

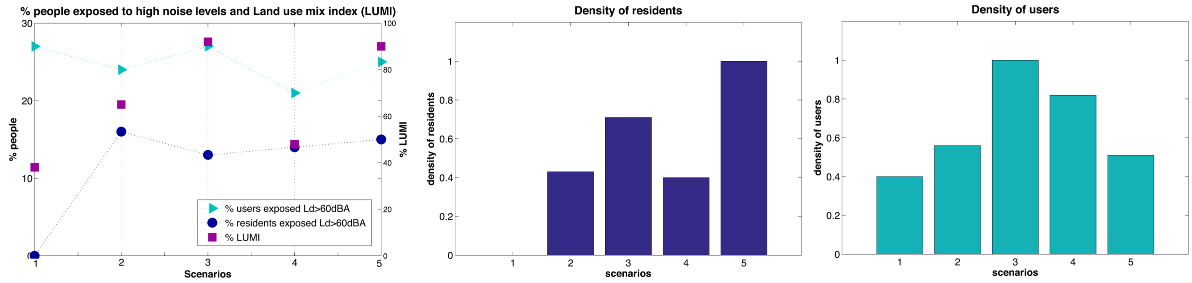


Figure 7 – Percentage of people exposed among different scenarios and the land use mix index

Assessment of transportation costs due to noise exposure and its consequent devaluation was used as a measure of robust and adaptable scenarios. Here, higher density of residents is not shown to relate to higher costs due to the noise exposure. Moreover, there is any trend indicating that the diversity of the land use influences the absorptive capacity of the scenarios in terms of price loss.

Impact on the sound environment as a consequence of transport and its interactions with the spatial heterogeneity is only showing a small portion of the agents involved in the production of cities. However, this inability to combine systems in the planning of the built environment, is leading the transport system to be, in general, the main responsible part for the failure to comply with the recommendations for air and acoustic quality.

2.4 (Young) space users and the acoustic experience

Finally, the interest focuses on space users as agents modelling the environment. The interest for this comes from the urban sound planning integrated approach, where the assessment tools go beyond acoustic control, towards the study of the urban sound experience. Here, a comprehensive approach and a continuous dialogue among interested partners is needed. Among those interested partners we find the final users as one of the most important ones. In this sense, listening becomes an active sense and its study demands a proactive approach. A common tool to study urban sound experience is the soundwalk (23) where, people rate the sites and their related impression about the sound environment. However, in this type of assessment, children are normally excluded, even though they are often considered as a group with high risk to noise exposure (24). A soundwalk was performed among a group of children from the fifth year of a primary school in Gothenburg, Sweden. The route (Fig. 8) with five scenarios was set around their school neighbourhood.

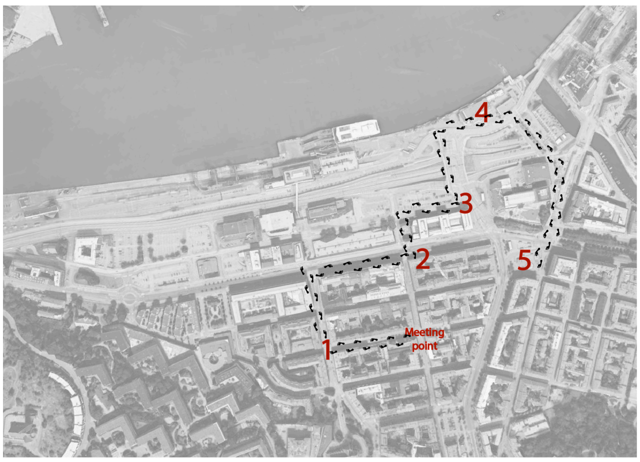
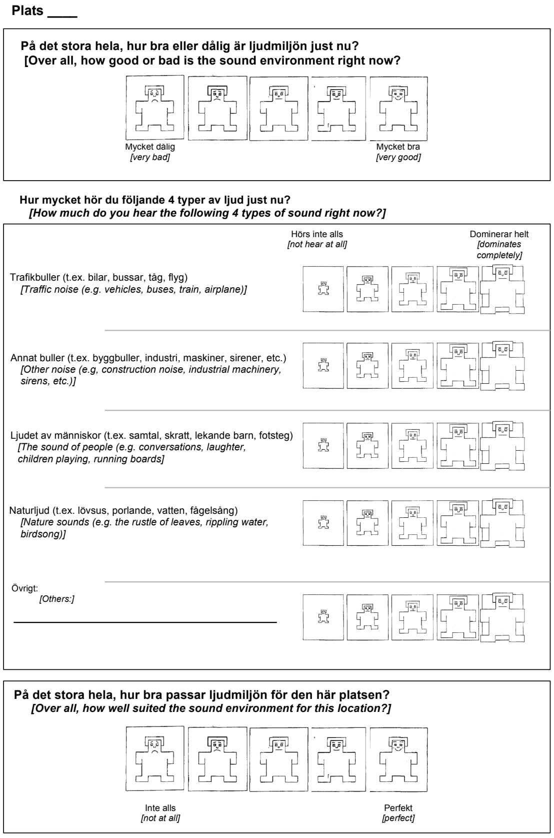


Figure 8 – Soundwalk route

An especially designed questionnaire for children, based on (25) was developed, incorporating the Bradley-Lang scale (26). The questions were divided in 3 main topics related to the description of the sound environment, the sources heard and the appropriateness of the sound environment to the place, as shown in Figure 9.


Plats ____

På det stora hela, hur bra eller dålig är ljudmiljön just nu?
[Over all, how good or bad is the sound environment right now?

Mycket dålig
[very bad]
Mycket bra
[very good]

Hur mycket hör du följande 4 typer av ljud just nu?
[How much do you hear the following 4 types of sound right now?]

Hörs inte alls
[not hear at all]
Dominerar helt
[dominates completely]

Trafikbuller (t.ex. bilar, bussar, tåg, flyg)
[Traffic noise (e.g. vehicles, buses, train, airplane)]

Annat buller (t.ex. byggbuller, industri, maskiner, sirener, etc.)
[Other noise (e.g, construction noise, industrial machinery, sirens, etc.)]

Ljudet av människor (t.ex. samtal, skratt, lekande barn, fotsteg)
[The sound of people (e.g. conversations, laughter, children playing, running boards]

Naturljud (t.ex. lövsus, porlande, vatten, fågelsång)
[Nature sounds (e.g. the rustle of leaves, rippling water, birdsong)]

Övrigt:
[Others:]

På det stora hela, hur bra passar ljudmiljön för den här platsen?
[Over all, how well suited the sound environment for this location?]

Inte alls
[not at all]
Perfekt
[perfect]

Figure 9 – Questionnaire for children

In the analysis, both the individual responses and the acoustic parameters were studied. Questions about description of the sound environment (q1) and appropriateness of the sound environment to the place (q3) resulted in similar mean values (M_{1q1}=2.9, SD_{1q1}=0.78, M_{2q1}=2.7, SD_{2q1}=0.8, M_{3q1}=2.1, SD_{3q1}=0.85, M_{4q1}=3.3, SD_{4q1}=0.89, M_{5q1}=3.5, SD_{5q1}=0.9 and M_{1q3}=2.9, SD_{1q3}=0.99, M_{2q3}=2.9, SD_{2q3}=0.97, M_{3q3}=2.8, SD_{3q3}=1.17, M_{4q3}=3.4, SD_{4q3}=1.02, M_{5q3}=3.5, SD_{5q3}=0.8). However, at study point 3 the differences become larger. In this study point, the sound environment was describe worst than the appropriateness of the sound environment to the place, however the equivalent sound pressure level was the same for both sites. The frequency analysis showed that the site 3 contains a stronger low frequency content than the second site, probably leading to this lower valuation of the sound environment (Fig. 10). However, the appropriateness of it to the place was ranked higher, since this place is located on a residual sidewalk close to a tunnel entry with a high amount of traffic coming from different places (see Fig. 8).

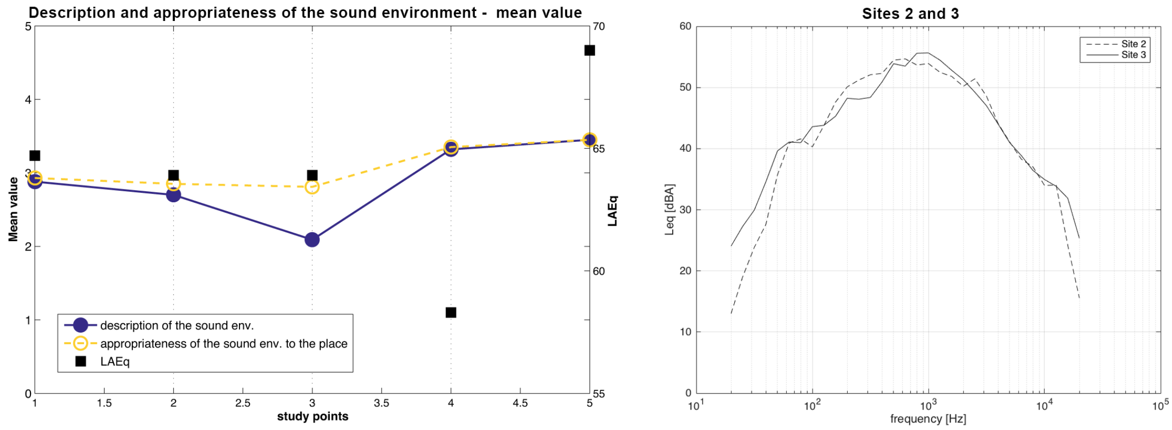


Figure 10 – Scenarios 2 and 3: assessment and physical measurements

The second set of questions (q2) corresponds to the study of the sound sources heard. Fig. 11 shows the number of answers in terms of frequencies related to the sound sources heard that were marked as 4 (dominates) & 5 (dominates completely) in a scale 1-5. The differences between the sites' sound environment description and the perception of them is related to the types of sources heard and its dominance. The best description and perception of appropriateness of the sound environment was scored at site 4 (10 children described it as good or very good, and 12 children perceived that it was appropriate to the place). Contrary, in site 3 none of the children described the place as good or very good, and just 5 of them perceived the sound environment was appropriate.

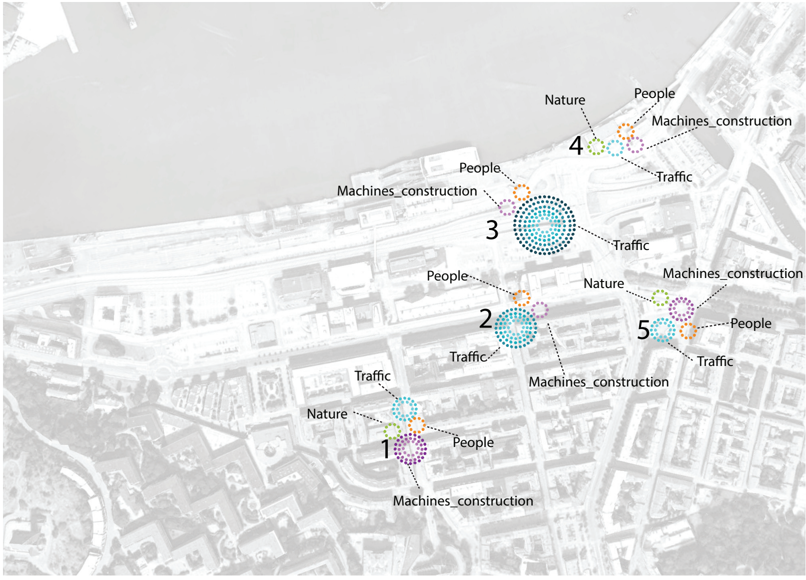


Figure 11 – Frequencies of answers about sources heard and scored as dominating (4) or dominating completely (5) for all sites. Each circle represents a minimum of 1 and a maximum of 5 children

DISCUSSION

The inevitable densification process is demanding better assessment of the consolidated urban spaces as well as the new ones. Controlling the acoustic environment by creating high quality in urban spaces capable to support health and wellbeing must be a priority. The approach intended here provides tools and knowledge looking through an anticipatory urban sound planning process capable to improve expert decision-making that could enhance the current urban practice. Here, the city must be seen as a compound of interactive systems where some of them are submitted to the output of others, however, many of them impact on the acoustic environment. The study goes from the improvement of calculation methods, as the quiet side implementation, obtaining accurate results compared to measurements. Then, the study moves toward the introduction of dynamic noise mapping and time pattern representations to study the vehicle kinematics and the noise emission bringing opportunities to assess different environmental qualities within a micro-scale level. The study moves forward to discuss the effect of spatial heterogeneity in transport and, hence, in the sound environment, where higher density population does not end up in a higher percentage of its population exposed to high noise levels. Finally, the assessment of the space users' experience is included through the development of a soundwalk with children as one of the main risk groups. Here, the functions and uses of spaces are presumably influencing the positive description of the sound environment more than just the present sound sources. Moreover, the same sound pressure level gave different assessments in terms of the quality of the sound environment and its appropriateness to the place, highlighting the importance of studying the spectra and the type of source, as well as the other stimuli involved in the description of the sound environment.

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