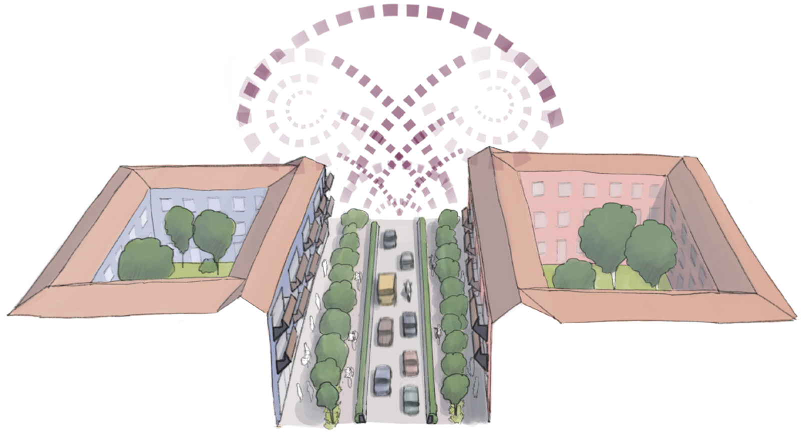
SONORUS is a European Training Network inside the Marie Skłodowska-Curie Actions funded by the European Commission. The goal of those training networks is to bring together universities, research centres and companies from different countries to train a new generation of researchers with a profile beyond existing professions.

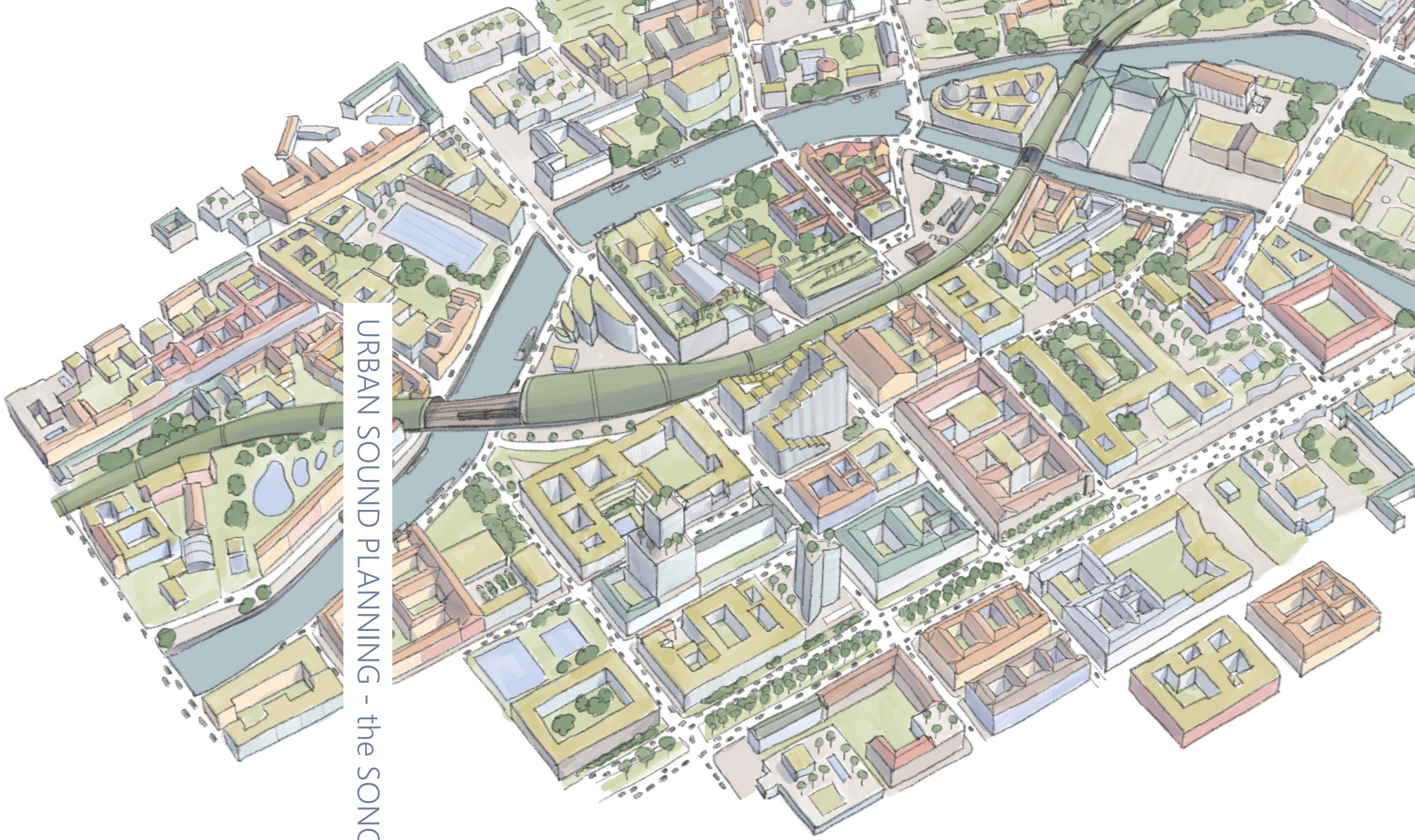
SONORUS' overall objective was and is to offer young researchers in the early-stage of their career the opportunity to develop their knowledge and skills in the area of urban sound planning. The complexity to handle the sound environment in our cities demands a transdisciplinary approach to master the planning process of an urban sound environment. A key issue for such holistic urban planning is the successful communication between all people involved in the process together with the inclusion of tools and methods for communication. To achieve this, the tools and methods that are needed go beyond today's state of the art.

SONORUS is the beginning of a process towards urban sound planning. Now, when reaching the end of the four-year project, the task of this booklet is to state where we are in this process and to summarize our views and experiences, but also our research in the field of urban sound planning.



ISBN 9789163918599
90000 >
9 789163 918599

URBAN SOUND PLANNING - the SONORUS project



URBAN SOUND PLANNING
- the SONORUS project

Editors: Wolfgang Kropp, Jens Forssén, Laura Estévez Mauriz
Coordinators of SONORUS project: Wolfgang Kropp, Jens Forssén
Illustrations and layout: Alexandra Bäckström

Project funded by the People Programme (Marie Curie Actions) of the European Union's Seventh Framework Programme FP7 2007-2013 under REA grant agreement n. 290110

Urban Sound Planning - The SONORUS project
Contact: Wolfgang Kropp, wolfgang.kropp@chalmers.se

ISBN 978-91-639-1859-9

Printed by DanagårdLiTHO, Sweden, 2016

URBAN SOUND PLANNING
- the SONORUS project

Foreword

SONORUS is a European Training Network inside the Marie Skłodowska-Curie Actions funded by the European Commission. The goal of those training networks is to bring together universities, research centres and companies from different countries to train a new generation of researchers with a profile beyond existing professions.

SONORUS' overall objective was and is to offer young researchers in the early-stage of their career the opportunity to develop their knowledge and skills in the area of urban sound planning. The idea of SONORUS stems from several observations.

First, the complexity to handle the sound environment in our cities demands a trans-disciplinary approach to master the planning process of an urban sound environment with all its related aspects such as city and traffic planning, architectural aspects, noise control and soundscaping, as well as political processes.

Second, a key issue for such holistic urban planning is the successful communication between all people involved in the process together with the inclusion of tools and methods for communication. To achieve this, the tools and methods that are needed go beyond today's state of the art.

Third, one rarely finds acoustic experts mastering the whole spectrum of knowledge. The demanded tools inside the field of acoustics needed for such a task include applying state-of-art sound prediction tools for shielded and quiet areas, being able to work with the concepts of soundscaping including aspects of behaviour science and psychology, having deep inside knowledge on noise control measures such as the application of quiet road surfaces or traffic management and being able to develop a holistic low noise pollution strategy for an entire city or a large urban area.

It is obvious that SONORUS can only be the beginning of a process towards urban sound planning. Now, when reaching the end of the four-year project, the task of this booklet is to state where we are in this process and to summarize our views and experiences, but also our research in the field of urban sound planning. This means that this booklet is rather a status report than a final toolbox for urban sound planning.

The booklet has been written by the young researchers participating in the training network. All authors contributed equally to their corresponging chapters and they are listed alphabetically. We are very grateful for all the effort they spent in order to summarize their experience, knowledge and insight into urban sound planning.

Thanks to all supervisors and colleagues from the cities who supported the training programme as well as the writing of the booklet. Finally, we would like to thank Alexandra Bäckström who added the wonderful illustrations.

Wolfgang Kropp, Jens Forssén and Laura Estévez Mauriz.

Members of the SONORUS consortium:

Senior Researchers:

Wolfgang Kropp, coordinator - Chalmers University of Technology, Sweden

Jens Forssén , coordinator - Chalmers University of Technology, Sweden

Beate Altreuther - Müller BBM, Germany

Dick Botteldooren - Gent University, Belgium

Salvatore Curcuruto - ISPRA, Italy

Kurt Heutschi - EMPA, Switzerland

Maarten Hornikx - Eindhoven University of Technology, the Netherlands

Nicole van Hout - Eindhoven University of Technology, the Netherlands

Jian Kang - Sheffield University, UK

Krister Larsson - SP, Sweden

Luigi Maffei - Second University of Naples, Italy

Timothy van Renterghem - Gent University , Belgium

Joachim Scheuren - Müller BBM, Germany

Rosalba Silvaggio - ISPRA

Members of the Educational Program:

Francesco Aletta

Sonia Alves

Gemma Echevarría Sánchez

Laura Estévez Mauriz

Karlo Filipan

Ignacio García Merino

Fotis Georgiou

Like Jiang

Mercury Kounturas

Efstathios Margaritis

Raúl Pagán Muñoz

Virginia Puyana Romero

Frederik Rietdijk

Georgios Zachos

City representatives:

Rebecca Beeckman (Antwerp)

Matthew Easteal & Simon Banister (Brighton & Hove)

Martin Knape, Henrik Nystedt & Maria Holmes (Gothenburg)

Guido Carati (Rome)

Contents

Introduction

The needs for urban sound planning in the context of accelerating urbanization

We are living in a time of rapidly increasing urbanization and urban development. To supply sufficient housing and infrastructure are key issues on the agenda of any bigger city in Europe and around the world. Having focus on what appears to be most urgent, there is a risk that we loose sight of other qualities also being relevant for a sustainable development of our cities.

This risk is drastically increased due to the often-observed fragmentation of urban planning processes. The fragmentation also precludes the possibility to utilize potential synergy effects provided by a holistic planning approach.
The sound environment in our cities is one of those qualities that typically appear on the agenda only very late and only when discovering that a project might not meet relevant regulations with respect to noise. In these cases regulations are experienced as hinders e.g. for an economically efficient urban development. This view reveals the lack of awareness about the tremendous importance

that an adequate sound environment has for the functioning of urban spaces.

We as acousticians might partly be responsible for this situation. Over many years we have been arguing that the sound environment strongly influences health and well-being. We have focused the discussion towards the negative impact of noise on society both with respect to health risks and their economic consequences. Although the problem of health risks and their economic consequences has been strongly confirmed during the recent years, the focus on these problems is rather diminishing the role of the sound environment in the context of urban planning instead of strengthening it.

The importance of the sound environment stems from the fact that the auditory perception of an urban setting is on par with its visual perception, a circumstance that also demands coherence between auditory and visual design. Residential areas, parks or meeting places are incomplete in their design when the sound environment is not coherent with the intentional use of the spaces. Non-adequate sound environments will reduce the functionality of such places or even destroy their usability completely.

To create the necessary awareness about the importance of the sound environment among all involved in the urban planning process is a tremendous challenge. A natural solution would be that architects include the sound environment into their design processes as self-evidently as they do with the visual aspects. At the same time the process has to aim on the inclusion of urban sound planning in the planning process of cities at the earliest stage.

For this to happen, it is also necessary that we acousticians understand and learn the process of urban sound planning in all its complexity. The task of urban sound planning requires a comprehensive view on the future development of cities, including the development of their transport and industrial infrastructure. To cope with the complexity of this task, the consequent application of a transdisciplinary approach is needed: urban and traffic planning, architectural aspects, acoustics, noise control, and soundscaping, as well as political and administrative processes and economic aspects, must be considered from the very beginning of the planning process.

In order to integrate urban sound planning in the overall planning process, it is essential that tools are developed for controlling, communicating and designing the sound environment on a level beyond todays engineering solutions.

The booklet comprises a description of such tools as they haven been developed in SONORUS. In Section 2 the control of the sound environment is related to e.g. decisions on traffic planning and urban form. Methods for predicting and auralising the sound environment, as essential tools for communicating the acoustic consequences of different planning scenarios, are presented in Section 3. Section 4 focuses on the use of the soundscape approach as a tool to design the perceived acoustic environment (i.e. the sonic environment) from an end-user perspective. Although tools are important, the most important advancement is the implementation of urban sound planning in real life cases. Section 5 presents four test sites where the idea of urban sound planning is converted to realistic scenarios for the cities of Antwerp, Brighton, Rome and Gothenburg. The discussions in the following text is adapted to the general view on planning by discussing urban sound planning on three different scales: on the macroscale, related to urban planning; on the mesoscale, related to urban design; and on the microscale.

Although the process of urban sound planning has been initiated and first attempts have been made toward using such a process, it is essential to recognize that the work documented in this booklet is just the beginning of a development.

The on-going urbanization demands a different way of planning, where a holistic view is essential to create attractive cities. A positive sound environment is an essential part of the perception of cities. Only an attractive urban environment will be successful on an economic level, by being able to develop, attract and to keep competence, enterprises and financial resources, as well as creating means and capabilities for further development of future social, cultural, environmental and economic sustainability.

Controlling the sound environment

Authors: Gemma Echevarría Sánchez, Laura Estévez Mauriz, Efstathios Margaritis,

Introduction

The process of Urban Sound Planning requires the possibility to control the sound environment. Traditionally we talk about noise control in this context, and during the past a multitude of noise mitigation measures have been developed and practical applications explored.

This includes tools such as noise barriers, low-noise road surfaces or the use of green roofs and facades. Here, the outcomes of the EC project HOSANNA may be a useful source of inspiration for the use of greenery in the context of noise control engineering.

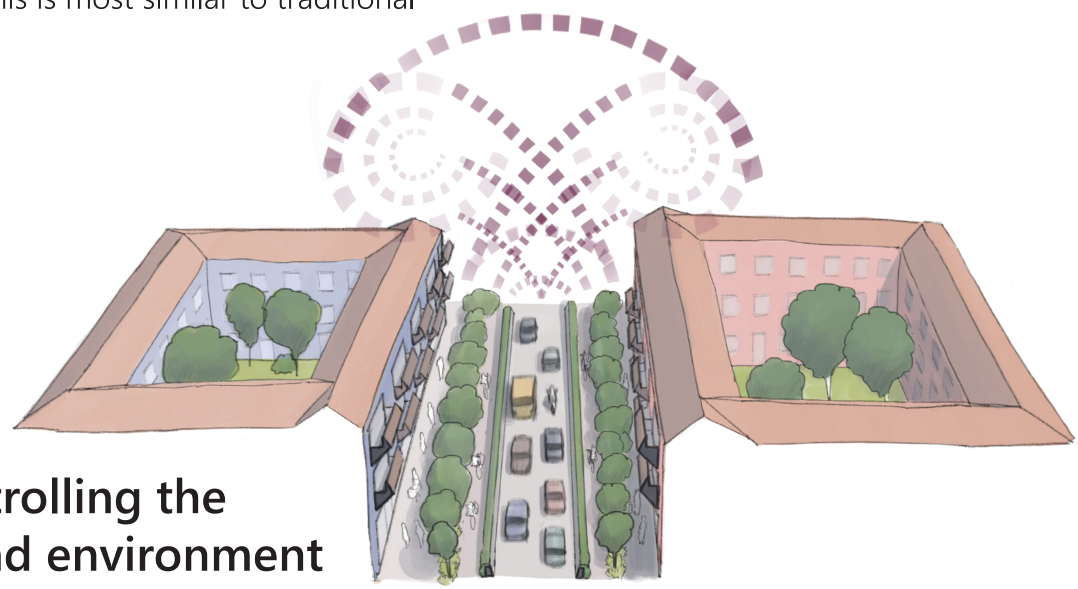
However, when it comes to Urban Sound Planning, the needs are beyond just controlling the noise. Tools are called for that allow for shaping and exchanging dominating sounds in an area. In addition, approaches are demanded which can be applied on all three scales:

On the macroscale, where an acoustic master plan may define the needs and also the ambition of a city with respect to the sound environment, tools and approaches are required for controlling the overall sound environment. There is also still a need to develop a theoretical framework supporting the planning on this scale.

On the mesoscale, where urban areas are considered, transport management and traffic design are important tools for controlling the sound environment.

On the microscale, local modifications are made to adjust the sound environment to the needs in a very limited area. This is most similar to traditional noise control engineering work. However, in an urban sound planning process, measures are motivated by thorough pre-considerations, e.g. of the architectural design.

In the following, approaches developed within SONORUS are presented which have the goal to control the sound environment on all these three scales.



Controlling the sound environment at microscale level

CONTROLLING THE SOUND ENVIRONMENT BY LOCAL ARCHITECTURAL ELEMENTS

In the urban context, motorized traffic and pedestrians or cyclists are often found in the same street canyon. Urban designers and architects are frequently unaware of the acoustical consequences that the presence of the different urban elements can have on the exposure of these people as well as on those living in the flanking dwellings. The facade shape, the width of the street, and urban furniture are natural elements in the urban

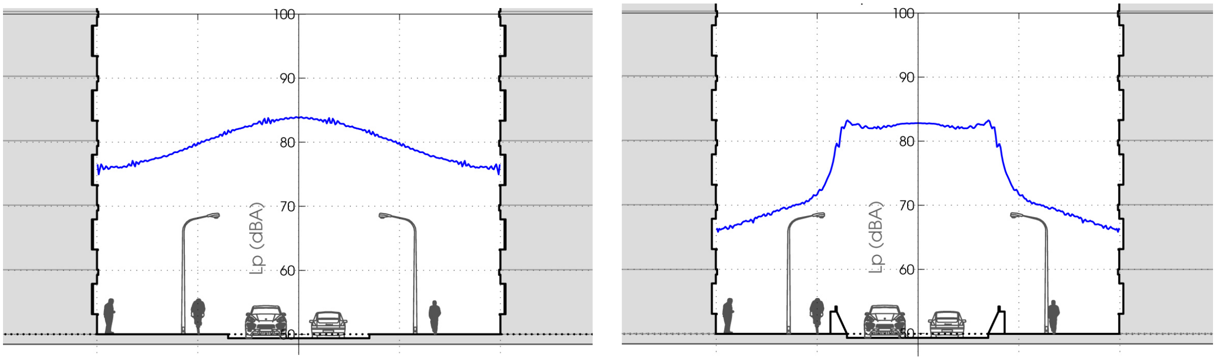


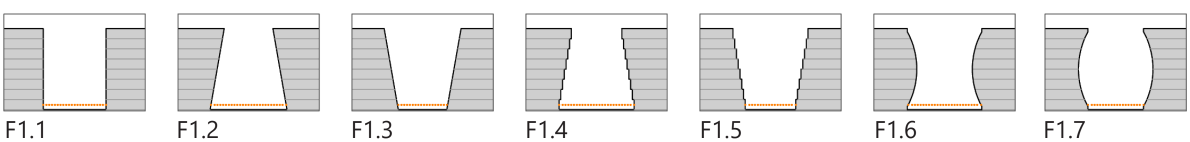
Figure 1 - Reduction of noise level at pedestrians by a low inclined barrier

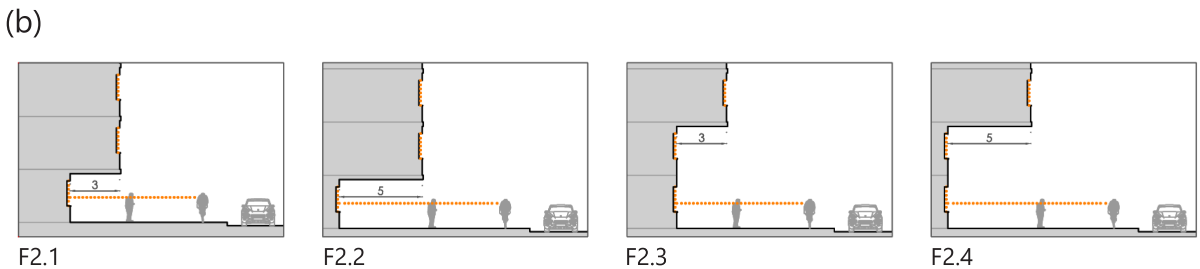
environment that can transform the propagation of sound. Add-on small barriers, absorptive layers, and shaped balconies can alleviate exposure. (See example in Figure 1).

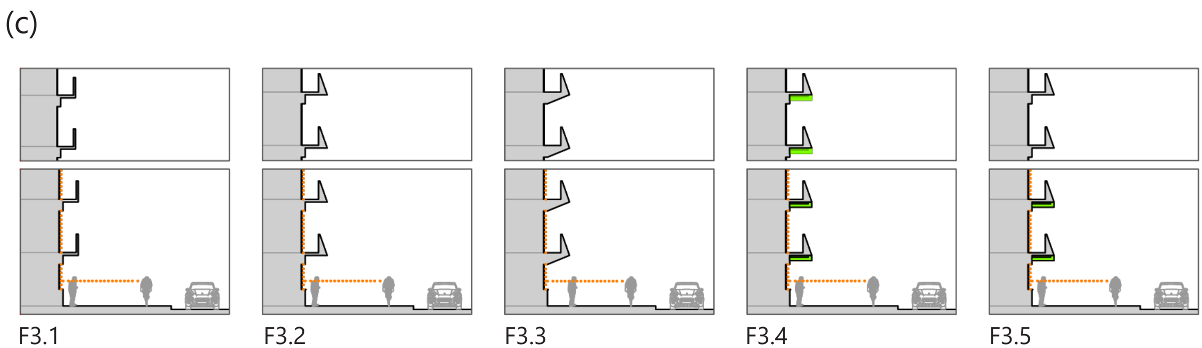
To quantify the potential benefit of each of these effects, a range of over 60 cases were calculated using a numerical method that can account for small geometrical details and all propagation effects they cause: A 2-D Finite Difference Time Domain method. All cases analysed are variations of a typical geometry of a 20 m wide canyon and 8-floor buildings (See Case F1.1 in Figure 2a), organized in street cases (S) and facade cases (F). The source is two-lane urban traffic at speed 50 km/h. The results from this study, given below sorted by efficiency, should be taken as an instructive guideline to understand the effect of different urban geometries on noise. The optimal design to achieve the greatest noise reduction for any other urban situation would need new calculations. The conclusions from these calculations are summarized below.

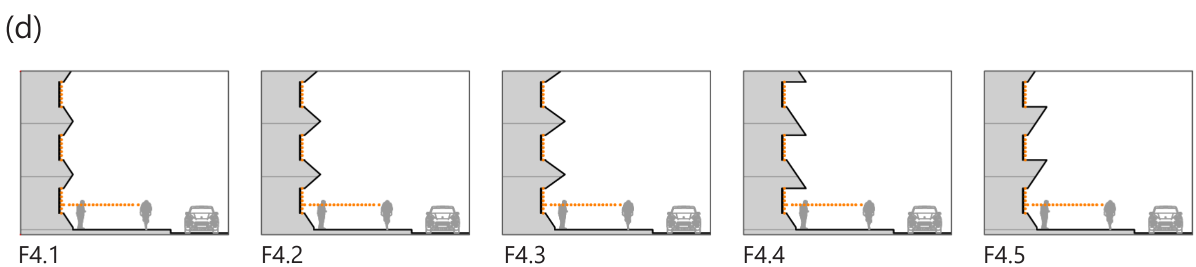
Facade cases:

(a)









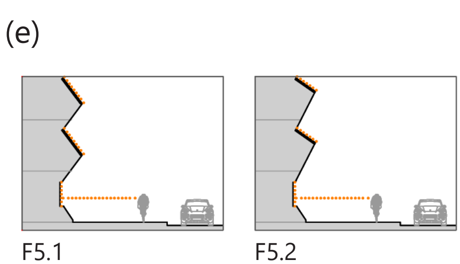
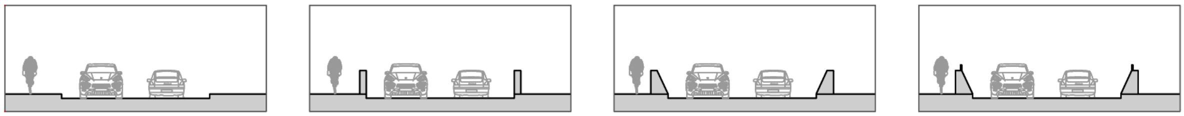


Figure 2 - Studied cases: General Building Shapes (a), Setback in lower storeys (b), Balcony geometry (c), Triangular prominences on facade (d), Shielded inclined windows (e), Low barrier shape (f), Absorption on a vertical low barrier (g), Absorption on an inclined low barrier (h), Depressed road (i), Two level street (j).

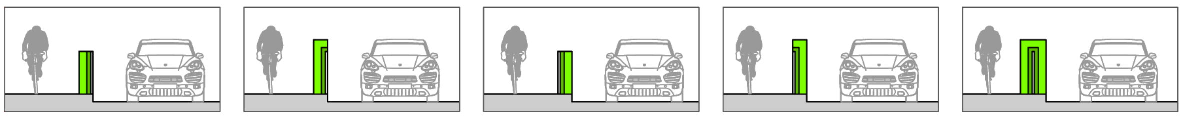
Street cases:

(f)



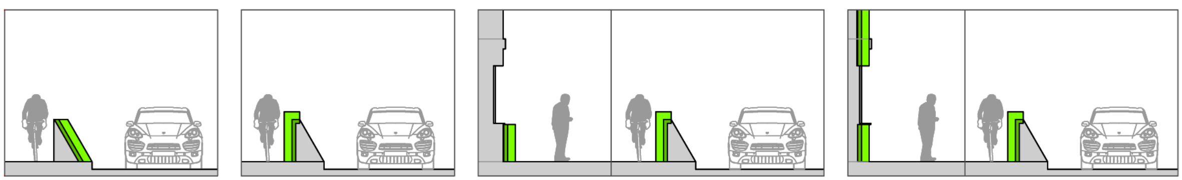
S1.1 S1.2 S1.3 S1.4

(g)



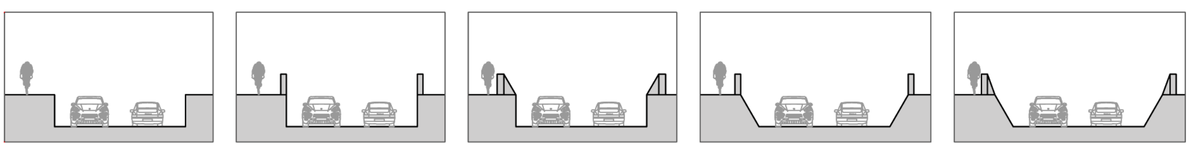
S2.1 S2.2 S2.3 S2.4 S2.5

(h)



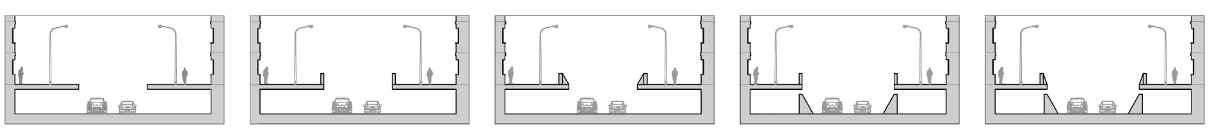
S3.1 S3.2 S3.3 S3.4

(i)



S4.1 S4.2 S4.3 S4.4 S4.5

(j)



S5.1 S5.2 S5.3 S5.4 S5.5

- General building shape has a limited influence on sound levels near pedestrians and on the facades.
- Upwardly inclined facades (F1.3) are most efficient for pedestrians, independent of facade material.
- Concave facades (F1.7) are also beneficial for pedestrians.
- Downwardly inclined facades (F1.2) should be avoided unless they are absorptive as they increase levels with up to 6 dBA for pedestrians.
- Full building facades in glass can increase exposure by 6 dBA for pedestrians compared to facades in brick.
- The position of pedestrian area varies with the facade geometry. It is advisable to locate the walkways as far as possible from the source.

- Setback in lower storeys may reduce noise by up to 4 dBA for pedestrians and on the facade in lower storeys
- There is not much reduction on the facade in upper storeys.
- The last case (F2.4) with a setback of 5 m depth and 2 floors height is the most efficient within the sequence.
- The noise reduction is proportional to the setback dimensions: increasing setback depth reduces noise for pedestrians and increasing setback height reduces noise on the facade.
- Additionally, it is recommended to add absorption to the ceiling of the setback to farther reduce noise levels for pedestrians.

- The addition of balconies has an important effect on the facade, reducing at least 5 dBA on each floor except on the ground floor.
- The presence of balconies does not have an important effect for pedestrians.
- Changing the balcony shape can reduce levels on the facade by 6 dBA if balconies are more or less continuous along the length of the street.
- Inclination of balcony ceiling (F3.3) is beneficial as they reflect sound directly towards the canyon opening.
- The balcony with absorption on the ceiling (F3.4) also results in important reductions for facade.
- The most efficient case would be a combination of inclined balconies with absorption on the ceiling only in the lower storeys (F3.5) which would additionally reduce noise for pedestrians.

- The triangular prominences have an important noise reduction on facade
- No positive effect is found for pedestrians.
- Different triangular shapes give 6 dBA variation

- Noise decreases with larger triangles
- Up vertex case (F4.5) is the most advantageous as it shields the windows which are the weakest element on the facade.
- Down-vertex (F4.4) is the least avantageous as it reflects sound directly towards the window.

- Increasing inclination of window achieves important noise reduction on the windows.
- However, it has a small noise increment on the first floor and for pedestrians.
- The case with a larger window iclination (F5.2) is the most advantageous for the facade.

- Small barriers have little effect on the exposure of facades flanking the street except for the lowest floors, yet they can reduce the level near pedestrians if shaped correctly.

- A small vertical barrier reduces noise levels with more than 4dBA for pedestrians.
- Inclination of a low barrier additionally reduces 3dBA for pedestrians (8dBA in total).
- 30 degrees inclination is the most beneficial for this canyon dimensions.

- Different absorption gives reduction of pedestrian exposure within 4 dBA range
- The most efficient face to place the absorption is the source side (S2.3) (additionally 2 dBA)
- The least efficient face is the receiver side S2.2
- The addition of absorption on the top of the barrier (in S2.2 or S2.4) reduces additionally 1 dBA for pedestrians, despite the small surface.
- The maximum reduction achieved compared to the non-barrier case is of nearly 9 dBA with all surfaces absorbent (S2.5)

However, the addition of absorption on an inclined low barrier has different effects than on a vertical one:

- Different absorption treatment for an inclined low barrier varies by 2 dBA.
- The most efficient faces for adding absorption are receiver side and top.
- The addition of absorption on the source side has no additional effect for the inclined barrier case.
- Absorptive wainscot does not additionally reduce noise for pedestrians.

- A road depression has no effect if sides are straight and reflective.
- The addition of an inclined barrier on the edge reduces noise by 7 dBA for

pedestrians and also achieves important noise reductions on facade.
- Inclining containing walls additionally reduces noise by 3 dBA for pedestrians and on the ground floor (11dBA in total)
- The case with inclined containing walls and inclined small barrier on the edge (S3.5) is the most efficient for pedestrians and on facade.

- A second level road has an important positive effect for pedestrians and along the whole facade.
- Parking space linking at both sides reduces noise by 5 dBA for pedestrians and by 3–5 dBA along facade
- A barrier on the sidewalk edge reduces additionally 4–5 dBA for pedestrians
- The case with inclined walls and inclined low barrier on the edge is the most beneficial, reducing up to 11 dBA for pedestrians and on the lower storeys.

General remarks:
- Changes in facade influence noise levels along facades whereas changes in the street mainly influence pedestrian exposure.
- Small geometrical changes can be a powerful architectonic tool to reduce noise.
- Inclination of geometries or the addition of absorption is shown to be very effective. Both treatments simultaneously do not bring further reduction.
- Reductions achieved can easily exceed reductions that could be obtained by lowering traffic speed or reducing traffic flow to a small fraction.

THE IMPORTANCE OF QUIET AREAS

The concept of quiet side has become more popular as they have been classified as a common restorative place to moderate the adverse effects of road traffic noise. These areas are identified as the ones not exposed to sound-pressure levels above a certain magnitude. Since they are considered as restorative places, our homes are the perfect place to have access to them. We must not forget that the quiet side concept is strongly linked to the quality of those spaces. The way we perceive our environment strongly affects the way we behave and how we feel. To make these areas attractive, attaining a low noise level is not sufficient. Other spatial qualities might influence the human response, such as vegetation, diversity, privacy, aesthetics, sense of community, thermal comfort, etc. For example, in a dwelling located close to a busy road, it may be of importance to

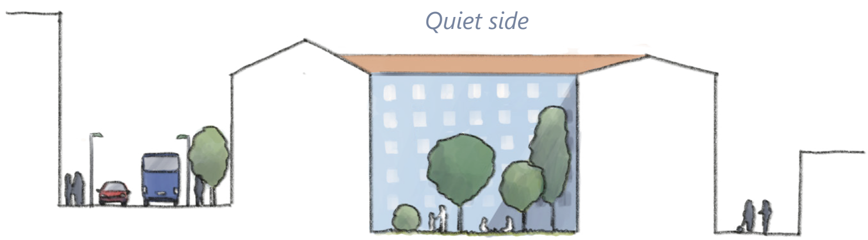


Figure 3 - Noise contribution to inner-yard

have one of its facades protected from high noise levels. The recommendation is to keep that level below 50 dB and preferably below 45 dB as a day-evening-night noise level.

What makes these areas so important is their tremendous capacity to influence the urban decision-making process, having an impact at all urban scales. These conditions are making the quiet side an incredibly powerful tool in the development of new urban areas, especially when densification of consolidated cities is pursued. (See illustration in Figure 3).

Normally, noise mapping has been the main tool to obtain noise levels at the quiet areas. However, they are regularly underestimating the noise levels in such type of areas. This is mainly due to the fact that the software used are developed to study the most exposed facade. In SONORUS the Qside engineering model that accounts for quiet areas is expanded, in order to implement it in real case studies and compare it with noise mapping prediction software. The main focus is on the diffraction over the buildings combined with multiple reflections in both the street canyon and the inner-yard.

Results between the implementation model and the noise mapping software show differences around 10 dB for low frequencies for hard facades, increasing with frequency (Figure 4). This is in the case we have 1 reflection order, which is usually how the noise maps from our cities are calculated. Results get closer to each other when the noise mapping software calculations include a higher order of reflections (20 in this case). The calculations are made for hard ground (dense asphalt) and for both soft facade (SF, 20% absorption) and hard facade (HF, 3% absorption).

The Qside implementation and noise mapping software calculations are compared with noise measurements at an inner-yard in the city of Gothenburg (see Figure 5). Similar spectra are found for the Qside implementation and the

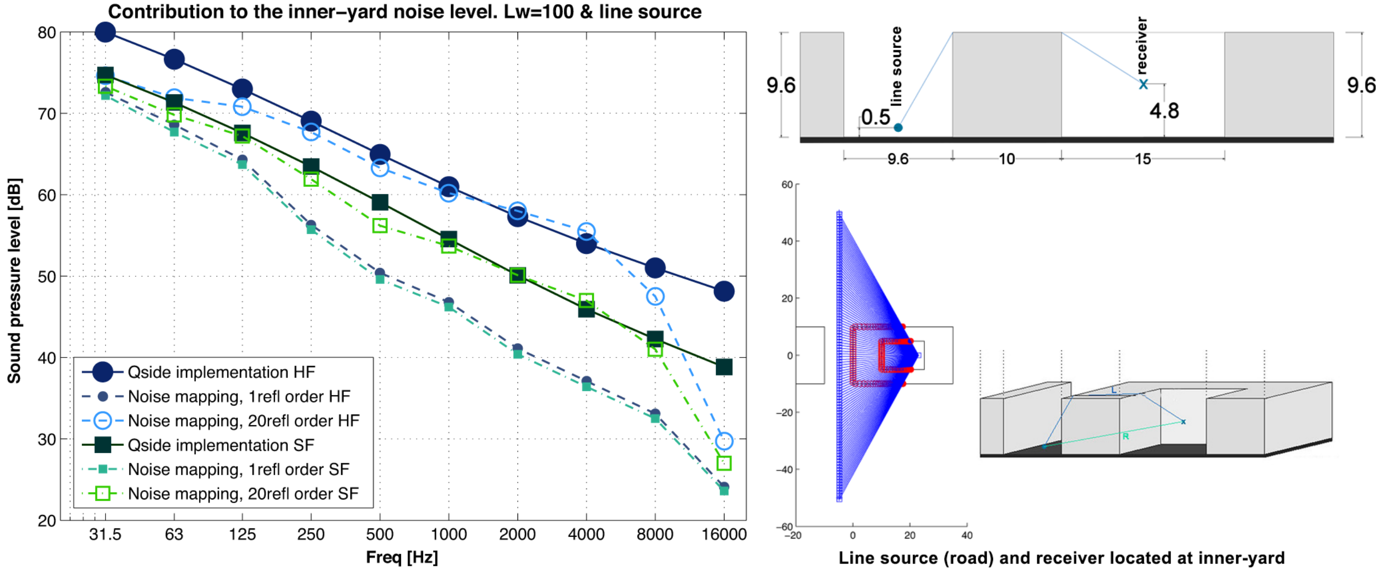


Figure 4 - Contribution to the inner-yard noise level from a line source (road). Differences between noise mapping software with different reflection order and Qside implementation with soft and hard facade materials.

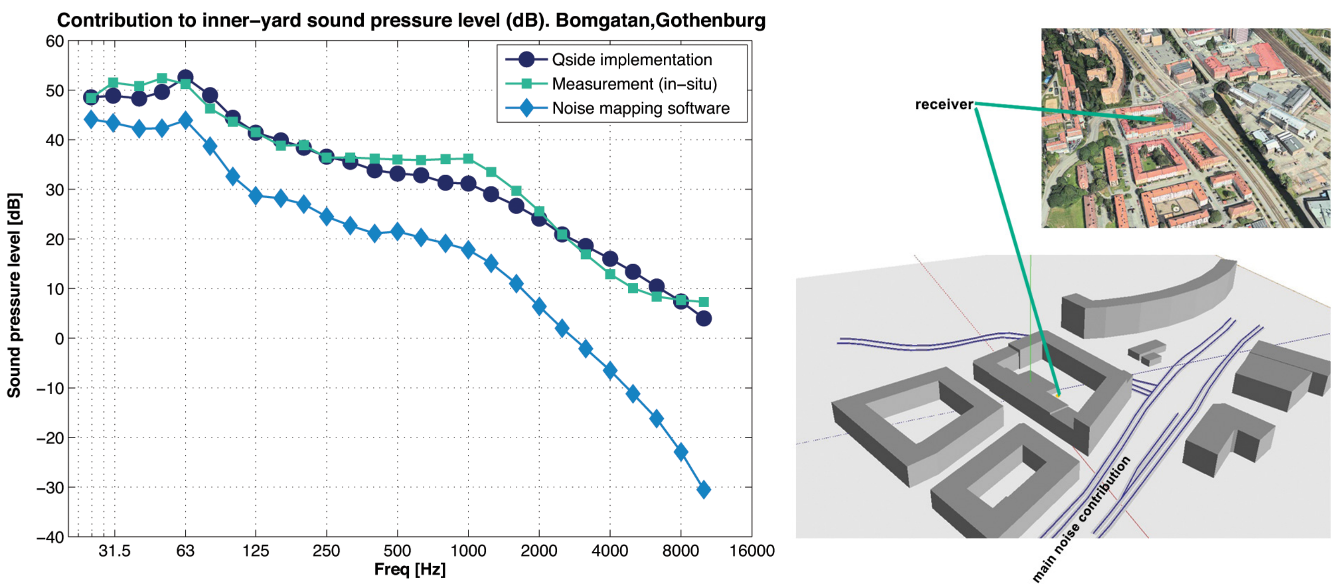


Figure 5 - Contribution to the inner-yard noise level. Differences between measurements, Qside implementation and noise mapping software.

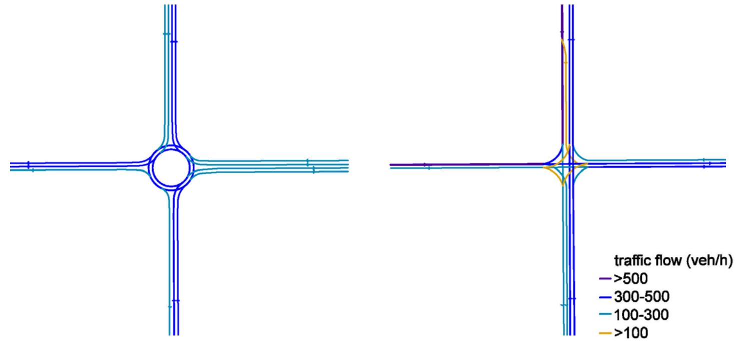
measurements, with a total deviation of around 3 dBA. Contrary, noise mapping prediction software showed a deviation of 15 dBA in the case of including one reflection order. These results show that the inclusion of this type of tool in the decision-making process of the city is highly needed as a complement to the current noise mapping software techniques.

TRANSPORT MANAGEMENT AND NOISE EMISSIONS: INTERSECTIONS

Among the microscale traffic study in cities, one of the most important designs is of the intersection. A common practice has been to replace crossings by roundabouts as a safer alternative. To compare these two intersection types, the influence of vehicle kinematics is studied in SONORUS through a microscopic traffic assessment. The two intersection types are based on the future urban development of Frihamnen in Gothenburg, with a different number of vehicles coming from the different streets approaching the intersection. The intention is to isolate key features that could help to understand their behaviour and the sound environment impact. For this, we study several indicators based on time patterns related to human annoyance for three scenarios of each intersection type.

Here, a flat and hard ground without buildings is modelled.

(a)



(b)

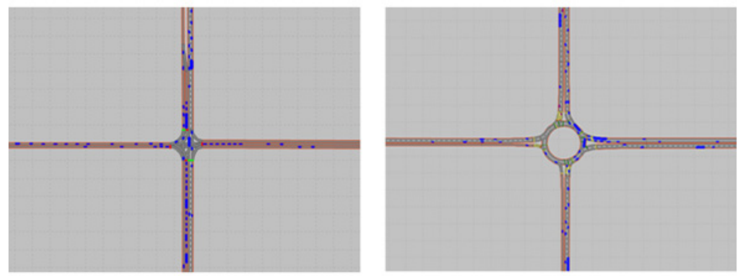


Figure 6 - Two intersection types. Crossing and roundabout. (a) Amount of traffic, (b) microscopic traffic simulation.

In the scenarios, the same amount of traffic was handled in both intersection types, adjusting the road layout. In Figure 6a, the amount of traffic is indicated, with a smaller total flow in the E-W direction compared with the N-S direction. Figure 6b represents the microscopic traffic simulations for both scenarios.

Table 1 – Scenarios for signalized crossing and roundabout: vehicle distribution

Case	**% Vehicles**		
	Light (LV)	Medium-heavy (MHV)	Heavy vehicles (HV)
1) LV-MHV-HV	92	4	4
2) LV-MHV	96	4	-
3) LV	100	-	-

Since vehicle types also have a strong influence on people's perception of the sound environment, we study alternatives of including heavy-vehicles (>12 tons as large buses and heavy duty vehicles) and medium-heavy vehicles (3.5-12 tons) in comparison with having only light vehicles (<3.5 tons) for the peak hour as the worst-case scenario (Table 1).

To study the differences between these two intersection types, 12 study points are included. The results, displayed in Figure 7, show that not all study points are less noisy for a certain intersection type, since it strongly depends on how traffic is handled:

- Queues at certain lanes make it difficult to enter the roundabout. In this case, if points are located close to the intersection, crossing has higher noise levels (1-4 dB);
- For sidewalks in the E-W direction, the roundabout tends to have higher noise levels (probably due to low traffic flow and the resulting higher driving speeds);
- For location points at 100 m of the intersection, the behaviour is similar for both.

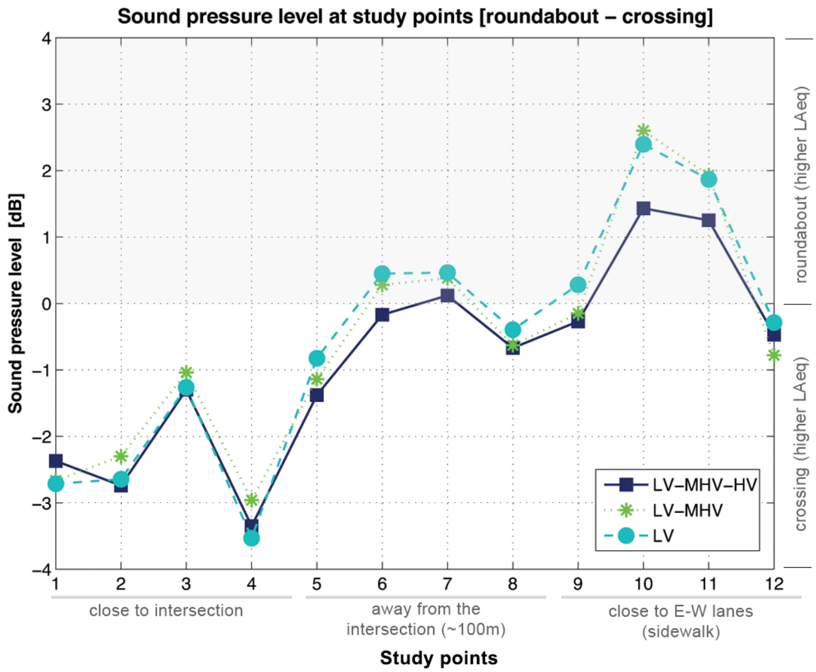
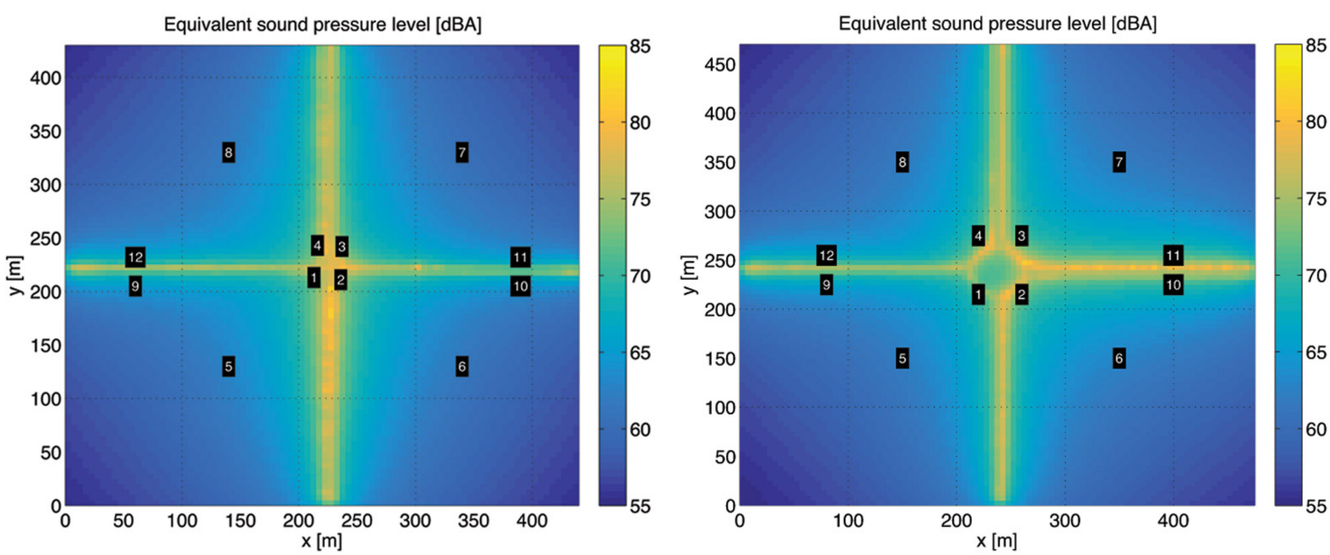
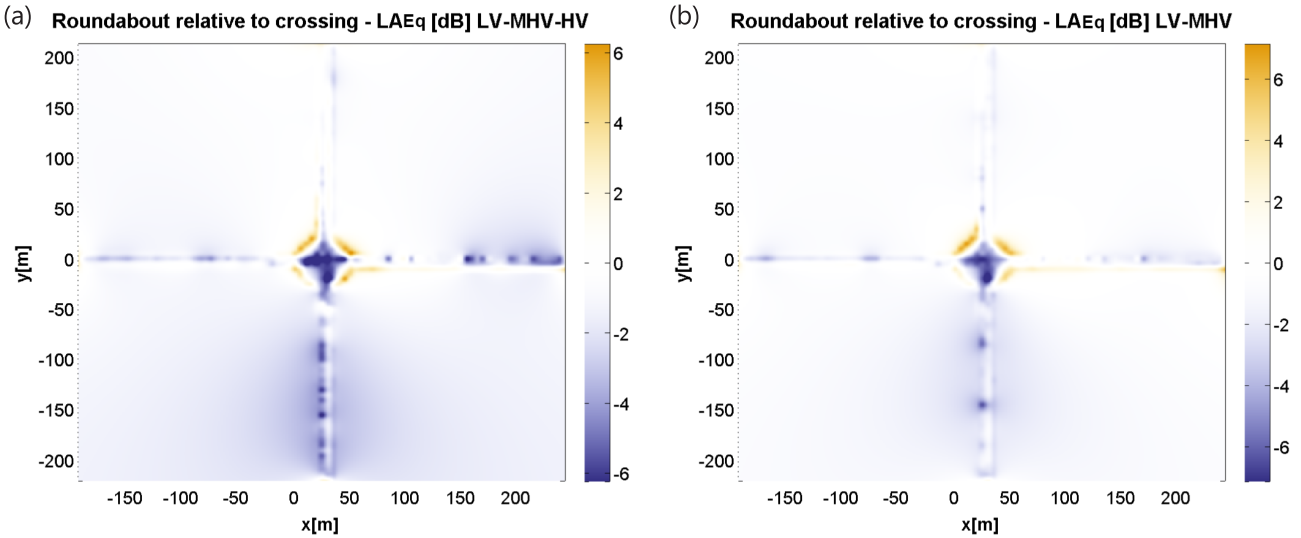


Figure 7 - The consequences of replacing the intersection types in the sound pressure level (dB) including heavy, medium-heavy and light vehicles.





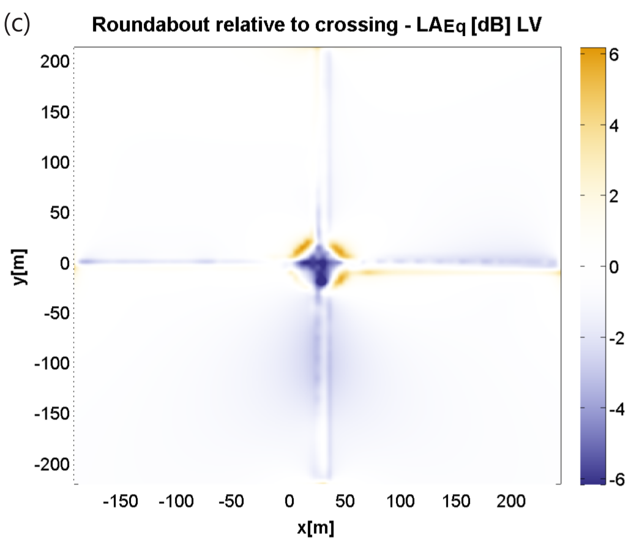
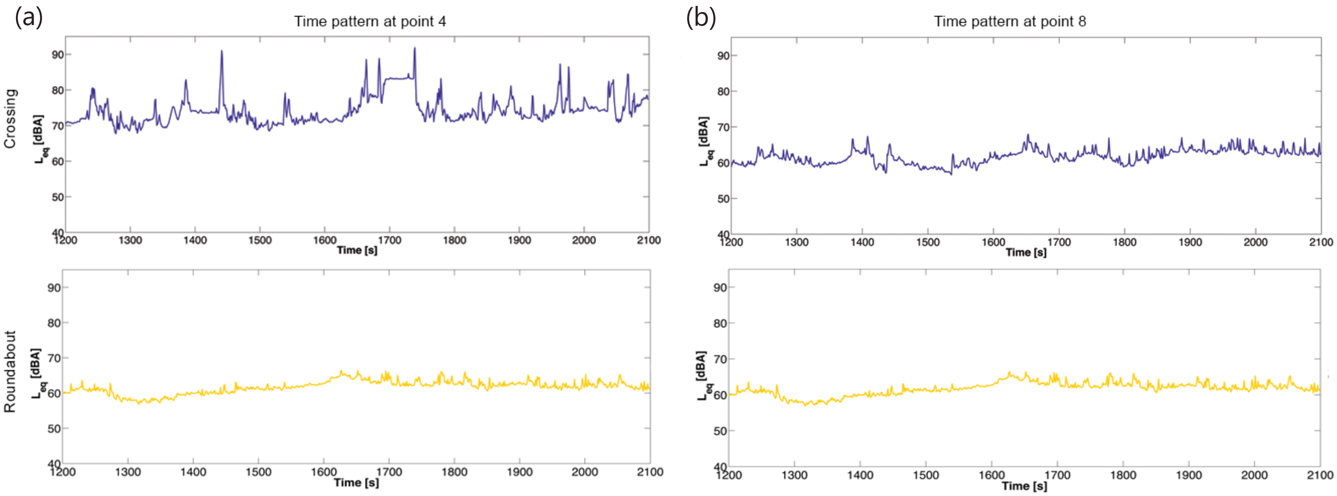


Figure 8 - Equivalent noise level difference maps for the crossing and the roundabout for the three vehicle types: light, medium-heavy and heavy vehicles (a), light and medium-heavy vehicles (b), light vehicles (c)

The equivalent sound pressure level difference maps present a useful tool to observe the different behaviours of the two intersections (Figure 8):

- With different vehicle types, the signalized crossing intersection is having a higher sound pressure level almost in the entire area (blue colour), being more equal when removing the heavier vehicles;
- The effect of vehicle kinematics is present and it is observable as a stop-and-go behaviour represented by blue dots that indicate higher noise levels due to interrupted traffic flow;
- With these types of maps is clearly observable that noise mapping software, which gives as output a constant traffic flow, is not enough in case we want to study how traffic behaves in urban areas and the impact on people’s health and behaviour.



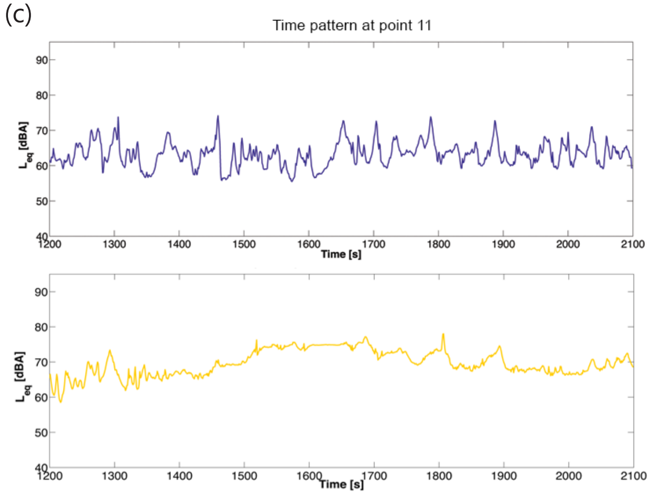


Figure 9 - Time patterns at (a) study point 4 (at the intersection), (b) study point 8 (at 100 m of intersection) and (c) study point 11 (at sidewalk) for the signalized crossing and the roundabout

At high traffic variations, as the ones present in dense urban environments, time patterns, as shown in Figure 9, become relevant since noise annoyance is partly determined by the noise events resulting from traffic flow. Moreover, if we are interested in the types of activities and uses that citizens can do of such urban spaces, the sound environment becomes even more important. For example, if one wants to experience the city-life, have a coffee with friends without being disturbed by road traffic noise, etc.

In the study of number of events above 60 dBA for these two intersections (see Figure 10), one can conclude that:

- There is a strong influence of heavy vehicles, resulting in a larger number of events, specially in the roundabout scenarios;
- As soon as the heavy vehicles are removed, the differences start to smear out.

(a)

(b)

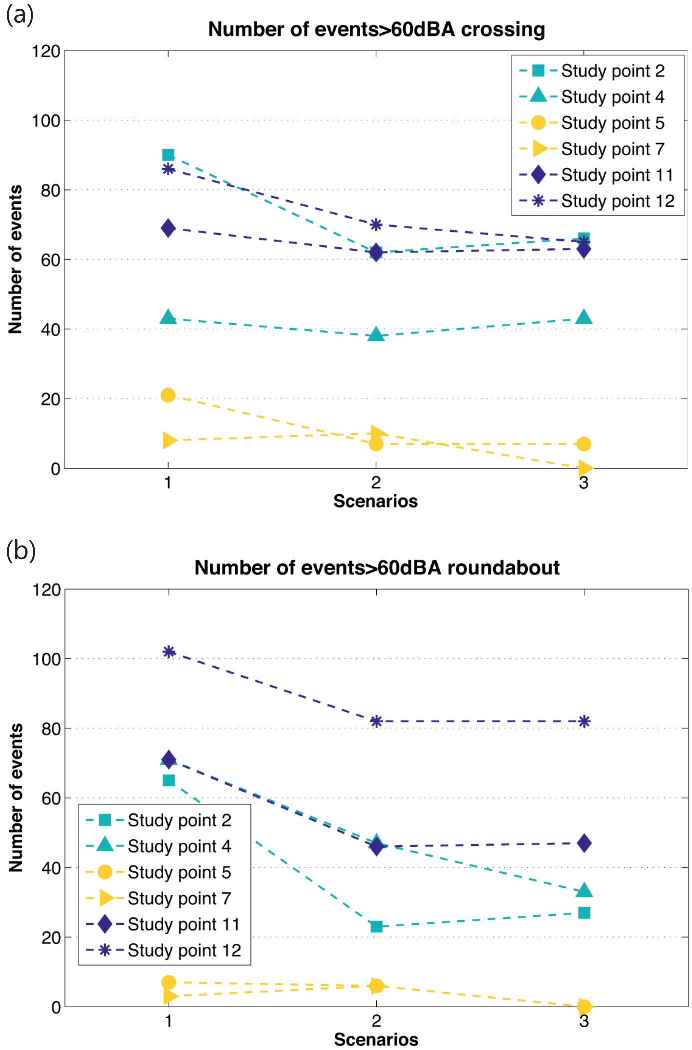
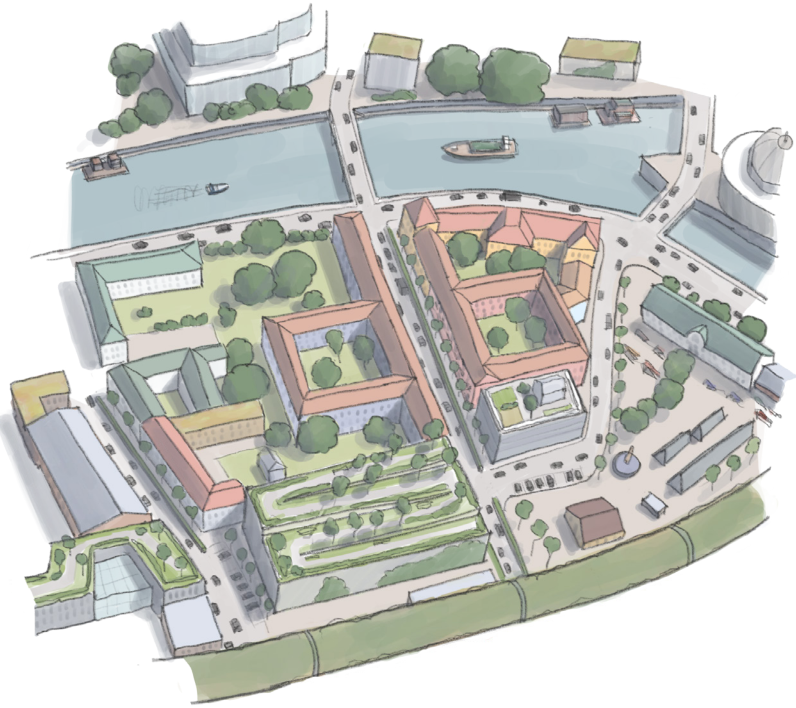


Figure 10 - Number of events above 60 dBA for the signalized crossing (a) and the roundabout (b)

- The behaviour within this type of analysis is rather different than in the study of sound pressure level. The implicit rule to yield to vehicles in the roundabout results in a higher congestion of certain parts of the network, as these vehicles need a larger gap to enter the roundabout, turning it into a complex situation in the case of high traffic flow.
- The signalised crossing maintains a more constant behaviour throughout the inclusion or exclusion of different vehicles types. In this sense, research has appointed that the presence of heavy vehicles led to higher unpleasantness scores in the roundabout cases.

These types of results are interesting in the study beyond the energy equivalent measures, accounting for noise events caused by traffic. With this, we want to go further in the understanding of traffic scenarios and its relation to traffic density and traffic flow related to the appropriateness of the sound environment to certain uses and functions.



Controlling the sound environment at mesoscale level

THE EFFECT OF TRANSPORT MANAGEMENT AND TRAFFIC DESIGN ON ROAD TRAFFIC NOISE

A major concern in the planning of our cities is to improve mobility, which is directly connected to transport management and traffic design decisions. Moreover, these decisions are deeply linked to the characteristics of the sound environment. All around Europe, chronic traffic congestion has become a problem, and around 30 million of EU citizens are exposed to road traffic noise levels above the World Health Organization targets (Ln<55 dB, Ld<65 dB). Controlling the acoustic environment by creating urban spaces with good quality that support health and wellbeing is a priority in the unavoidable densification process of cities. These aspects have enormous consequences in the currently high construction rate, which makes later remodelling complex and expensive.

Environmental noise levels depend on the strengths of the sources and on the propagation paths. Transport decisions have consequences on both of them. Urbanization processes and environmental sustainability are under a constant collision and, due to its relevance, infrastructures are normally seen as the battleground of play. One of those infrastructures refers to the transportation system. In SONORUS we focus on the transport management and traffic design, looking towards a more efficient transport layout, bringing opportunities to improve the sound environment by studying time patterns and vehicle kinematics, strongly linked with annoyance and health effects among citizens.

The mainstream prediction tool for traffic noise is through static traffic flow analysis. These instruments, commonly known as noise mapping prediction tools, are very useful as a first attempt to study the noise level exposure of larger areas. Here, we are under the framework of a macroscopic analysis with mean speed and flow (veh/d) as input, and day-evening-night noise level as output.

In urban areas, traffic is characterised by high fluctuations in terms of acceleration due to the presence of pedestrians, intersections, parking places, etc. In these cases, the study turns towards a mesoscale and a microscale level. In such situations, the traffic noise assessment can be underestimated by noise prediction software. Here, features from transport dynamics become relevant, having a strong influence on the source strength. This becomes extremely important since, in recent decades, research has pointed to the effect of road traffic noise events on noise annoyance and other health effects, especially during night-time where sleep disturbance is more evident.

In SONORUS a tool is developed to improve the city decision-making processes in terms of road traffic and noise emission, bridging the gap between current situations in cities and urban planning practice. The dynamic assessment tool consists of a series of microscopic traffic simulations that allow for the inclusion of vehicles kinematics. The traffic simulation gives as output single-vehicle data in terms of position, speed and acceleration, used to compute the noise emission of each vehicle along time. For this part the tool is composed of a series of in-house Matlab scripts implementing the road emission model of the Common Noise Assessment Method in Europe (CNOSSOS-EU) (see more in the Chapter on "Prediction and auralisation of urban sound environments"). Main outputs are noise contribution maps, i.e. respective contribution from each road segment to a selected receiver, and time patterns enabling to study the effects of vehicle kinematics.

To test it under a real case scenario and explore its possibilities, the new urban development of Frihamnen test site has been used. This way we are able to evaluate the impact that the transport management and traffic design of the new development plan will have on the noise emission and the sound environment. Moreover, we can test plausible traffic strategies to explore new possibilities that may improve the quality of certain urban areas. The study focuses on 9 traffic alternatives. As an example, we show here 5 different strategies: (1) base-scenario for the future plan, (2) remove a road and move its traffic towards other adjacent roads, (5) reduce speed in the highway located near the area, (8) remove medium-heavy and heavy vehicles, and (9) neglect the effect of acceleration. The "Applied Urban Sound Planning" Chapter includes more about the results on a real case study.

To understand the possibilities of the tool, the equivalent sound pressure level is plotted for the selected scenarios for different study points (check Frihamnen area section at "Applied Urban Sound Planning" to locate them). In case the heavy and medium-heavy vehicles are removed from the network (8), equivalent sound pressure level (LAeq) reductions at the selected points are between 1 and 3 dB. The same occurs if acceleration noise is omitted (9).

With this type of tool, we can study time patterns in any form of indicator depending on noise level, e.g. L50 meaning the level exceeded 50% of time, or e.g. an event, defined to occur when a chosen noise level threshold is exceeded, lasting for at least 3 seconds, and then it is finished when the level has decreased 3 dB from the threshold. In our real case study (see Figure 11), the number of noisy events as the ones above 65 dB, are drastically reduced in the scenario without heavy vehicles (scenario 8) for the majority of the points (up to 60% less noise events at several points). In case there is a change in the traffic network (scenario 2), the reductions are visible at several study points, however, other ones are having an increase in the number of noise events as a consequence of the added traffic. In Figure 11, the equivalent sound pressure levels (a) and number of events above 60 dB (b) are plotted for the different scenarios.

This type of tool might be very useful as input for road traffic auralisation as a further step in the study of new development areas, giving a new perspective in the study of the urbanisation process (see "Prediction and auralisation of urban sound environments" Chapter).

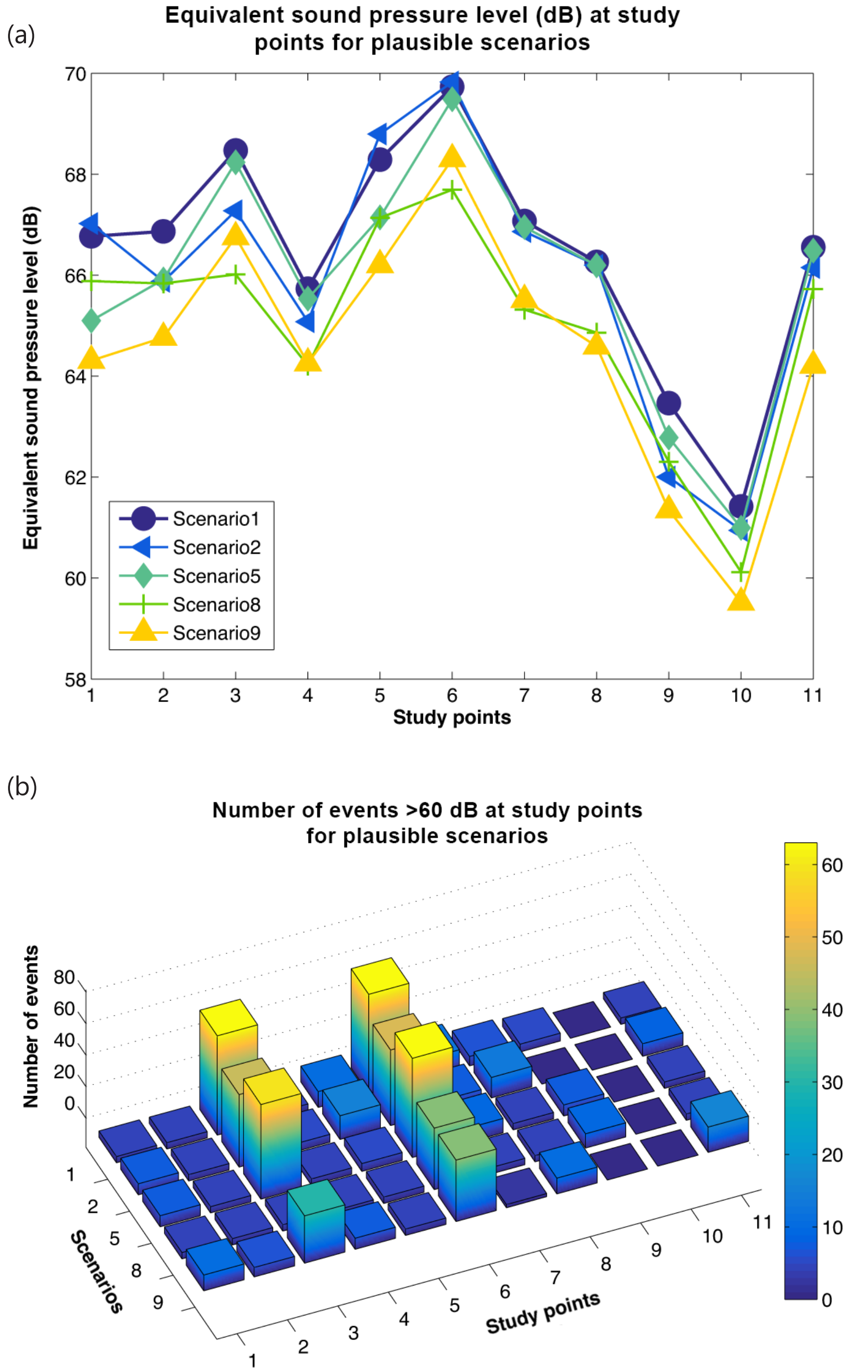


Figure 11 - Equivalent sound pressure level (a) and number of events above 60 dB (b) for all study points and plausible scenarios

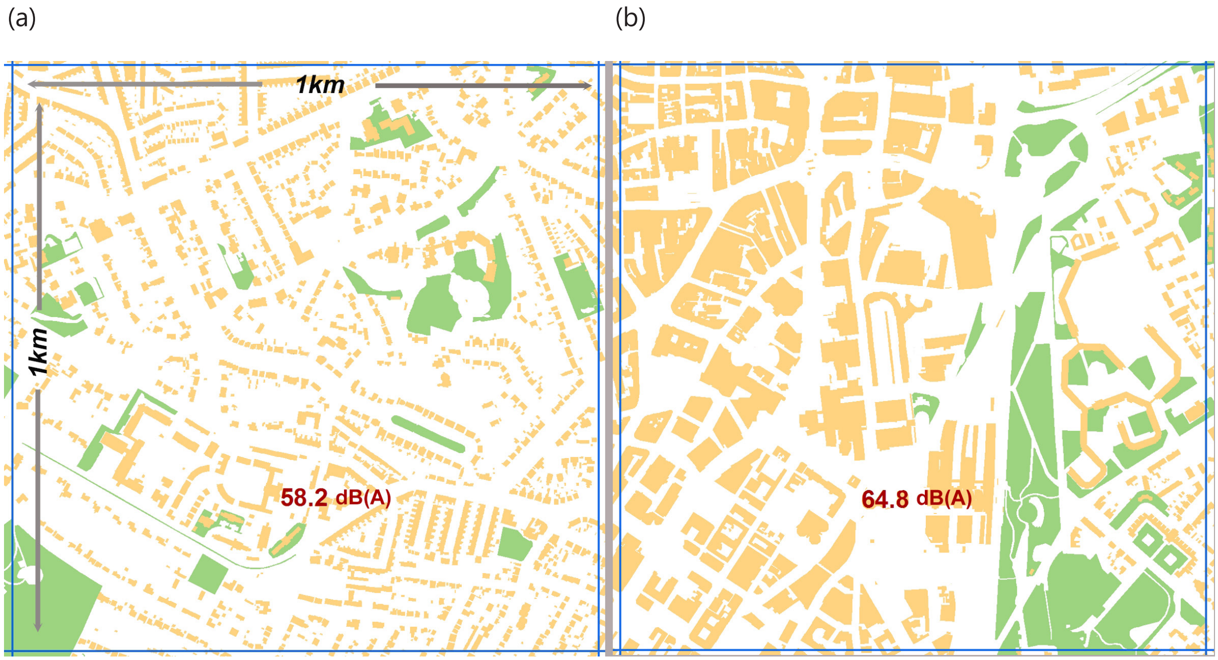


Figure 12 - (a) Case with dispersed green space pattern (left) (ANN=0.79), (b) case with clustered green space pattern (right) (ANN=0.84).

THE EFFECT OF GREEN SPACE PATTERN ON TRAFFIC NOISE DISTRIBUTION

Green space becomes important in the analysis of the sound environment. The analysis of green space coverage itself is sometimes not enough to be used as a predictor for the average noise levels. Another issue is that frequently, cities express an unequal spatial distribution of their green space pattern depending on the morphology of the place and the socioeconomic status of the area. Overall, the green space pattern as a parameter is sometimes more important than the green space coverage itself. Small areas with similar green space coverage and different green space pattern exhibit different noise levels (Figure 12).

The same conclusions were found in a city-scale approach. Eight average-sized UK cities were investigated using a sample area of 30 km2. A preliminary study is presented in Figure 13a, where the population density ranges between 4,300 and 7,200 residents/km2 with Brighton being the most densely populated city. Regarding the car availability (Figure 13b), there are relatively small differences among the cities and a

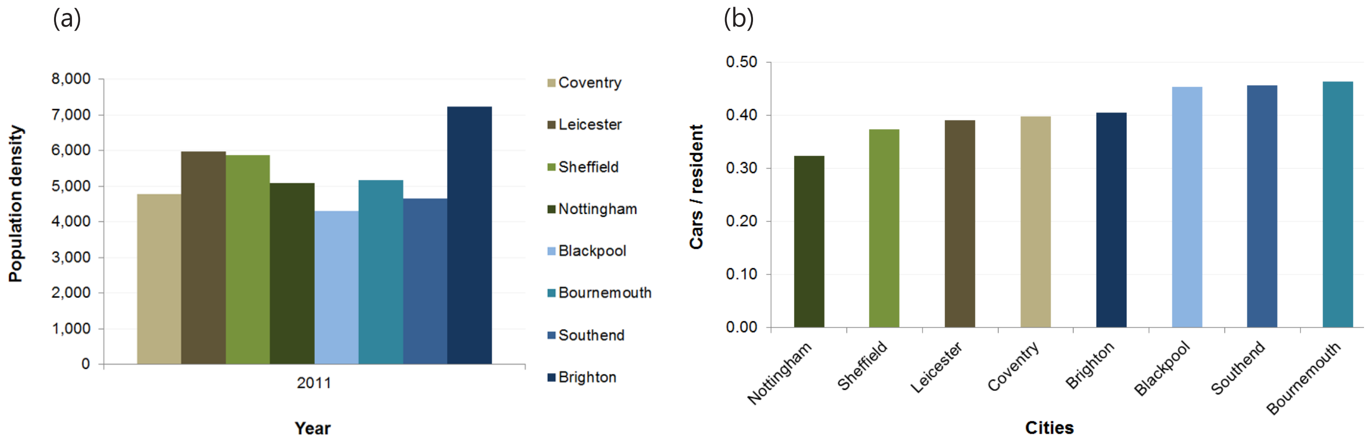


Figure 13 – (a) Population density (residents/km2) in the sample area for the eight cities, (b) car availability per resident in the sample area

range between 0.32 and 0.46 cars/resident. In this case the order of the cities was not consistent with the population dynamics. In particular Brighton comes in the fifth place with Bournemouth to have the highest ratio out of the eight cities. The two figures combined show that the fluctuations in population and car availability are relatively small, which makes the cities comparable for a further analysis. It should be noted that here we assume that the acoustic output power is proportional to the car availability ratio, since no traffic count data was available at that stage. This argument is also strengthened by the positive correlation between the total number of cars per city and the sound pressure level as presented in Figure 14.

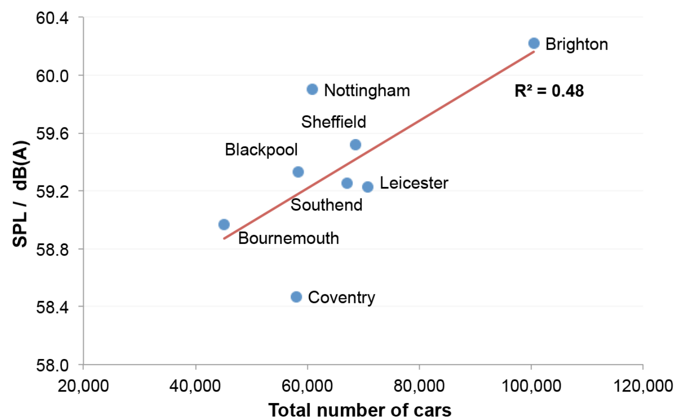


Figure 14 – Positive correlation between the total number of cars and the sound pressure level (SPL) in the eight cities

Regarding the green space pattern in the eight cities, it was shown that the existence of small and dispersed green space patches can lead to lower average noise levels. The extent of dispersion was measured by the Average Nearest Neighbour (ANN) index where higher values denote a dispersed pattern (see Figure 15).

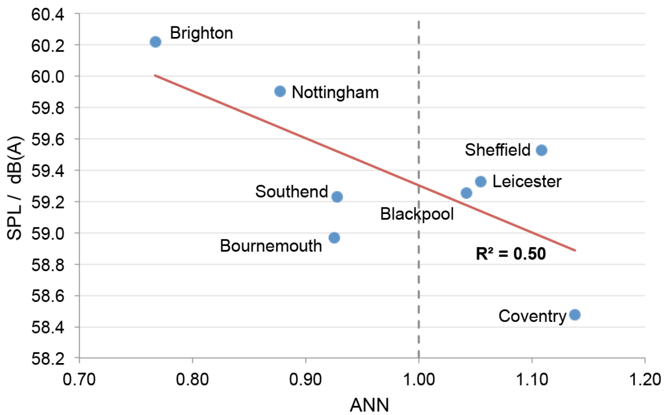
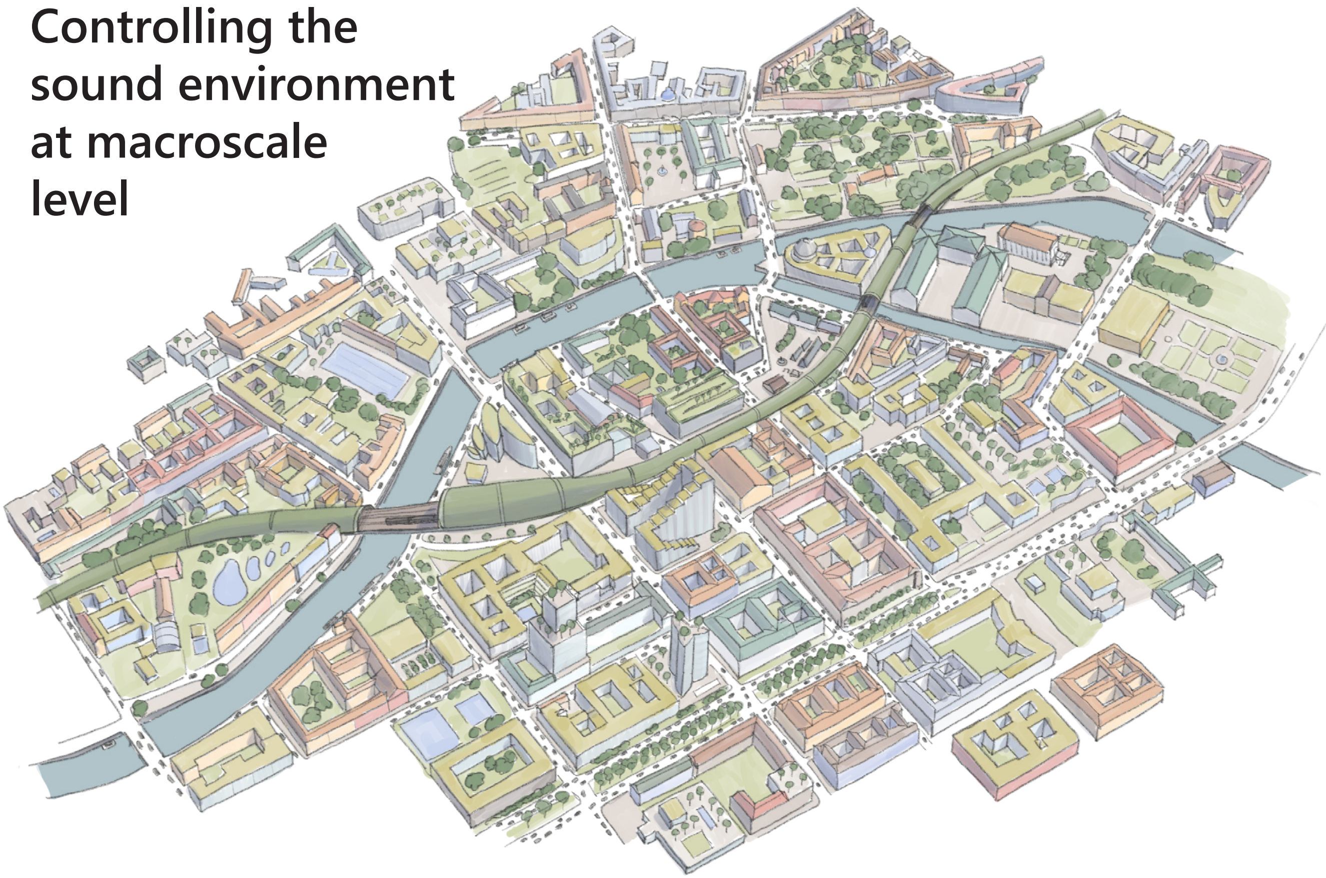


Figure 15 - The effect of green space pattern (ANN) in various UK cities

On the contrary, a clustered green space configuration within the same area tends to lead to higher noise levels. The distances observed among the green space patches ranged between 47 and 107 m. From the planning perspective, these findings can also provide a positive input to the green space accessibility and proximity standards for the citizens. Such guidelines already exist for the UK standards, but not for the European, since the most common guidelines refer just to the total green space coverage or the amount of green space per capita.

One restriction by testing the same indicators in different scales is that usually results tend to be scale-dependent. This means that indicators that are correlated in the macroscale can be rejected as uncorrelated in the mesoscale or inversely.

Controlling the sound environment at macroscale level



THE EFFECTS OF CITY STRUCTURES ON ROAD TRAFFIC NOISE

Each of the previous cities (see Figure 15) has a unique road network structure affected by the morphology of the area and the way it evolved over time. For planning purposes, existing structures of all cities were classified in three systematic forms: radial, linear and grid. Examples of a ring road structure and a linear one are presented in Figure 16.

A comparison between the green space coverage and noise levels of each city (Figure 17) shows that those surrounded by a ring road (radial) have a significantly higher percentage of green space coverage (Figure 17a). However, as presented in Figure 17b it was not directly clear whether at this scale results could be drawn for noise levels. Nevertheless, from the planning viewpoint, a distinction in the city's form can provide initial

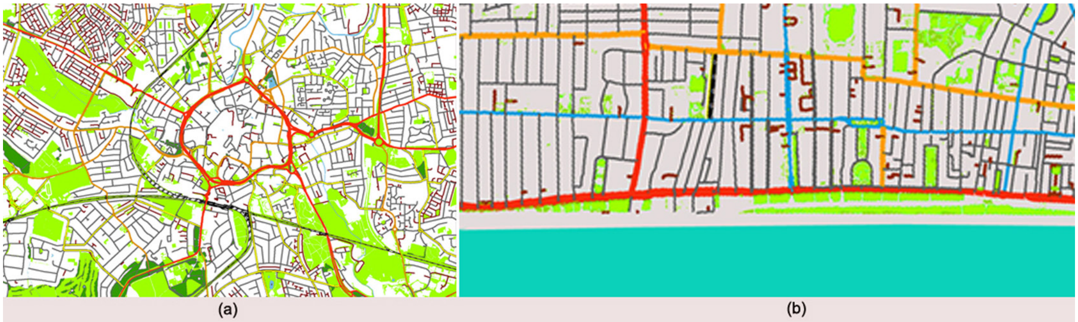


Figure 16 - (a) Ring road in a radial city (Sheffield),
(b) Long main road next to the sea in a linear city (Brighton)

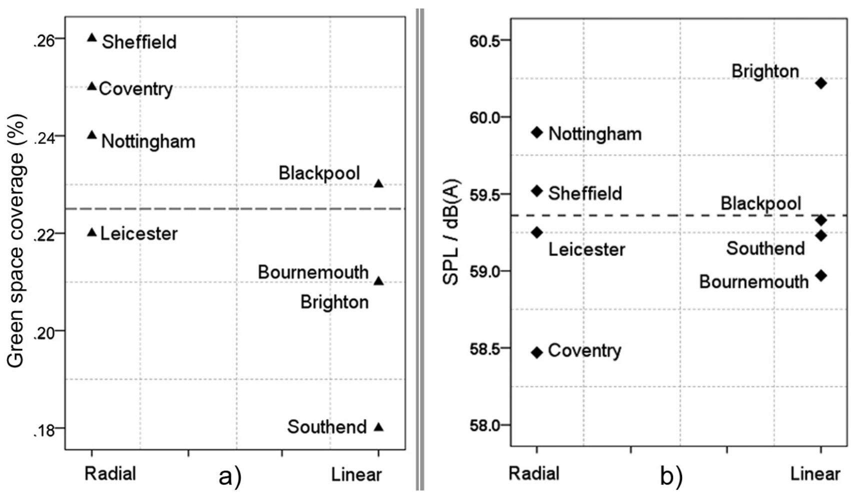


Figure 17 – Description of the relationship of radial and linear forms with: (a) Green space coverage ratio, (b) Noise levels

evidence for the cost of possible noise interventions or the policy that should be followed. Characteristic examples are the ones referring to the Outline Zoning Plans and the compatibility of different land uses.

THE EFFECT OF SPECIFIC GREEN SPACE VARIABLES ON TRAFFIC NOISE

To relate traffic noise prediction and the effect of green space, two typical average-sized UK cities were chosen as Sheffield and Brighton. Sheffield, apart from being a radial city, is also con-

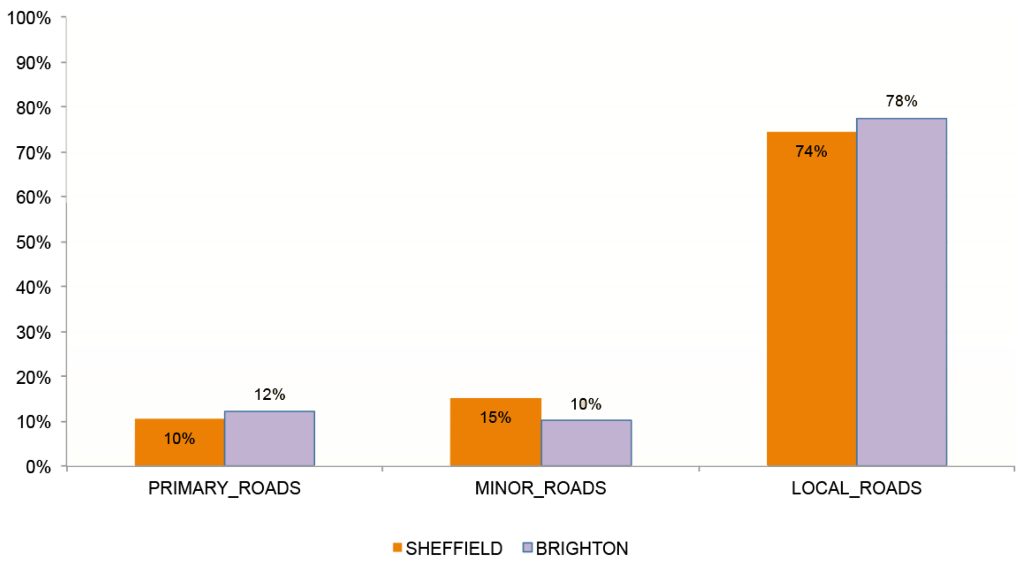


Figure 18 - Comparison of the road coverage in the two cities in primary, minor and local roads

sidered one of the greenest cities in England. On the other hand, Brighton is a mid-size linear city with less natural green spaces within the selected study area. Both cities present similar characteristics in terms of the road coverage in the different categories as presented in Figure 18. They also have similar values in the car availability per resident, which allows for further comparison between them.

The analysis on the green spaces in these two typical UK cities has shown that green areas, such as parks, urban forests and gardens can affect traffic noise distribution. This was especially noticeable in purely residential areas with high green space coverage. For example, the "Gardens ratio" referring to vegetated backyards or front yards, could be a good predictor for traffic noise, since it contributed up to 38% in the Lden explanation for the current case studies (see Figure 19). The combination of detached or semi-detached houses and their gardens (Figure 20) reflects the noise resistant areas, favoured also by the small local roads around them and their distance from the city centre. Such results can be further used in the planning field, when designing residential areas in combination with the traffic management system. Another parameter that was also proved significant is the total number of cars, which in this particular case was negatively correlated with the amount of green areas within the same study sites (Figure 21).

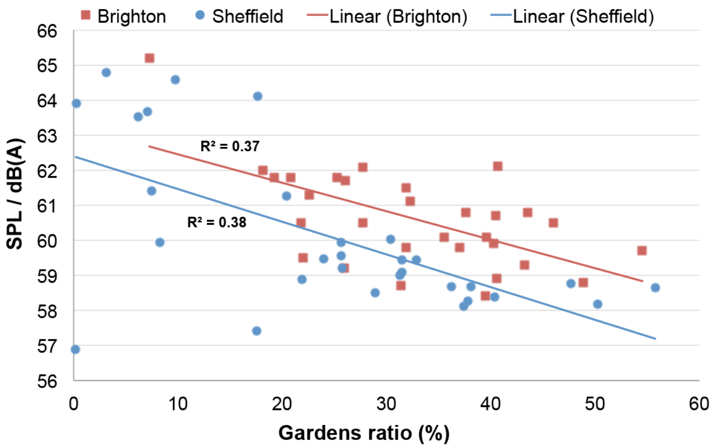


Figure 19 - The effect of Gardens ratio in the Lden levels

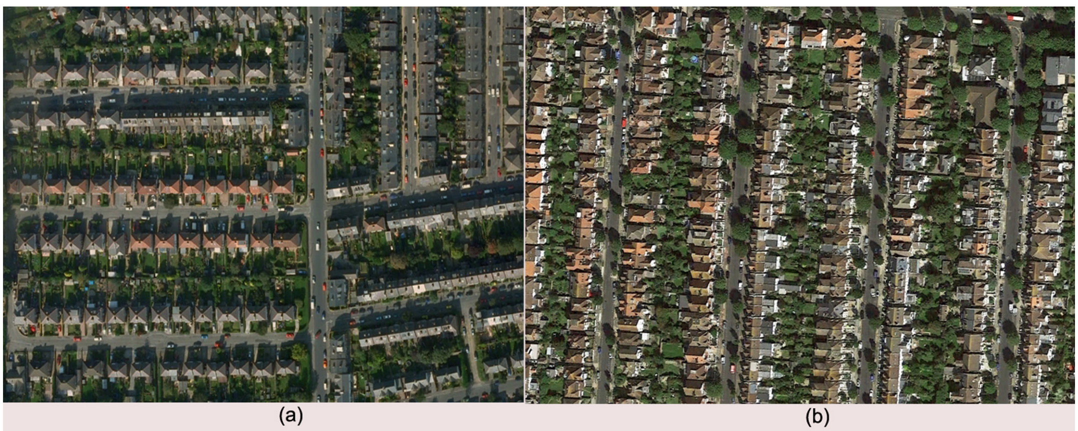


Figure 20 - Example of houses with vegetated backyards or front yards in (a) Sheffield, (b) Brighton

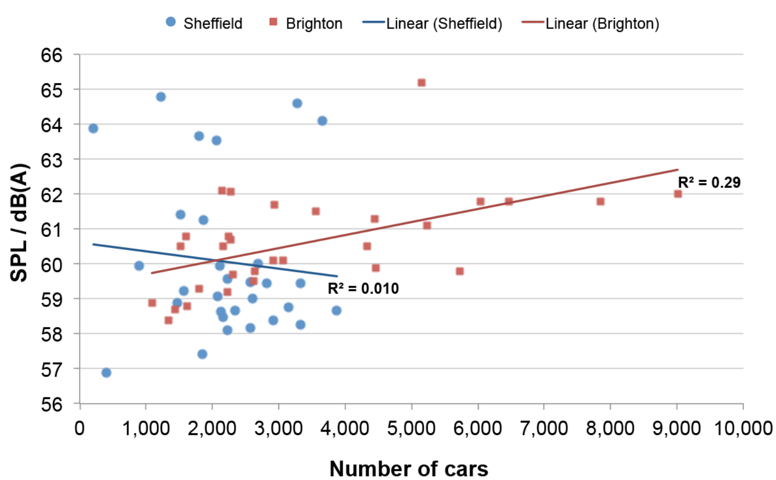


Figure 21 - Correlation between the total number of cars and the green space coverage in the investigated cities

PREDICITING THE EXTENT OF QUIETNESS IN CITIES BASED ON GREEN SPACE DATA

The macroscale level holds a great number of systems and stakeholders, which are constantly interacting. This manifold of interests makes the study from the acoustic point of view even more complex. As an attempt, the research in SONORUS started to analyse the extent of quietness in cities based on the green space data. This has been done through a comparison of the land cover data (green spaces) and the correspondent city classification. The classification was done in a descending scale, assuming that the greener ones will also be quieter.

The approach has a theoretical basis in terms of the physics of sound propagation, since green areas such as parks, usually have low noise levels within the urban context of a city. However, the research in various European cities showed that this assumption is not always true. For example, Antwerp (Figure 22), with a high percentage of greenery, was also proved noisier. Novel indicators going beyond the traditional approaches as the green space availability (m²/person) gives a better understanding of the urban sound environment. In this sense, an indicator such as the porosity of the city (Δ_{porous}) considers the ratio of green areas to the built-up ones (building and road coverage), as presented in Eq. 1. This indicator can also be used as a predictor for traffic noise levels in the macro scale.

$$\Delta_{porous} = \frac{Green\ space\ coverage}{Building\ coverage + Road\ coverage} \quad (Eq. 1)$$

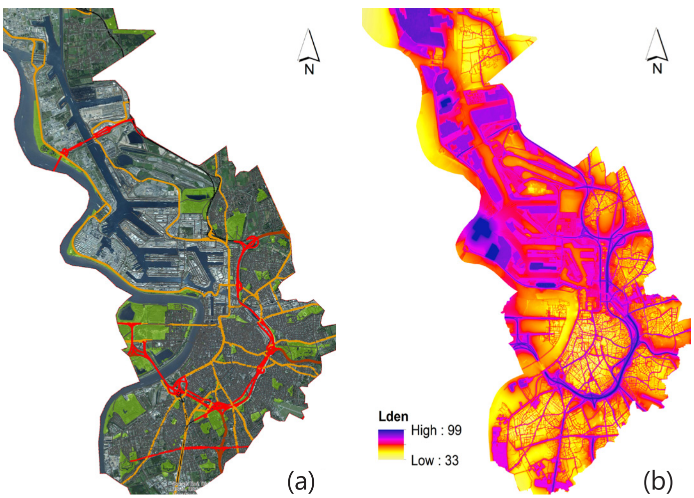


Figure 22 – (a) Green space distribution in comparison with the highway network of Antwerp, (b) Noise level distribution according to the strategic noise map of the city

Prediction and auralisation of urban sound environments

Authors: Fotis Georgiou, Raúl Pagán Muñoz, Frederik Rietdijk, Georgios Zachos

Introduction

A key role in the acoustic planning and design process of urban areas is played by the numerical prediction of sound propagation. Being able to simulate the sound field in urban environments can be used to facilitate the decision-making and closing the communication gap among the diverse groups participating in the planning process.

Nowadays, prediction methods are widely used in Europe for noise mapping purposes in order to fulfil the EC noise mapping requirements and, additionally, they are of large importance for evaluating the impact of noise control measures. Here, we make a distinction between the prediction methods typically used for noise mapping, referred to as engineering methods, and the computational urban acoustics methods, which predict the urban sound field with high accuracy by numerically solving the governing physical equations after some simplifications.

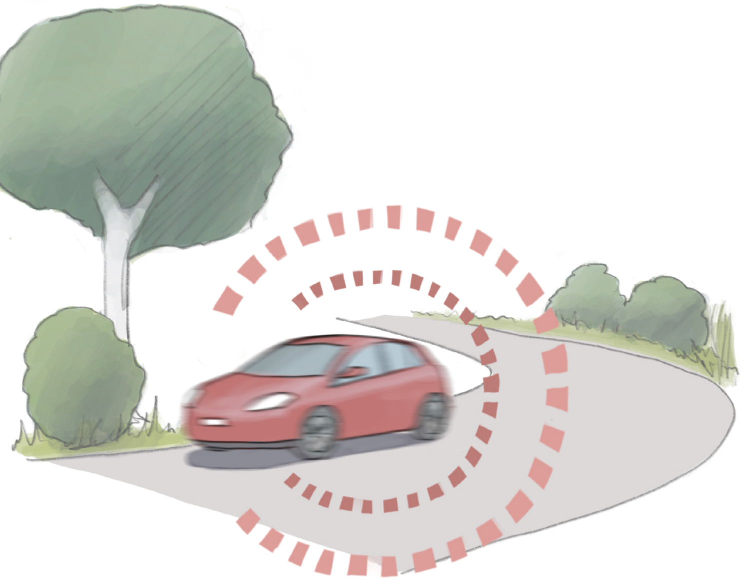
The predictions also form the basis for auralisation purposes, i.e. making the urban environment audible in a virtual reality sense. It can be seen as the process of simulating a listening experience. While developed originally for room acoustical purposes during the recent decades, auralisation of outdoor environments has gained an increased interest during the last decade. Being able to listen to a planned environment before it has been built is not only informative for decision makers and users at all levels, including the citizens, but can also be used as input for further computer aided analysis and tools.

A sound environment can consist of audible contributions from a large number of sources. The sources may be stationary in space, like a splashing water fountain in a park or a humming bus on idle, or moving through space, like a flying seagull making its alarm call or the siren on a passing ambulance. The source signal of the auralisation can be a recorded or a synthesised sound. Due to the large possible variation in output of environmental sound sources, it is attractive to use models for the synthesis of the source signals rather than relying on recordings.

The sound propagation effects, during the travel from the source to the listener, are separated from the source model, whereby the same propagation modelling can be applied to different sound sources. The usually unavoidable propagation effects of importance to model are the distance decay, the ground reflection, and the air absorption, as well as the Doppler effect in case of a moving source (or receiver). Other propagation effects may involve reduction due to screening objects, reflection/scattering in facades and other objects, focusing due to wind and temperature profiles, and wave distortion due to turbulence in the air.

Since the calculation of the propagation effects may be numerically expensive, it is of interest to try and simplify the physical modelling. For instance, for auralisation puposes, the modelling of a distant road (macro or mesoscale background sounds) may be simplified if there is a more prominent sound event, e.g. a car passing by on a nearby local road (microscale foreground sound). Simplifications leading to a reduction of the numerical cost may thus allow for a higher level of detail in the modelling of the more prominent sound events, enabling real-time auralisation of more complex situations.

Conventionally urban environmental noise is assessed with noise measurements and noise mapping software. Also, noise control measures are usually ex-



pressed as a reduction of sound pressure level, e.g. of the Lden value. This way of evaluating an acoustic environment and a noise control measure can indeed help in getting a good insight and helps in the decision making regarding the action that needs to be taken in order to improve the acoustic environment. However, since the noise sources in the urban environment are time varying they cannot be assessed only by equivalent noise levels like Ld, Ln, Lden etc. Moreover, urban noise sources can be masked by a positive sound source. For example, a fountain on a square will increase the noise levels but the overall acoustic quality can be improved since the sound from the fountain, which is usually considered a positive sound source, may mask the unwanted traffic noise. This effect would not be observable on a regular noise map. Therefore, new tools are needed for the design of the uban environment, where more detailed prediction and auralisation has its place, also supporting the concept of soundscapes. Furthermore, combining aural and visual information enhances the experience giving a feeling of immersion. The level of immersion can be greatly enhanced by creating the possibility to interact with the simulated environment, for example by using virtual reality glasses that allow you to look freely around.

Prediction methods

During the last decades, different techniques have been developed for sound field prediction. Among them, geometrical acoustics methods, diffuse field methods and wave-based methods have been of main importance. Geometrical acoustics and diffuse field techniques can be regarded as engineering methods. Basically, in geometrical acoustics the sound waves are computed as rays that interact with boundaries while the diffuse field approach is based on the propagation of the sound energy instead. Both methods are mostly appropriate in the high frequency range where the assumptions taken in their implementation fairly well fulfil the conditions of the sound environment. For geometrical acoustics methods, the environmental objects need to be large in comparison with the sound wavelength, where a small wavelength corresponds to a high frequency.
Diffuse field methods are applicable when the sound field is similar to an indoor space and is spatially smooth, i.e. they may be applicable mainly to inner city environments and at sufficiently high frequencies such that individual standing waves are not prominent. On the other hand, the precision of the geometrical acoustics computations highly depends on the number of reflections included in the calculations. This order of reflections is a key factor for those inner city environments where the direct sound coming from the source is not the main contributor to the sound field, hence a too low amount of reflections in the calculations will cause an underestimation of the sound levels. However, including more reflections increases the computational time. Furthermore, engineering methods are limited in accounting for complex meteorological effects and for irregular facade shapes. Nevertheless, engineering methods are suitable for noise mapping purposes at macroscale level with a reasonable balance of accuracy and computational time. In the last years, a unified method based on geometrical acoustics has been developed for noise mapping according to the European Noise Directive (END). The method, referred to as CNOSSOS-EU, harmonizes the operational approach to be used in future rounds of strategic noise maps in the European Union.

Wave-based methods account for all phenomena of wave propagation in their approach and when all input data is appropriate, mainly sound source features, atmospheric conditions, urban topology and other properties of boundaries (facades, streets surfaces, vegeta-

Table 1. Most popular computational urban acoustics methods

Method	Acronym
Pseudo-spectral time-domain	PSTD
Finite-differences time-domain	FDTD
Boundary element method	BEM
Equivalent source method	ESM
Transmission line matrix method	TLM
Parabolic equation	PE
Finite element method	FEM
Discontinuous Galerkin	DG
Digital wave-guide mesh	DWM
Lattice Boltzmann method	LBM

tion, etc.), the sound field solutions are highly accurate. The major limitation of the wave-based methods is the computational cost, which is increasing with frequency and with size of the area to be calculated, whereby their main application nowadays still remains in the low to mid-frequency range at micro to meso-scale level. However, due to the advances in computer power, the capabilities of these methods keep growing. There is a wide variety of wave-based methods using different approaches when solving the governing equations. In general, they are divided between time domain and frequency domain methods depending on in what domain the equations are defined and solved. The discussion of the main features of these methods is out of scope here, but to make the reader familiar with the names of the approaches, Table 1 includes a list of the currently most popular ones.

The next figure shows a comparison between the sound propagation in a section of a street computed with a wave-based method (PSTD) and a geometrical method. This figure facilitates the understanding of some of the limitations of engineering methods when compared with a wave-based approach.

Computational acoustics methods are of large importance for validation or improvement of engineering methods. There are numerous examples of wave-based methods used as reference to refine noise mapping calculation methods. For instance, FDTD simulations were used to fit an analytical function describing canyon-to-canyon sound propagation, a multiple-reflection correction term in noise mapping was derived with the help

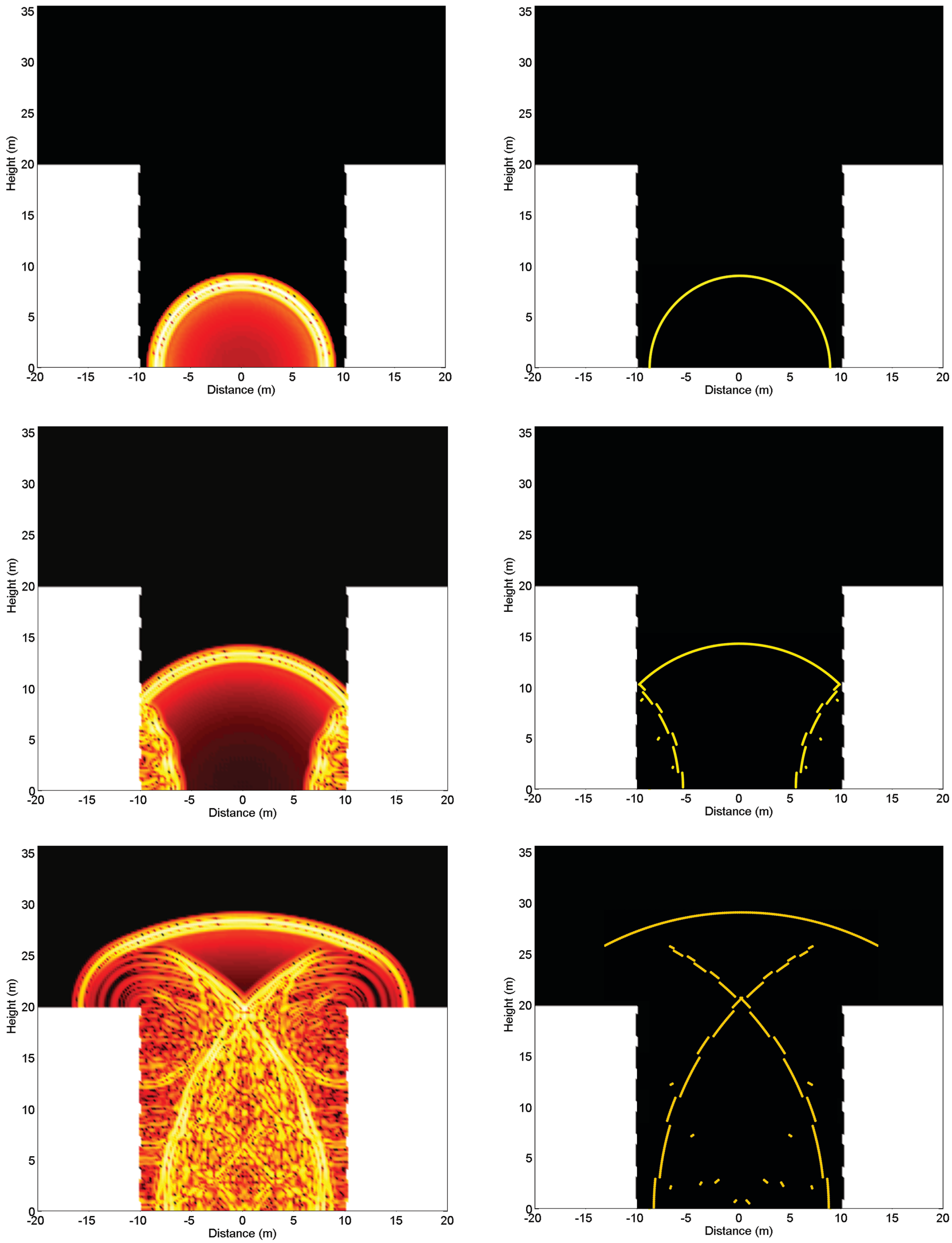


Figure 1 - Snapshots of wave propagation in a section of a street computed with a wave-based method (left column of graphs) using PSTD and a geometrical method (right column of graphs)

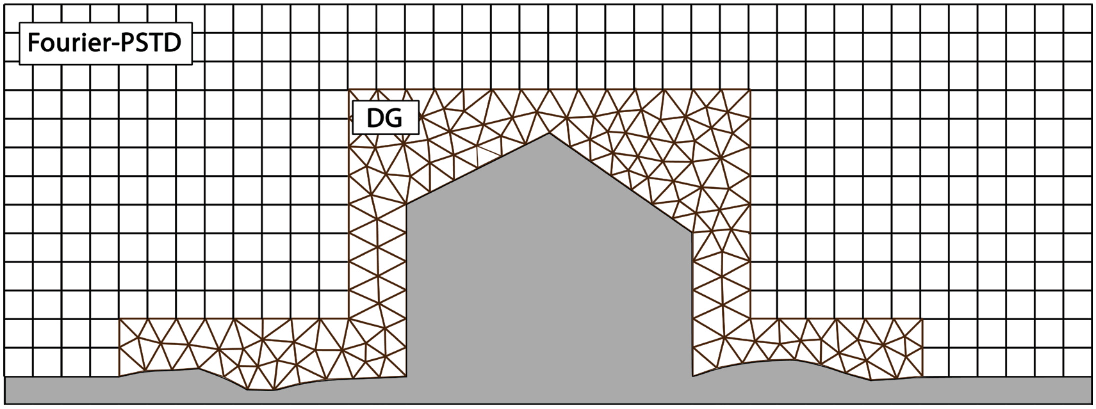


Figure 2 - Schematic example of an application of the hybrid method developed within the SONORUS project for a two-dimensional domain

of PSTD models, and the parabolic equation and the equivalent source method have been used to characterize the excess attenuation of intermediate canyons to obtain a correction factor for engineering methods.

SONORUS has contributed to further developing some of these numerical methodologies. For instance, a novel hybrid method combining PSTD and DG has been implemented to allow the computation of arbitrary boundary conditions and complex geometries as shown in the schematic example of Figure 2 and in an application of the methodology to a 2D irregular shape, as shown in Figure 3. Additionally, source directivity has been incorporated in PSTD by using spherical harmonics technique and currently these developments are used for the auralisation of inner city car pass-by. Other projects within SONORUS have used numerical simulations in their investigations. For example, at microscale level the influence of the urban canyon shape has been investigated using the FDTD method and at macroscale level several SONORUS projects have worked on combining noise control and urban planning by using engineering methods for noise and exposure assessment. More details about these projects can be found in the "Controlling the sound environment" Chapter.

As emphasized above, wave based methods (FDTD, PSTD, etc.) are more accurate than geometrical acoustics methods, while being computationally heavier. Furthermore, geometrical acoustics methods may become more appropriate at high frequencies where complex wave based effects may be neglected.

a)

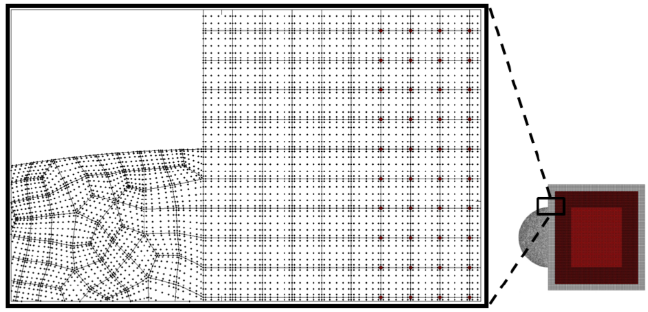
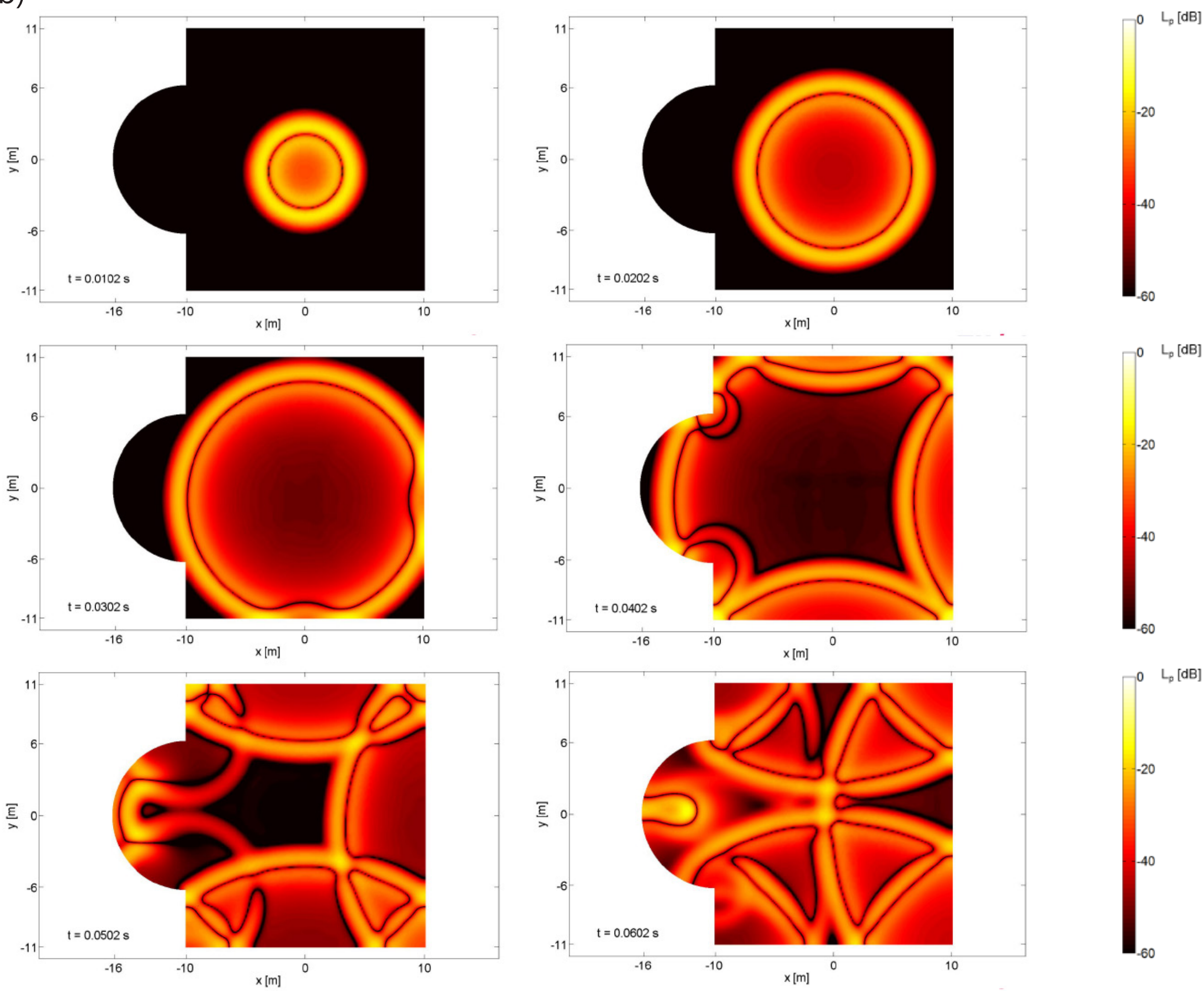


Figure 3 - Application of the hybrid PSTD/DG method developed within the SONORUS project to a 2D irregular-shape; a) detail of the hybrid grid and b) snap-shots of wave propagation

b)



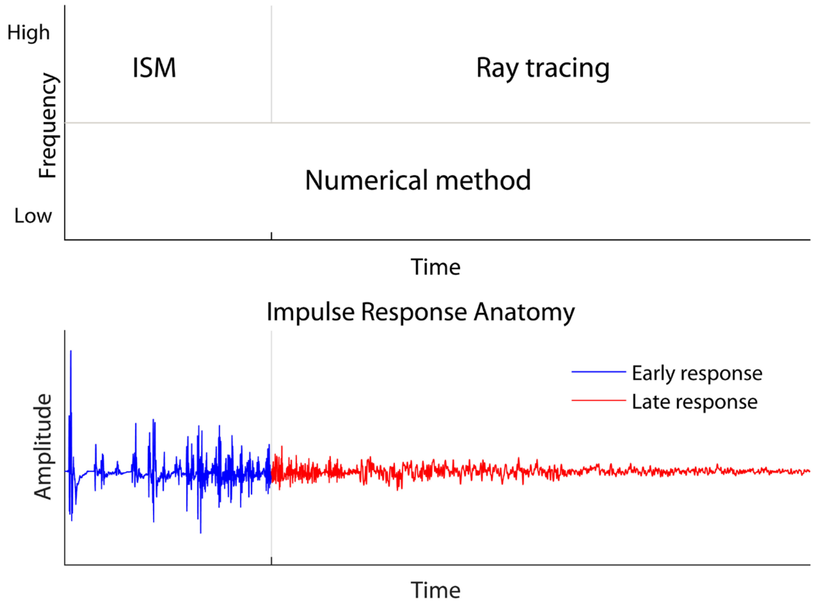


Figure 4 - Top figure: Layout of a potential hybrid auralisation of urban environments.
Bottom figure: anatomy of an impulse response in an urban environment. The low frequency part is modelled using a wave based method for both early and late parts of the simulation and for the high frequency part the early reflections are modelled with an image source method (ISM) and the late with a Ray tracing method.

This initializes the design of a hybrid auralisation methodology where a wave based method is used for the low frequencies and a geometrical acoustics method for the higher frequencies. During the past two decades there has been an increased research interest in this approach. An impulse response (the acoustic response of an environment to an impulse excitation) is composed as follows using the hybrid approach. First, two impulse responses are computed using the wave based and geometrical acoustics methods, and second, those two impulse responses are combined. A graphical demonstration is shown in Figure 4. How to combine the impulse responses is not straightforward and is still an open question. Also, further work is needed to identify the appropriate crossover frequency between the two methods.

Numerical methods for computing sound propagation in the urban environment have not yet been fully developed. One main reason is the continuous development of computer architecture (e.g., parallel GPU's) that will keep progressing in the coming years, requiring that the numerical methods are continuously updated in order to exploit the computational power. Also, there is a need to bring the urban acoustics prediction codes to real-life applications and open source codes, facilitating the application of the methods by others, outside the academic and research institutes. Furthermore, there is a lack of acoustic input data for the models (e.g., absorption coefficient of facade materials, source features, etc.), a point that must be addressed in the coming years since, clearly, this is most relevant for the accuracy of the final results. Input data for the models can be obtained via experiments or using other numerical techniques, e.g. simulating the acoustic features of materials.

Auralisation

For the sound synthesis of the source, several methods exist. Synthesis can be achieved by determining the physical properties of a source, with possible sub-sources, and determining their sound spectrum. Then noise according to these spectra can be generated and updated. Spectral modelling for example, will construct a sound spectrum by adding frequency components. Subtractive synthesis on the other hand will remove unwanted components from a noise spectrum. Another method is synchronous granular synthesis, an idea first conceived for musical purposes. Granular synthesis will acquire small grains of sound, usually from recordings, saved as a library for a source and picked up according to the preferred source property. This has been proven useful for sources that contain cycles of operation, just like a car engine. For example, a group of grains has been recorded for a certain gear and engine speed (rpm) of a car and can be reconstructed to a seemingly continuous sound stream. This way, a car with a variable speed across its route can be given a sound with smooth and controlled transitions. Aside from the spectrum of the source, its temporal behaviour is generally also needed. Examples are amplitude modulations in the emission of wind turbines and jet engines as well as impulse-like sounds.

Directivity of a source refers to the angular distribution of the sound field generated by the source. The major sources of noise in urban environments, road, rail and air traffic, have a directional character. A realistic auralisation of these noise sources in urban environments requires taking into account these aspects in the prediction method.

Another factor that affects the perceived sound field is the effect of the head, outer ears and torso of the listener.

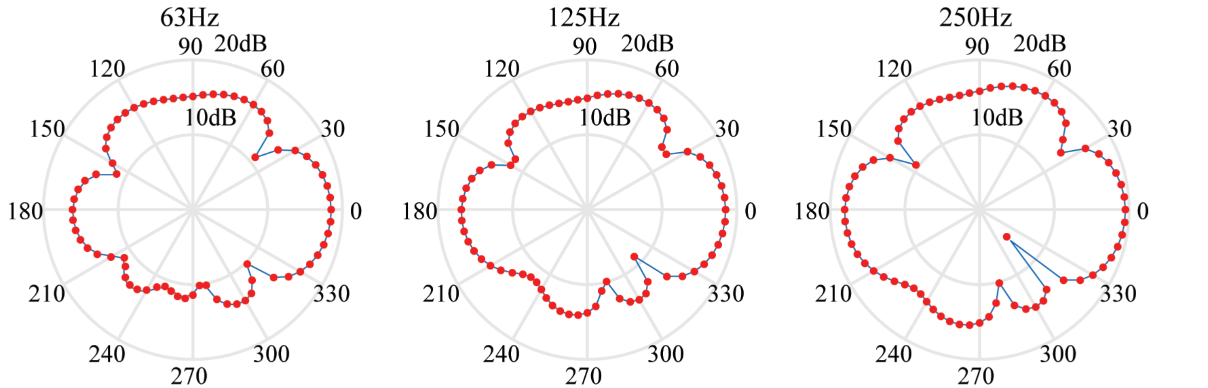


Figure 5 - Directivity in horizontal plane: analytical directivity (blue solid) and modelled directivity (red dotted) in PSTD for the octave-bands with centre frequencies 63Hz, 125Hz and 250Hz

This is referred to as the head related transfer function (HRTF) or head related directivity. An HRTF is the response that characterises how the human ear receives the sound from a point in space. With the use of HRTFs a 3D sound experience can be achieved with the use of only two audio channels (headphone playback). By incorporating directivity and HRTFs in auralisation the quality of auralisation is significantly improved.

Source directivity and HRTFs have been incorporated in various geometrical acoustics methods and computational methods. Within the SONORUS project a methodology to include source and head related directivity in the pseudo-spectral time-domain method (PSTD) has been developed. In Figure 5, directivity patterns of an analytically derived and a PSTD simulated source are shown for three different octave bands.

A valid auralisation tool will not necessarily simulate accurately all of the physical properties and processes of an environment and its sources the way they are taking place in reality, but through translating these will give useful results for the situation. Source models can be constructed by using psycho-acoustic properties of the human hearing, for example taking into consideration temporal and frequency masking. In the SONORUS project, a method for auralisation of background road traffic has been developed, with the aim to concentrate computational power to foreground events, e.g. a car passing by on a local road where the listener is located. The approach uses modulation

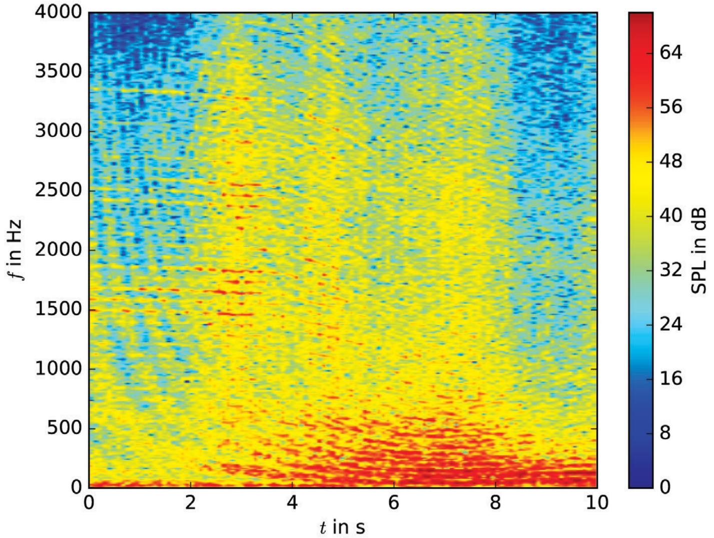


Figure 6 - Spectrogram of an aircraft auralisation. The instantaneous sound pressure level is shown in the colour scale as function of time (x-axis) and of frequency (y-axis).

transfer functions, i.e. rippled noise spectra that shift with time, which appears to be a compact and promising way to model a time varying noise event. Initial listening tests have been carried out for this approach and further work is ongoing.

Aircraft are a major contributor to noise in urban environments. The amount of people exposed to aircraft noise increases every year due to urban densification and increasing flight movements. Within the SONORUS project tools have been developed to simulate how it sounds when an aircraft flies over an urban environment. The developed tools can be used to study the impact of aircraft noise on humans.

The propagation model takes into account typical effects like spherical spreading and air absorption. Especially important with aircraft auralisation are the often strong Doppler shift and ground effect. Also, while listening to aircraft noise, one can typically hear fluctuations that are relatively slow and random. These fluctuations are often due to atmospheric turbulence. An important contribution of the project was a model to simulate the effects of atmospheric turbulence on sound propagation resulting in more realistic sounding auralisations.

Figure 6 shows a spectrogram of an auralisation of an Airbus A320 taking off from Zurich Airport. Strong tonal components can be observed during the first seconds as the aircraft approaches the observer, visible as horizontal lines in the figure. A strong Doppler shift occurs and, as the aircraft passes, the relative strength of the tonal components drops significantly. Interference between direct and ground reflected paths results in a clearly noticeable interference pattern. How noticeable the interference pattern is depends on the ground type and the atmospheric turbulence condition.

The overall directivity of the aircraft is stronger to the rear, and therefore as an aircraft approaches and flies over, the level quite rapidly increases. This is expected to contribute to the disturbance.

An equally important stage to the auralisation process for creating the wanted sounds is the way the produced sounds will be used. Initially it has to be decided whether the auralisations will be used as a final product or as a means for extracting further information. In the first case, choosing a reproduction method is needed, e.g. headphones or multi-channel loudspeaker setups.

Although it might seem straightforward, for critical listening, headphone reproduction should be handled with care. Even when using high-end headphones with a known frequency response given from the manufacturer, each unit will show irregularities. To avoid these, the units can be measured in lab to create filters that will compensate for the irregularities and ensure a controlled listening experience. Moreover, since headphones do not usually offer good low frequency response they could be used together with a loudspeaker, like a subwoofer, while using open-back headphones. This will enhance the listening experience, of importance for most traffic sounds, and may furthermore provide vibrations that radiate through the human body. As it can be seen, headphone reproduction cannot easily be used in a mobile set-up, except for preliminary or screening listening tests.

The simplest loudspeaker setup for listening tests is the vector-based amplitude panning (VBAP), giving the common “stereo” effect. This method offers a small sweet-spot area , i.e. the position where the contribution of each loudspeaker of the setup is correctly balanced with the others and gives the desired spatial imagery. As with all loudspeaker reproduction setups, the room that the listening test takes place should be properly treated. VBAP can also be combined with HRTFs to give more realistic results. As mentioned, HRTFs output a signal for each ear of a listener, and as such, sound due to e.g. the loudspeaker representing the right channel, will contribute to the left ear, and this may be counteracted by using the HRTFs, in what is called cross-talk cancellation.

Reproduction of sound: Headphone and multichannel loudspeaker setup

More multichannel setups exist, where the most popular ones are higher order ambisonics (HOA) and wave field synthesis (WFS) rendering techniques. The main difference between these two is that HOA has a sweet spot, although it can be expanded and controlled, whereas WFS, with its large number of loudspeakers, avoids the sweet-spot limitation. For the latter, virtual sound sources are spatially located within the listening area, and the listeners can navigate themselves within this acoustic field. Both HOA and WFS can be configured to create a correct acoustic field in either a 2D plane or a 3D volume. It should be noted that the headphone setup coupled with HRTFs, HOA or WFS techniques, can be enhanced by using sensors tracking the position and rotation of a listener, and adjusting the output.

Designing a subjective listening

test itself is a part of the field of psychoacoustics. Here, the statements under test should be decided in order to define the structure of the test. If, for example, the purpose is to validate an auralisation, the test would vastly differ from one that investigates a certain noise abatement measure within the context of urban sound planning. For the former case, the auralisation should be tested either against a reference (e.g. a recording or an already validated sound), or using certain tracking abilities and responses of the listener (e.g. perception of speed of car pass-by, detection of individual cars in a mixed traffic sound environment, etc.), which will assess the realism of an auralisation. For the latter case, the attributes that are tested should be carefully chosen as they may bias the result. It is, for example, common to test for the perceived annoyance, which may be self-introduced in the results already by asking about it.

Subjective listening test methods can be further developed by including objective data from the subjects. These can be muscle movements and heart rate variations when introducing a sound, as well as brain responses, although this is yet a largely unknown area. By obtaining these data with properly designed tests to avoid biases and cross dependencies between fixed and non-fixed parameters, useful indicators that describe attributes of urban environments may be created.

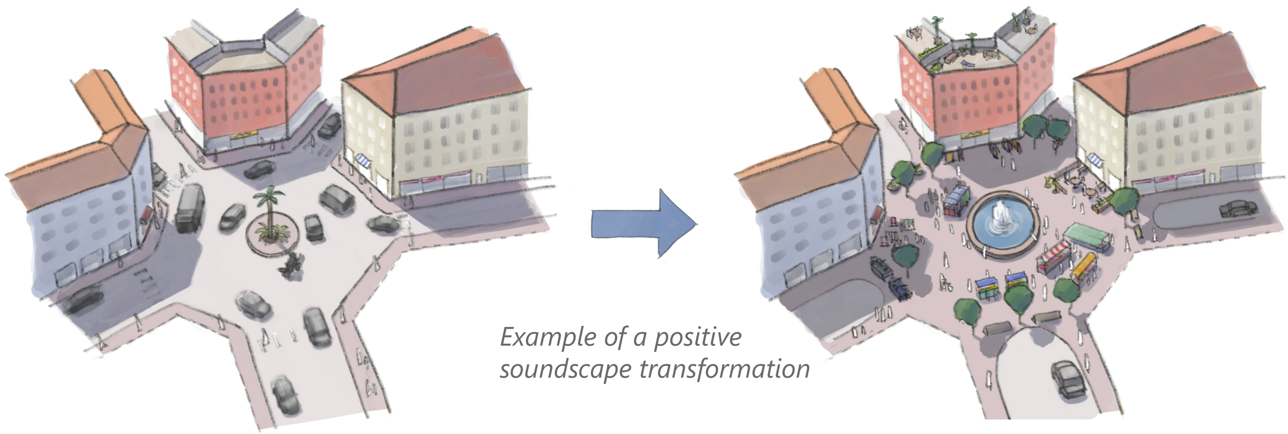
Urban soundscape

Authors: Francesco Aletta, Karlo Filipan, Virginia Puyana Romero

The approach to the evaluation and design of the urban sonic environment can be tackled from different perspectives regarding the scale, the potential users of the areas and the complementarity with other kinds of interventions. In this Chapter, an overview of the whole design process has been undertaken, from the establishment of the general objectives to the definition of the soundscape proposal. Examples of the application of the soundscape design can be found in the "Applied Urban Sound Planning" Chapter in the sections referring to the cities of Brighton, Rome and Antwerp.

What is (urban) soundscape?

The concept of 'soundscape' was originally rooted in the music and acoustic ecology research areas. It quickly expanded to other disciplines, such as environmental noise, architecture, environmental health, psychology, sociology and urban studies, claiming for a holistic approach to the way we conceive the sound around us. Soundscape research investigates how humans experience the sonic environments and tries to establish the relationships between the physical world and the human response to it.
It involves the cooperation of human, social and engineering sciences. Soundscape planning and design represents a paradigm shift as it explores the diversity of soundscapes across countries and cultures, and considers environmental sounds as a 'resource' rather than a 'waste'. Soundscape is a key approach in the urban sound planning process advo-



Example of a positive soundscape transformation

cated in this booklet.

Soundscape can be considered at different degrees of abstraction, covering different fractions of the urban space, and influencing different amounts of people. At a macroscopic scale, the whole city and even a bigger audience of visitors may experience the effect of a change. This can be related to typical sound marks. Indeed, if the sound of Big Ben would change, it would extensively change the soundscape for London inhabitants and many others who have visited it. Also changes in the use of urban space may lead to macroscopic soundscape effects. For example, rethinking mobility in city centers creating larger areas free of motorized traffic sound may affect how the city is perceived acoustically by its inhabitants and visitors alike. Most often, however, soundscape designers work at the mesoscale, rethinking the sonic environment of a functional area, for example an urban park. At this scale the variability of the soundscape over the area and the creation of sonic subspaces is of importance. Matching soundscape to the (expected) users and the use of the space is crucial for creating congruent soundscapes. At the microscale a single experience of the sonic environment is considered. It can be related to a private garden affecting only its owners or a small part of public space.

In this Chapter, the stages of soundscape planning and design will be briefly described and analysis techniques that can be used during this process will be discussed. The former can be applied at macro, meso or microscale while the analysis methods are mainly applicable at the mesoscale.

Design process in urban soundscape

The design of the urban soundscape is an iterative process involving planners and stakeholders that aims at defining and implementing a matching soundscape for a given context (Figure 1). When designing, the urban sound planner has to be aware of the long-term vision for the urban environment, including its soundscape. The planning process starts by defining a vision on the desired soundscape, the soundscape character (e.g. tranquil park, vibrant promenade, peaceful cemetery) that becomes the objective in an urban sound planning process. By introducing or accentuating (i.e. making them more noticeable) matching sounds or suppressing sounds that are unwanted within this soundscape vision, for example using noise control engineering (to know more see the Chapter on "Controlling the sound environment"), the desired soundscape is then implemented either directly in the field or in simulations (see the final Chapter on "Applied Urban Sound Planning"). The implementation is later checked using established soundscape analysis techniques and relevant stakeholders and planners are apprised on the new situation. Finally, the objectives are evaluated and the procedure reiterated to achieve the long-term vision. This adaptive iterative process reflects the volatility of the urban soundscape.

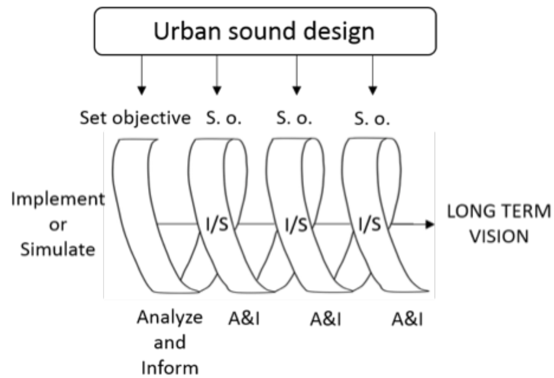


Figure 1 - Iterative design process in urban soundscape

SETTING THE SOUNDSCAPE OBJECTIVE

Soundscape, the acoustic environment as it is perceived and understood by an individual or society within a context (ISO definition), has to be considered within a wider context of urban design. Visual context, the typical use of the space (shopping, relaxing, retiring at night, etc.), its typical users, cultural and climatological context reflect in the process of creating a vision on the soundscape and setting the objectives. The urban soundscape design can be part of a wider intervention comprising different fields such as urbanism, community affairs or environmental protection, so in this case the objectives must be compatible with a set of global objectives for the area. For soundscape design to succeed, the drawing up of these objectives should involve the active engagement of the stakeholders from the outset of the decision making process.

Urban soundscape methodologies have been mostly applied for open outdoor public spaces with a typical use. For these, and in particular for parks and squares, literature on sound preference has established different kinds of wanted sound sources, such as natural (sound of rustling leaves, wind, water sounds, birds...) and cultural sounds (bells, traditional festival sounds, sound marks...), contrasting the unwanted sound (mechanical and technological sounds). However, soundscapes along routes connecting different functions of the city should not be forgotten. Indeed, transition gives stronger impressions than a sustained sonic environment as the human ear quickly adapts and filters. Finally, objectives for the environment of the private home have some specific demands. Here, the feeling of being in control of the sound environment becomes particularly important.

Different methodologies could be envisaged to derive soundscape objectives. The process could be part of design competitions for (re)development of an area. The question "How will it sound during different parts of the day or in different seasons?" can be answered together with more usual questions such as "What will it look like?" or "How will it be used?" The technology is there to illustrate this vision to a broader audience (see Chapter on "Prediction and auralisation of urban sound environments"). Co-creation of the public space, including its soundscape, by several stakeholders together is certainly also an option.

Some examples of acoustic objectives include: "I want the sound of water to be noticeable", "I want the sound of the traditional music of the festival to dominate completely" or "I do not want to hear the noise of the trains passing by". The achievements of these goals at the soundscape scale can lead to meet the global goals that influence people's mood, behaviour and quality of life.

CONSIDERING HUMAN PERCEPTION

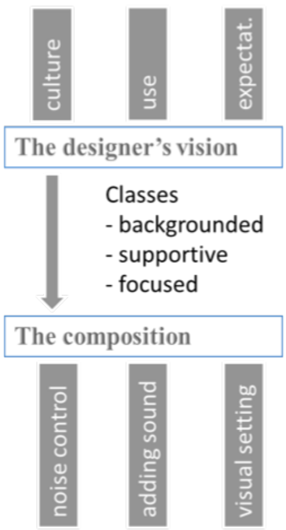
When implementing the objective, a practitioner has to be aware of how the changes in the sonic environment will influence human perception and thus the soundscape. Therefore, some basic knowledge on attention and the effect of personal beliefs is useful.

People who find themselves in the specific soundscape usually do not listen for the specific sounds, but their attention enables them to select from a multitude of sounds sources. When attending to the sound, two mechanisms interplay – bottom-up and top-down selection. Bottom-up selection is based on characteristics (features) of the sound listened to, in particular its saliency (i.e. how much the sound stands out of the overall sonic environment). Top-down attention represents the listener's intention on focusing on a specific event. Therefore, the soundscape objective implementation has to take into account what are the characteristics of the sound sources and how much would they attract human attention.

With noticing sounds in mind, a classification of desired soundscapes in three large categories is suggested:

- Backgrounded soundscape. This vision assumes that soundscape does not contribute significantly to the experience of the space. Hence the purpose of the design is to assure that users do not notice the sounds and that they are affected in the least possible way by the sound environment. This rather unrealistic design unfortunately is a rather common vision.
- Supportive soundscape. The soundscape supports the experience of the public space but the experience is not primarily focused on sound. In other words, the soundscape has to be congruent with the vision of the space that is mainly determined by other factors.
- Focused soundscape. In this last situation, the sonic environment itself is the purpose of being in a place. Obviously, open-air theatres, street performance spaces, etc. fall under this category. In this case not only the sound itself but also the acoustics of the environment becomes relevant. Reverberation, clarity, warmth, and signal to noise ratio have to be considered.

Users of a public space have their beliefs and viewpoints on how such space should sound. Considering that the visitors have a prior knowledge of sound sources, sounds that are familiar are usually easier to recognize. However, unexpected or incongruent sounds could also be more salient because they disturb the overall expectations based on an earlier experience of the environment. Therefore, it needs to be clear which visitors will visit the newly designed urban soundscape and what are the possible influences of their personal beliefs to perception.



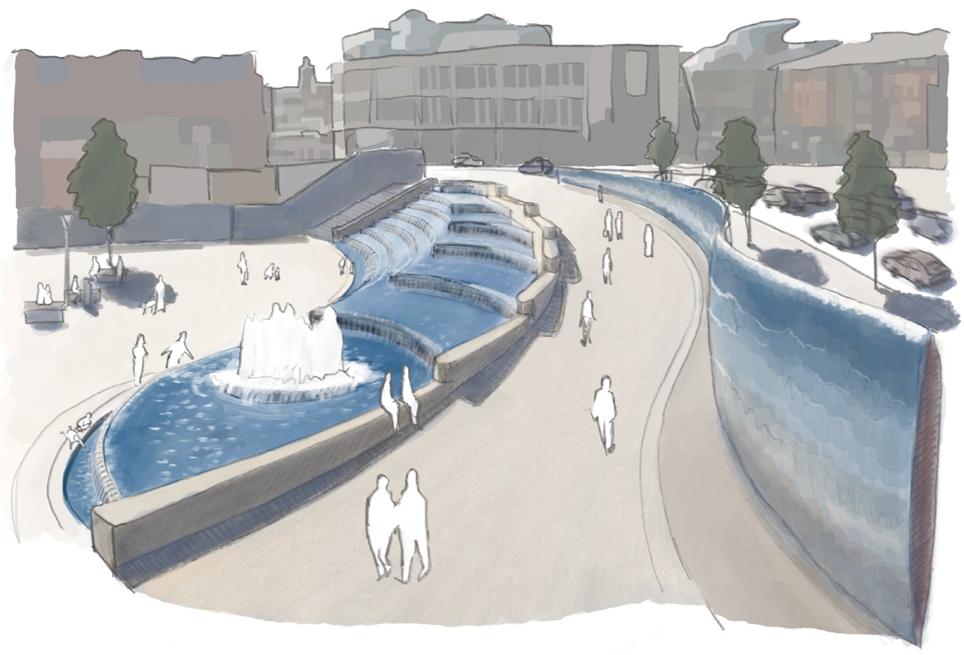
DEFINING THE ACOUSTIC STRATEGY

Once we have established the objectives of our intervention, we have to define an acoustic strategy on how to achieve them. To define this strategy, evaluation by listening to the existing or new scenarios and prediction of the improvement (see Chapter on "Prediction and auralisation of urban sound environments") could both be used. The main acoustic strategies applied in the urban soundscape management and planning are listed below.

Noise control technologies (see Chapter on "Controlling the sound environment") are necessary tools for the noise abatement in soundscape interventions. They could be applied at the source, on the transmission path between the source and receiver, or at the receiver, and tend to mitigate the negative effects of noise in the environment.

Masking techniques are often used when it is not possible to adequately reduce the environmental noise with noise control techniques. Energetic masking may be applied in the cases in which we want to avoid certain sources to be heard. This energetic masking is introduced via sounds that are created naturally or artificially (i.e. by means of electroacoustic devices). Attentional masking consist of the introduction of positive sounds that attract the attention of visitors and decrease the perception of unwanted sounds. However, limitations include environments with high background noise levels, above 65 dB according to some literature, where the noise levels should firstly be reduced through noise control measures.

A different approach can be undertaken

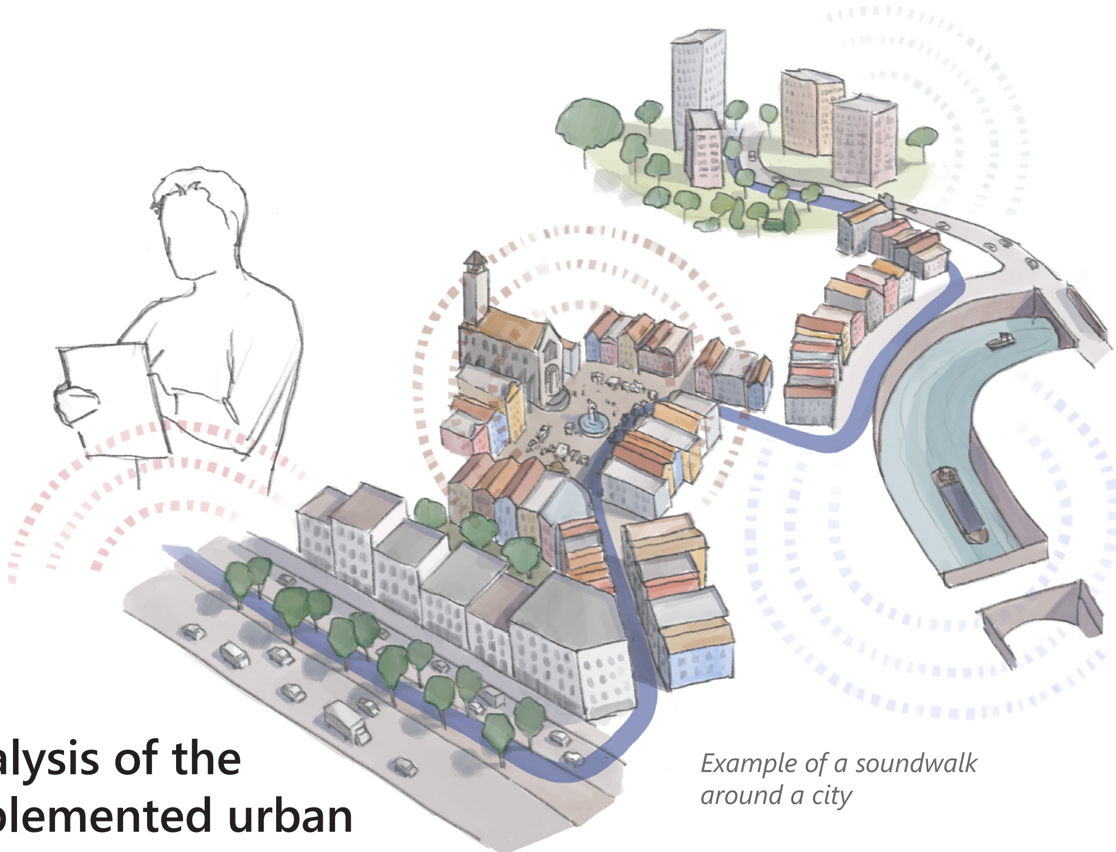


Example of soundscape intervention using water features for masking and noise barriers for sound level reduction

in the urban soundscape design tending to reinforce the dominant role of vision on the overall process of perception. This approach may for example enable the visibility of elements with known positive effects on soundscape perception such as water or vegetation, and can be combined with masking techniques. For instance, trees can be used to reduce the noise annoyance when seen from the dwelling's window. To obtain the optimal results, the adequacy of the designed scenarios may be evaluated with virtual reality test in which auralised sounds or sound recordings are played simultaneously with the visual changes that the proposal introduces into the environment.

FINALIZING THE DESIGN PROPOSAL

The conceptualization of the design proposals is left to the creativity of the planner or designer. For instance, if an objective for an urban park close to a busy road is "to hear the rustling of leaves" and the implementation is to achieve this through energetic masking, a suitable water feature (fountain) could be designed for this purpose. Nevertheless, in real case scenarios it is not likely that a single strategy will achieve the predefined soundscape objective and combined use and iterative process of different strategies and solutions might be required.



Example of a soundwalk around a city

Analysis of the implemented urban soundscape

Once the soundscape objective is transformed into a specific implementation, several steps have to be observed to test the characteristics of the changed environment.

COLLECTING PERCEPTUAL DATA

There are many ways to experience the acoustic environment. This can happen when we are actually on site, in a laboratory, or we can just recall it from memory. Every such experience will be associated with a different perception of soundscape. It is important to decide how we are going to gather information on urban soundscape, according to the different types of experience of the urban environments. Previous soundscape studies have used various methods and today the most common extend to:

- Soundwalk
- Interview
- Behavioural observation
- Laboratory experiment

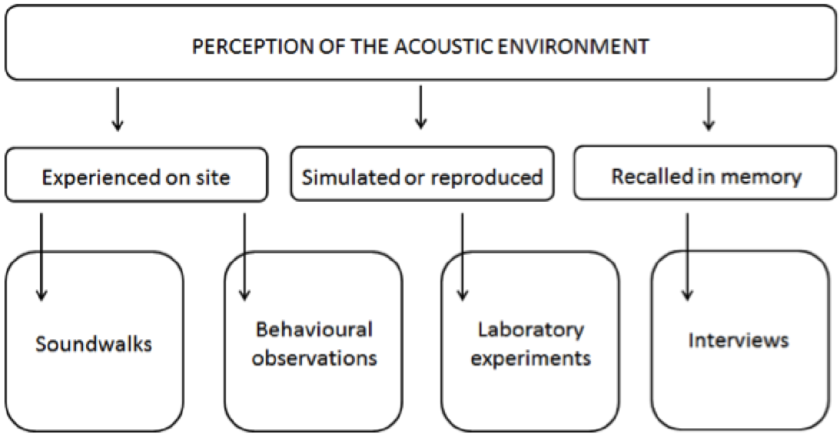


Figure 2 - Methods and tools used for gathering soundscape perceptual data

Every method will likely be related to different ‘tools’ necessary to achieve the desired goals. In particular, all of the mentioned methods except laboratory experiment have the advantage of being administered in situ and to the people that have recently experienced the environment in question. On the other hand, laboratory experiment brings the possibility of having the controlled environment when investigating the particular characteristics of the soundscape. To summarize the main approaches used by researchers and practitioners, methods and associated tools are presented in Figure 2.

MEASURING PHYSICAL ENVIRONMENT

Every time we collect soundscape data, it is crucial to measure also the ‘physical’ part of the acoustic environment, so that the information later can be further processed with respect to its ‘perceptual’ counterpart. Several techniques for recording exist and the most commonly used today are: Ambisonics recording, binaural recording and recording with portable devices.

Ambisonics recordings are used for capturing 3D sound environments. The equipment is placed usually in a stationary measurement position. Main advantage of Ambisonics is the possibility of the listening to a real sound environment in laboratory conditions. However, this implies that a listening room with specifically positioned loudspeakers has to be created. Although used widely in research on spatial audio, the custom created solution is always necessary. Another advantage is the possibility to convert the Ambisonics recordings to a

Recording of an urban soundscape using an artificial head

range of available formats (stereo, Dolby formats, binaural). This gives the practitioners the possibility of having their recordings stored in a universal format with an easy conversion to any reproduction format required.

A widely used type of capturing physical environment is recording the binaural signals. They are based on the characteristics of human hearing where only two signals coming to each ear are enough to capture the spatiality of the sound. These recordings can be made using an artificial head or by placing the microphones in or on the listener's ears. The former type is usually used as stationary recording while the latter one is used in mobile systems. Binaural format provides an easy transition from measurements to a listening experience since the necessary equipment in the whole chain consists of microphone, recorder, playback device with the equalizer and headphones. Finally, the commercial solutions both for recording and reproduction are easily accessible.

Latest trends in soundscape research focus on the use of portable measurement devices. Their applications extend mostly to the acquisition of a sound in dynamic and large urban environments. The measurement device is often set only to record a single channel, while in some cases the sound is captured with spectral levels alone. This in turn enables collection of large datasets in a relatively short time. For such purpose, the professional calibrated devices paired with positional information (GPS) can be used. On the other hand, for gathering data from the general population, recording with smartphones is a viable option.

In addition to the purely acoustic data, multisensory perception usually manifested through the interplay with the visual environment can also influence the soundscape. The most common techniques to capture visual characteristics of an environment are photos and videos. In a subsequent analysis or presentation, these can be paired with their respective sound recordings to enhance the experience of the investigated environment.

ANALYSING THE URBAN SOUNDSCAPE WITH COMPUTATIONAL MODELS

In addition to measurements, soundscape can be analysed with created models that mimic characteristics of human perception using specifically constructed computational algorithms.

People that experience soundscapes seldom visit the space with a single purpose to listen to the sound. Therefore, their perception of soundscape is influenced mostly by the sound sources that at times their attention focuses on. Computational models that aim to determine how much the specific sounds in the environment attract attention are the ones predicting auditory saliency. During the years, researchers proposed different models for saliency extraction. Such models form their calculations on a specific feature extractor (spectral, Gammatone, MFCC, etc.) and summarize the obtained features to a single time-varying indication of sound saliency.

Considering the complete model for human auditory perception based on the current scientific knowledge, features extracted from the input sound – likely the same as the ones that determine saliency – form an input to a complex neural system of adaptation, voluntary attention and memory. When modeling such a complex system, the most appropriate computational algorithm is a multi-layered artificial neural network. Although the basic implementation of a neural network mimics the neural signal transmission in a human brain, without specific adjustments, not all cognitive processes are simulated accurately.

It should be noted that the research on computational models that predict attention to salient sounds, or directly recognize the sounds from recordings, is still in the early stages. However, the possibilities that such models provide for automatic analysis and long term monitoring in the future should encourage their use within the practitioners' community.

MODELS DEVELOPED DURING SONORUS PROJECT

A new model for extracting auditory saliency from environmental sound has been developed. The features of the model are based on spectro-temporal modulations found to induce direct response in the human brain. Implemented in the model are the procedures that mimic processing in human auditory pathways, as well as the simulation of activation and inhibition of neurons in the human brain.

The output of the model represents a single-number time-changing saliency evaluation of the input sound. The model can be used when (single-channel) recordings from real or auralised sonic environments are available. To the planners, its output would present a clear indication when the visitors of a recorded place would likely pay attention to the sound. As displayed in Figure 3, when given a recording, the model marks auditory saliency with a signal that peaks where noticeable events are detected. As a result, analysis of recordings of soundscape could be greatly simplified by extracting only the parts that are deemed salient and discarding the other subliminal (i.e. non-noticeable) signal portions. This automatic procedure would find its application in large sensor networks that gather 'big data' and help the planners to focus on what is most important in the soundscape.

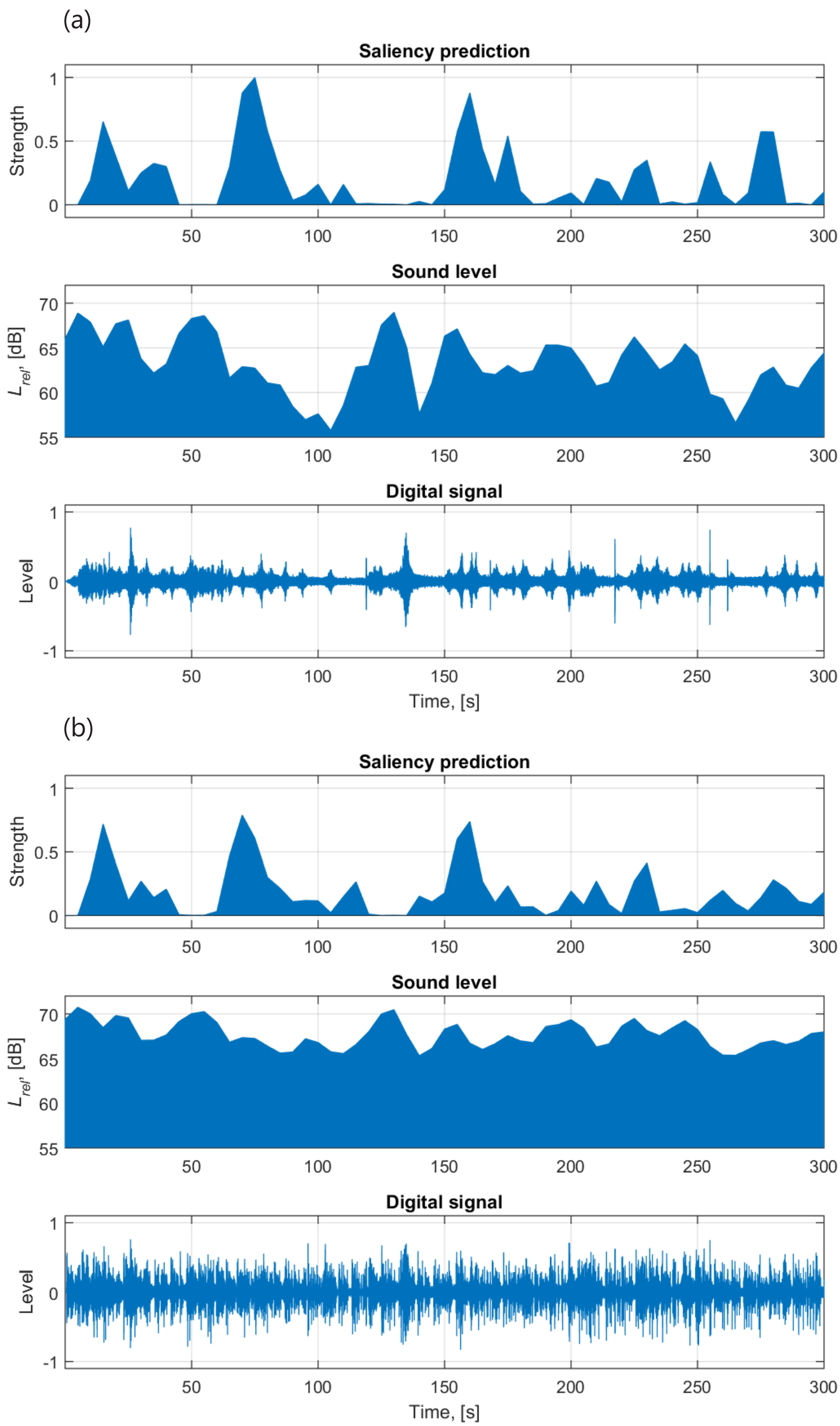


Figure 3 - Saliency output from a traffic noise with honk sounds recorded in Ghent (BE): (a) original recording; (b) recording with added speech

Presenting information about urban soundscape

Gathering data from several sources can imply that the structure and internal coherence useful for the study needs to be created. According to the goals, we have to select and organize information into more meaningful structures for representation.

"WHAT ARE WE GOING TO REPRESENT?"

Most of the authors agree that the perception of the sonic environment is influenced by the context in which the sounds are perceived and by the individual differences. Regarding this general approach, we can represent acoustic, contextual (related with visual or spatial information, odours, temperature, illuminance…) and individual data (demographic data, noise sensitivity, mood scales…). Other classifications of the represented data may be done regarding the way of gathering the data – physical, perceptual or from computational models.

In soundscape research the most frequently used acoustic variables related to the physical environment are Leq, LAeq, LA10, LA50, LA90, LCeq-LAeq and LA10-LA90. In addition, psychoacoustic parameters related to the sound perception can also be evaluated with examples of: Loudness, Sharpness, Roughness and Fluctuation Strength.

Spatial metrics are algorithms that define features of the landscape structure on the basis of land use. In the analysis of urban soundscape, these metrics are used to investigate the influence of urban landscape on the perceived sonic environment. Some other spatial and visual parameters can be used, such as the height of the buildings, distances from the sound sources, and percentage portion of elements perceived in an area and finally visibility features.

Different measures for evaluation of the sonic environment according to perceptual responses have been considered. These include indicators related to soundscape quality, acoustic comfort and noise annoyance. To obtain a detailed description of the sonic atmosphere, semantic scales may be used to evaluate people's appraisals on soundscape or to study how people experience an environment.

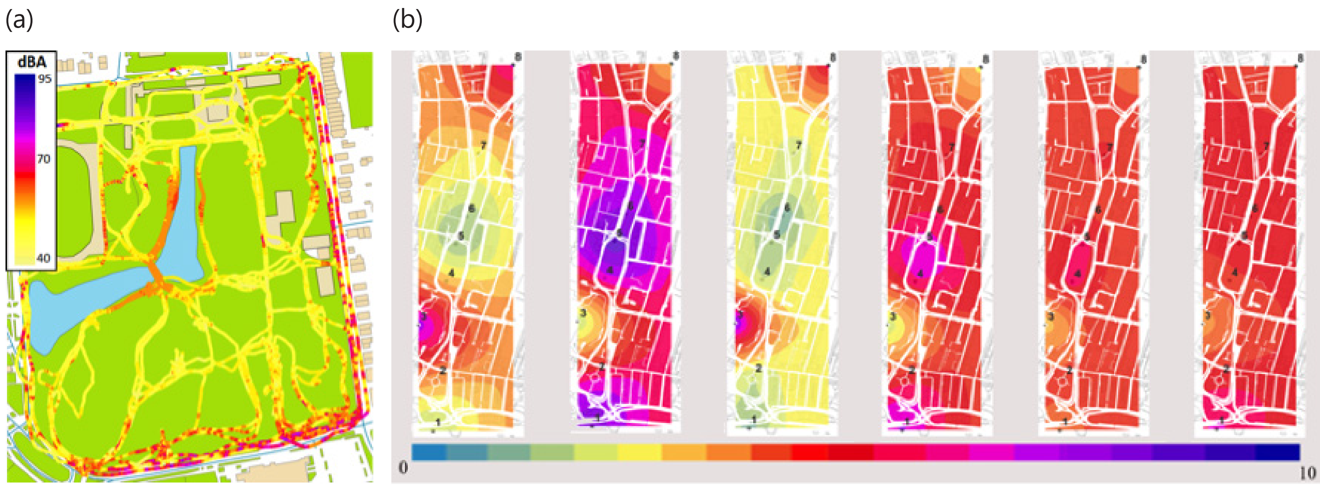


Figure 4 - Maps showing: (a) acoustical data measured in Rivierenhof park, Antwerp (Belgium); (b) perceptual indicators from questionnaire survey in Valley Garden area, Brighton (UK)

"HOW ARE WE GOING TO REPRESENT IT?"

The way in which we represent the information should arouse the interest and be easily understandable by stakeholders and concerned people. We have at our disposal a number of tools that provide a framework for data representation, which range from the typical statistical instruments to geographical information representation showing the spatial distribution of certain sound attributes. Below is a brief list (non-exhaustive) of some of the most used instruments to depict the outcomes of the study of urban soundscape.

- Statistical tools (bar and line graphs, boxplots, scatterplots, jittered plots, surface modelling graphs, polar and radar graphs, heat maps...)
- Acoustic level distribution graphs (histograms, spectrograms, time histories...)
- (Interactive) maps (dots, classes/categories, interpolated values)

Although there are many ways to represent the soundscape information, we would like to highlight the capability of maps for showing the spatial variability of the collected data (to know more see the Chapter on "Applied Urban Sound Planning"). The traditional noise maps represent the noise propagation of certain artificial sound sources (road, train and air traffic or industrial sources) calculated with specific engineering prediction methods (see the Chapter on "Controlling the sound environment"). Representation of the sound propagation of other artificial (engines, commercial and leisure activities…) or natural sounds (birds, water…) may also be used as complementary information in the soundscape evaluation. In contrast, maps with alternative information to that offered by the traditional noise maps may be developed, showing for example the classifications of areas regarding typologies of soundscape or the distinctive spatial and temporal variability of sound (Figure 4a).

The perception of a single soundscape attribute from semantic differential scales may also be represented using maps (Figure 4b). Geo-statistical methods of interpolation, based on the continuous spatial variation of the same pattern may be used for the representation of these variables. The main assumption of interpolation is that the collected data samples are correlated in space. Such procedure can be understood as a prediction of the spatial behaviour of the variables, and the results of the interpolation can be cross validated with other predictive statistics.

These maps can also be intended to show different perceptual information than the acoustic one, for example related with appraisals on the security of a place, the beauty of landscape or the potential benefits to offer an alternative information to soundscape data, which can affect the overall environment perception.

Finally, as people experience soundscape by visiting the space and listening (attending) to the sound, it is very important for the planners and stakeholders to do the same. Although other methods we presented provide good representations and general overview, to experience soundscape by listening will provide a significant advantage to the planner. Therefore, in order to imagine a specific soundscape that matches an environment – a goal that every urban sound planner should aim to achieve – listening in every possible occasion will provide not only the ideas but also the feedback necessary to successfully accomplish this rewarding task.

Applied urban sound planning

Authors: Sónia Alves, Laura Estévez Mauriz
Contributions to introduction: Matthew Easteal
Contributions from working groups:
Antwerp: Gemma Maria Echevarria Sanchez, Efstathios Margaritis, Karlo Filipan, Sónia Alves
Brighton & Hove: Francesco Aletta, Raúl Pagán Muñoz
Gothenburg: Laura Estévez Mauriz, Georgios Zachos, Sónia Alves
Rome: Virginia Puyana Romero, Fotis Georgiou, Ignacio García Merino, Mercury Kounturas

Introduction

Worldwide, cities are expanding at an unprecedented rate. Population growth in city centres places unprecedented demands on existing city infrastructure systems that are bringing many EU cities to a breaking point.

Traffic noise, people noise, pollution, poorly planned and managed places within our cities threaten the health and wellbeing for all of us. Large scale and well-planned infrastructure developments are therefore needed to face this challenge.

The requirement to improve people's mobility within cities will increase, which inevitably affects the urban infrastructure, resulting in the expansion of the transportation networks. Consequently, negative impacts such as noise and air pollution are expected to rise. In order to meet these challenges, the integration of urban and transport planning will be fundamental to the future of successful cities. The delivery of collaborative transport, public realm and regeneration projects can achieve this. It has therefore never before been more important for technical, social and ecological systems to work together.

In such a dynamic environment, the newly established discipline of Urban Sound Planning combines synergies with the other planning processes in a unique way. The Urban Sound Planner brings a different perspective and contributions to the process of delivering well-designed cities that work for people rather than harm them. This is achieved by improving the quality of sonic urban environments, not simply trying to make things quieter, but proactively designing to avoid noise generation and defining policies and strategies to value, introduce and preserve the characteristics of a good sonic environment.

Presently, the main objective of an acoustic intervention is defined in the regulations as a noise ceiling and is usually considered after the urban plan project is already decided, limiting the opportunities of approaches to other than traditional engineering noise control. This approach is usually restricted in space (to the most exposed receivers) and in time (short-term perspective), missing the opportunity to contribute to improved environments, sometimes missing to take advantage of high-quality potentials. The holistic approach of SONORUS to urban sound planning relies on preventing the occurrence of noise, by not limiting the interventions to the obvious noise engineering solutions but to include a combined approach that coordinates actions of different acoustic fields to provide an integrated solution.

In this Chapter, we are summarizing examples where urban sound planning is applied within the SONORUS project. The intention of including practical cases in the project is to develop exemplary application to real case scenarios within the urban sound planning approach. This work aims to contribute to improving the current situation and reversing the growth of poor urban sound environments. Four different scenarios are included, varying in scales, methods and outcomes: Rivierenhof Park in Antwerp (Belgium), Frihamnen area in Gothenburg (Sweden), Valley Gardens in Brighton & Hove (UK) and the Colosseum, Palatine and Roman Forum area in Rome (Italy).

DIFFERENT SCALES, DIFFERENT NEEDS, DIFFERENT TOOLS

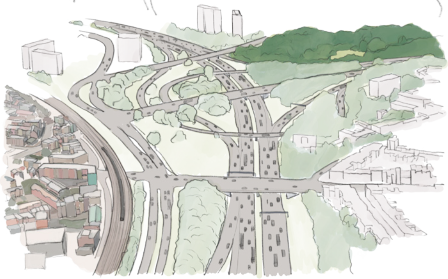
The holistic approach has the ability to assess the sonic environment at different urban scales, from growing mega-urban developments to the small urban park. Mega (more than 10 million inhabitants) or Meta cities (more than 20 million inhabitants) are in a growing trend and by 2050 the number of megacities is expected to rise to 41. However the pressure it adds in terms of urban infrastructure demand is enormous: the increased need to commute from peripheral areas into the city centre will add even more traffic resulting in increased pollution and lower quality of life. History has shown that building more road infrastructure will only increase traffic. In order to cope with this previously unseen demand for mobility, innovative and integrated approaches are required. Efficient public transportation systems and functional and safe paths for pedestrians and cyclists will support a sustainable mobility and, at the same time, contribute to the improvement of the sonic environment.

Specific innovative tools developed for the analysis of sonic environments can be integrated into the overall planning at this level, contributing to an optimized solution. For both macro and mesoscale planning of the built environment, urban sound planning shall be applied at the beginning of the planning process. This is the only way to obtain a coherent solution. Within the SONORUS project, several tools have been developed attending to the different urban scales. At the mesoscale or larger, a comprehensive and truly holistic approach can be applied to set the basis for a good acoustic characterisation of environments and support future planning strategies. This may include: dynamic noise map tools, contributing to an optimization of the traffic layout (Gothenburg test site); integration of noise engineering concepts, protecting inhabitants from high noise levels (Gothenburg and Antwerp test sites); and preservation of public spaces at a larger scale by means of soundscape analysis (Antwerp and Brighton & Hove test sites). In a microscale planning level, the focus is narrowed down to the users, the residents and their wellbeing, e.g. through the development of multisensory perception tools including visual and aural stimuli, allowing for testing different scenarios (Rome and Brighton & Hove test sites). Here, small projects take into account the individual needs and try to improve the liveability of spaces, promoting interactions between people, in safe and healthy environments.

It is extremely important to remark that all scales are influencing each other. For that, we must extend the acoustic interventions to exploit all the potential benefits to obtain a good sound environment, even when noise has not come up as a matter of concern. Therefore, the use of available tools and the development of new ones will ensure a proactive urban sound planning approach.

Map of Antwerp (Rivierenhof park marked in green)

Road that crosses the park, dividing it in two parts



Highway on the west side of the park, with the only connection between the city centre and the park being the Turnhoutsebaan bridge

Highway running on the south side of the park

Applying urban sound planning: our study fields

ANTWERP

PLANNING GOAL: Improve the access and use of a park area.
MAIN RESEARCH TOPIC: Controlling the sound environment through noise prediction methods and soundscape of urban parks.

Mesoscale level

OUTPUT: Impact study of measures to control the sound environment by FDTD calculations (finite-difference time-domain) and further development of a model for human perception of environmental sounds and its translation to an artificial sound perception model.

Description

Antwerp is one of the most populated cities in Belgium located in the centre of several road infrastructures connecting Europe. Road traffic and the associated noise and air pollution are major environmental challenges for the city.

The study area in which the urban sound planning praxis is applied in Antwerp is composed of four sub-areas affected by a road infrastructure node situated at the northeast part of the city with intense traffic that combines two major road infrastructures and a ring road with local roads.

AREA 1: Spoor Oost is the location chosen to place a major funfair (Sinksenfoor) that happens every year in summer. During the rest of the year this open space is expected to be a pleasant meeting point for the nearby residents.

AREA 2: Hof ter Lo is a residential development exposed to high noise levels. The city asked for several guidelines and a series of actions to protect the residents.

AREA 3: Rivierenhof Park is one of the most important green areas of the city, however, the park is affected by high noise levels due to the busy highway that surrounds the park on the south and west sides. Additionally, a local road divides Rivierenhof in two parts.

AREA 4: The Turnhoutsebaan bridge is the only access to Rivierenhof Park from the city centre. It is of remarkable importance, since the area located to the west of it lacks green areas. A few hundred meters of roads (the Singel-Ringway) and a railway separate the two areas. Despite the spatial proximity, in reality, it is difficult to access the park, as the bridge is extremely noisy, unpleasant and unsafe. It is mainly working as a barrier instead of a connector.

Urban Sound Planning in praxis: strategies and results in Rivierenhof Park, Antwerp

- Soundscape design through individual perception model, green space and membership

Different acoustic challenges demand different approaches. Thus, in the following paragraphs, the main tools applied at these test sites will be described. The work is mainly focused on the third area, Rivierenhof Park.

In order to study the human perception of environmental sounds, the influence of green areas, natural sound sources and relative membership are investigated. The main strategies used are based on a soundscape approach. The idea is to develop statistical and computational models to be used by urban planners to assess the soundscape of urban parks. Based on a comprehensive study, a human auditory attention model is developed and tested including:

- The conduction of a large-scale measurement campaign.
- The development of a model for human perception of environment sounds and its translation to an artificial sound perception model.
- The application of environmental sound monitoring at the park.

The first step of this study was to gather data in a large-scale measurement campaign conducted not only at Rivierenhof Park, but also at several other urban parks in Antwerp. The measurement campaign included the recording of the sound environment during 22 days with mobile sensor nodes carried on all paths inside the parks. The recorded data included sound spectrum in 1/3-octave bands, audio signals and GPS position, enabling a spatial representation of all measurements (Figure 1). At the same time, visitors of the parks were questioned about their perception of the sonic environment.

The outputs of the measurement campaign include equivalent sound pressure levels (LAEq) averaged over 1 second along the paths inside the park, complemented by a comprehensive characterisation of the sound environment using several indicators:

- Percentile indicators to get the dynamic characteristics of the 1-minute sonic environment: 50-percentile to illustrate the average, 90-percentile to illustrate the background and the 10-percentile to illustrate the high values. The difference between C-weighted and A-weighted levels as an indicator that depicts the low-frequency content of the measured sound, as well as the

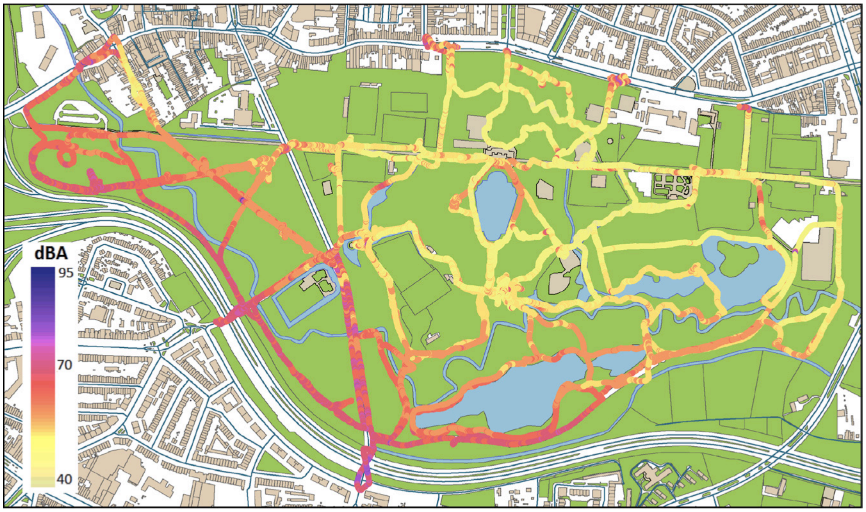


Figure 1 - Noise map of Rivierenhof Park (LAeq,1s)

Figure 2 – The yellow-to-purple coloured dots represent the 1-minute moving average of the indicator of high frequency content (S50,1min)

sharpness, which is a psychoacoustic parameter that describes high frequency content. For this reason, it can be used as a proxy indicator for sounds such as voices;

- Green space data (grass and tree coverage) as indicators that might affect noise level distribution due to different properties in absorption, diffusion or scattering.

The measurement results show that Rivierenhof Park has the highest noise levels adjacent to the busy highways with LEq between 60 and 75 dBA. Additionally, the background noise level (L90) is between 60 and 75 dBA. It can be seen that the sharpness indicator in the park in Figure 2 has highest values at the centre as well as in areas where people would be the more dominant sound source compared to road traffic noise.

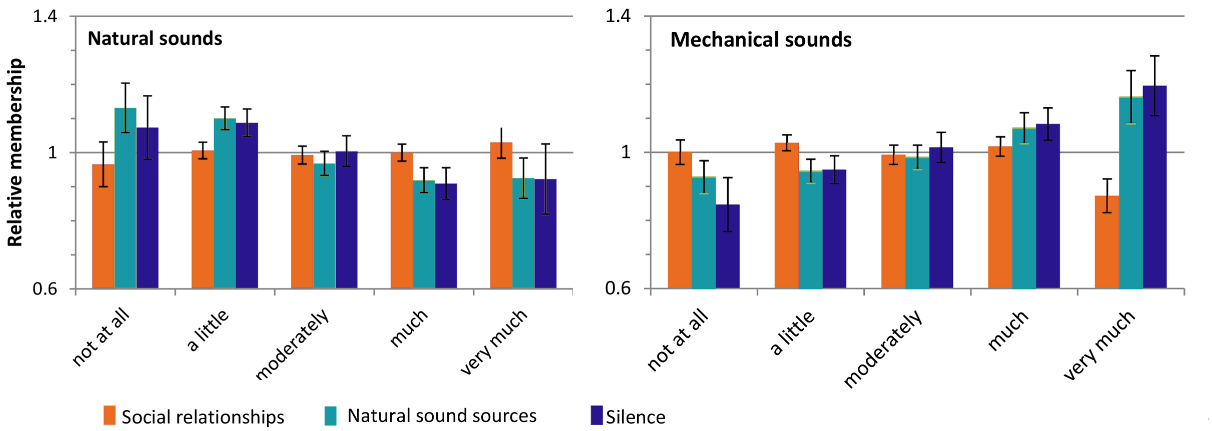


Figure 3 – Appreciation of sounds in parks

In order to evaluate the subjective response to the sound environment, the public was asked to complete a questionnaire including 13 statements to analyse the influence of the park, the meaning of tranquillity and the heard (attended) types of sounds and the relative membership. All of their responses were assigned to the calculated tranquillity viewpoint group with a relative membership (social relationships, sounds and nature, and silence). The questions relate the sounds that the park visitors reported to have heard during their visit to the park and the degree of membership of the three viewpoints on tranquility.

As can be seen in Figure 3, the participants who heard a large number of natural sounds do generally not belong to the groups associating tranquillity to natural sound sources or to silence. On

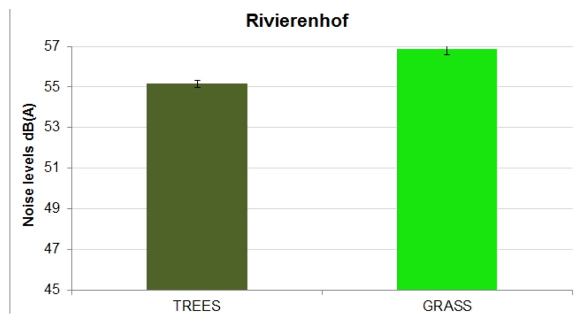


Figure 4 – Average values of L90 and relative confidence intervals depicted for each green space category in Rivierenhof Park

the other hand, in the group of participants belonging to the same tranquillity belief groups, a pronounced increase is found in the hearing of mechanical sounds. Correspondingly, it can be argued that the mechanical sounds (often characterized as unwanted) are noticed more by those people associating tranquillity to silence and natural

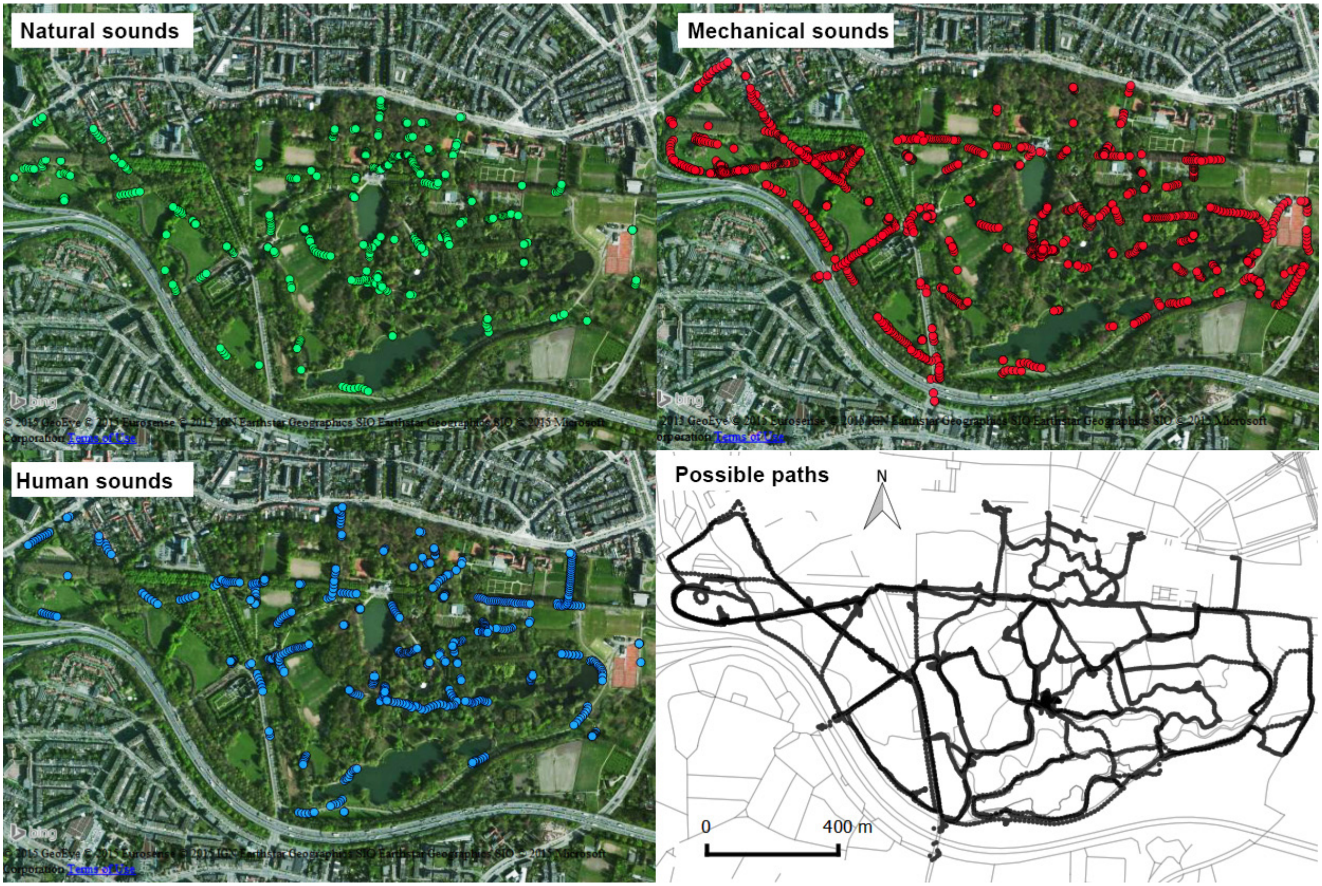


Figure 5 – Artificial sound attention model output for Rivierenhof Park

sound sources. Therefore, such people hear these antagonizing sounds more than the sounds that they actually want and expect to hear in a tranquil environment.

Rivierenhof Park is also the objective of study for the interaction of green space parameters and sound levels. In this case there is a negative correlation between the tree coverage and the average levels of L10 and L90, suggesting that an increase in the amount of trees within the parks can provide further noise level attenuation (Figure 4). A second outcome is that the noise levels within the "tree coverage" are lower than the noise levels in the "grass coverage".

To continue with the application of urban sound planning, the study continued with the development of a model for human perception of environmental sounds and its translation to an artificial sound perception model (see Figure 5). The current status of technology allows a monitoring of cities with a high spatial resolution. However, the challenge starts within a soundscape approach that analyses the person-environment interaction, i.e. the perception. The inclusion of such translation will strongly help in the understanding and assessment of urban sound environments. Although the models will not be described in detail (for more information, check the "Urban soundscape" Chapter), it is worth to mention that they describe and implement two basic listening styles: the first characterizes the holistic background listening experience and the second implements the analytic listening considering the person's attention and the noticed sounds

The model is expected to give statistical information about individual perception. For example, mechanical sounds were almost constantly noticed next to the busy roads. Human sounds appear mostly in the centre area of the park. Natural sounds were often noticed in the north area of the park. However, the model also includes an important portion of human sounds activation in areas without many people during the measurement campaign. As a consequence of the implementation of attention processes, the model allows not listening attentively to either of the sounds, as a human park visitor would do.

To complement this study applying an urban sound planning approach, the study goes beyond the analysis of the distribution of different activities within the park, with the aim to make it more attractive to the users. The proximity of different paths, the accessibility of the park and different activities have been studied, as well as the quality of integration in the city. It was concluded that the southern part of the park has more chances to be visited than the northern part due to the presence of water (lakes) and the activities around it. Improving accessibility, creating new paths, and enhancing the lake as the final destination could result in more visitors for these areas.

Controlling the urban sound environment: improvement of road layout

Rivierenhof Park is divided by a 1 km road with two traffic lanes, each with an adjacent bicycle and pedestrian path. The current urban layout decreases pedestrian safety and interrupts the cohesion of the park as only four crossing points are available. At the same time, the linear geometry of the road enhances vehicle acceleration. From the aesthetic and visual point of view, it gives

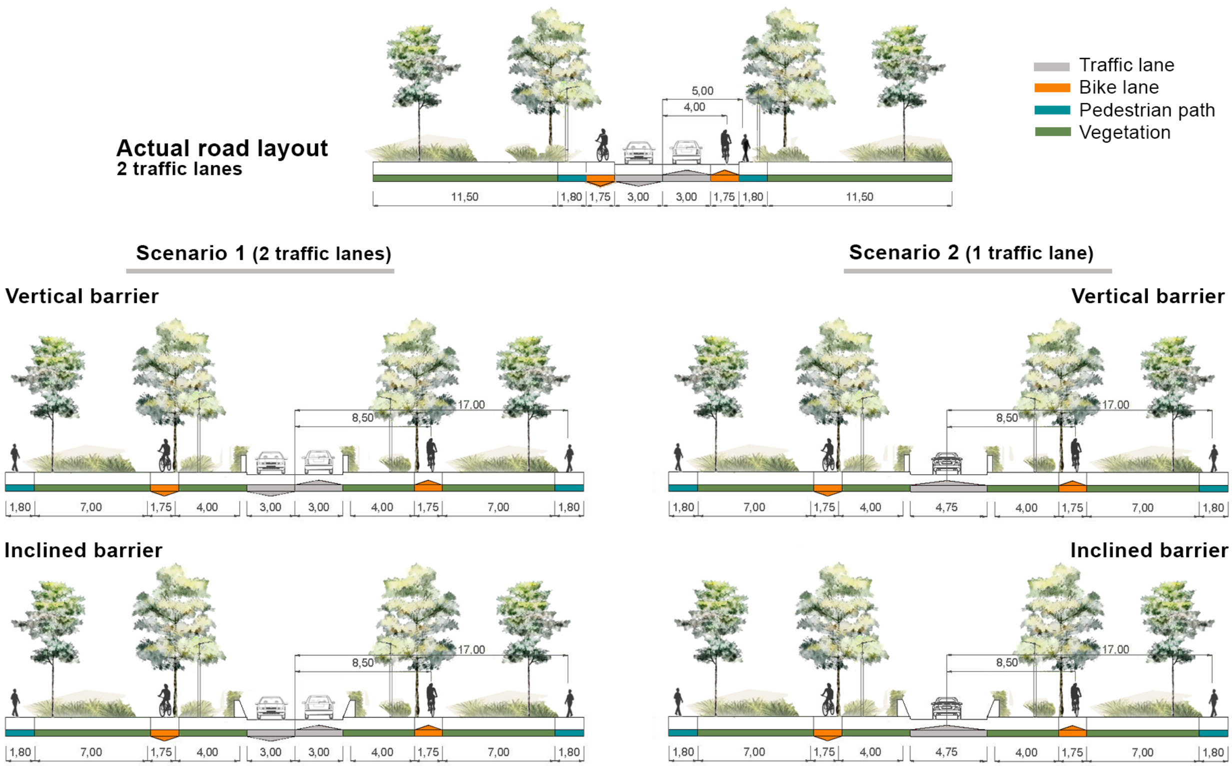


Figure 6 – Scenarios modelled: current scenario, scenario 1, scenario 2

the misleading impression to the visitor that this is the end of the park. Additionally, this road is a significant source of road traffic noise, with LEq values around 70 dBA.

In this regard, the working group proposed the following solutions to mitigate the problems generated by road traffic, reducing road traffic noise emission and increasing pedestrian safety and urban green space quality:

- Separating the two traffic lanes;
- Reducing the number of lanes: redistribution of the traffic flow to other possible routes;
- Reducing traffic speed with calming measures, such as the inclusion of chicanes along the road, known to reduce traffic speed. This measure will also avoid the linear perception of the road, giving visual continuity to the park;

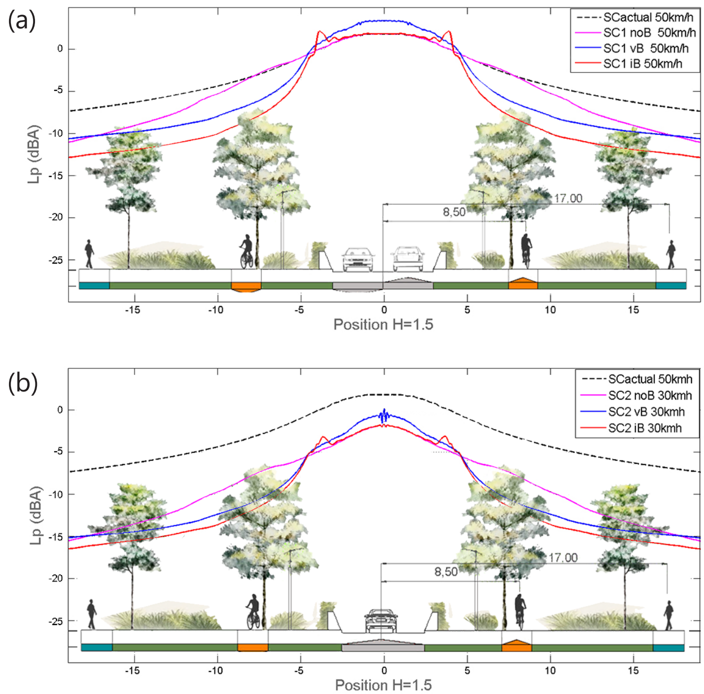


Figure 7 – Noise exposure along the cross section at 1.5 m height. (a) Scenario 1, (b) Scenario 2

- Adding a porous road surface material, reducing noise emission;
- Locating vegetated low barriers next to the source (see "Controlling the urban sound environment" Chapter);
- Including absorbent vegetated areas between source and receiver, reducing noise levels at the pedestrian paths while giving visual continuity to the park;
- Locating pedestrian paths and bike lanes at a further distance from the road.

Most of the proposed solutions were acoustically calculated using a wave model (a Finite-Difference Time-Domain method, FDTD) (to know more, see the Chapter on "Prediction and auralisation of urban sound environments"). The addition of different shapes of low barriers was also assessed (see the "Controlling the urban sound environment" Chapter).

The different noise abatement measures are included in two new scenarios: scenario 1 (Sc1) keeping the two-lane road, and scenario 2 (Sc2) modelling a one-lane road (see Figure 6). Both scenarios are compared to the current situation, where both the cyclist and pedestrian paths are located next to the road. Seven different cases are calculated, including the current scenario, the two future scenarios without barriers and the future scenarios with the two barrier types (see Figure 6). In both proposed scenarios, pedestrian and cycling path are located at a further distance from the road (8.5 and 17 m respectively), making it possible to include two absorbing green areas.

Two different low barrier types (vertical or 30 degrees inclined) of 1.1 m height have been assessed taking into account different traffic speeds (50, 40 and 30 km/h). Both barrier types are modelled with absorbing vegetation on the top and receiver sides. The total sound pressure level distribution along the section at 1.5 m height in the different cases are compared to the current situation (see Figure 7). The inclined low barrier for scenario Sc2 is the most effective solution, with a reduction of 11.5 dBA in the exposure for the same position. The comparison between the two charts shows the importance of limiting the traffic speed achieving around 5 dBA reduction. It should be noted that the modelling results have been performed in two dimensions, assuming no variation along the third dimension. They correspond approximately to a 3D model from the section infinitely extruded, which is not a real-life case. However, they are useful for comparing the efficiency of each noise abatement.

The exposure reduction in dBA relative to the reference values in the current case (cyclist at 4 m and the pedestrian at 5 m) is displayed (see Figure 8). Here, large noise reductions are shown, especially in the cases with the inclined low barrier, where a 25 dBA reduction is achieved on the cyclist exposure at 8.5 m distance and 30 dBA reduction for the pedestrian exposure at 17 m in scenario Sc2.

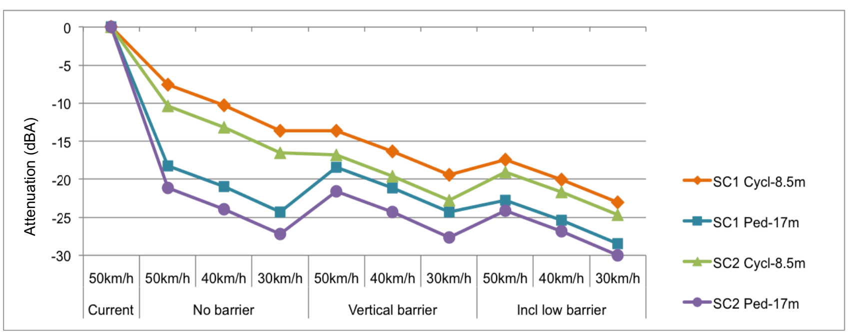


Figure 8 – Noise reduction (dBA) for cyclist at 8.5m and pedestrian at 17 m from the road centre in both scenarios. Vegetated substrate is considered

From this analysis the main conclusions are that:

- The combination of different noise abatement measures proposed, including distance increase, can reduce up to 25 dBA for cyclists and up to 30 dBA for pedestrians;
- The suppression of one traffic lane gives an overall reduction of around 3 dBA;
- Decreasing the speed from 50 to 40 km/h reduces an overall noise level by around 3 dBA. Reducing the speed from 40 km/h to 30 km/h additionally reduces noise by around 3 dBA;
- Displacing the cyclist and pedestrian lanes further away from the source achieves a reduction of around 7 dBA and 17 dBA respectively.
- Vegetated ground surfaces only reduce noise at far distances. Reduction of around 6.5 dBA is achieved for pedestrians at 17 m from the road.
- The addition of a low vertical barrier reduces noise by around 6 dBA for cyclists, but practically no effect is found for pedestrians.
- The inclined barrier achieves bigger reductions than the vertical one in all cases. It additionally reduces noise by around 4 dBA in Sc1 and around 2 dBA in Sc2 for cyclists. For pedestrians, a reduction of nearly 5 dBA is achieved in Sc1 and 3 dBA in Sc2.

Virtual Reality as a tool to combine visualisation and auralisation

The Virtual Reality technology is an interesting tool to combine visualisation and auralisation, allowing a comprehensive analysis of the urban environment during the design phase. Additionally, it is an effective means to communicate proposals to stakeholders as they can be virtually transported to the newly designed urban area.

Virtual Reality was applied in SONORUS to improve the urban sound environment, assessing different renovation designs for the Turnhoutsebaan bridge, which passes over a busy Highway in Antwerp and is the only access to Rivierenhof Park from the city centre. Despite the spatial proximity, the conjunction of roads and railways constitutes a real obstacle to reach the park. Walking on this bridge is currently extremely noisy and gives a feeling of insecurity.

A test was performed with normal hearing participants experiencing a walk over different virtual environments on the bridge using the Oculus Rift (see Figure 9). Different urban arrangements were modelled and different noise abatement measures (noise barriers) were conveniently auralised.

It was shown that human perception of the urban environment is multi-

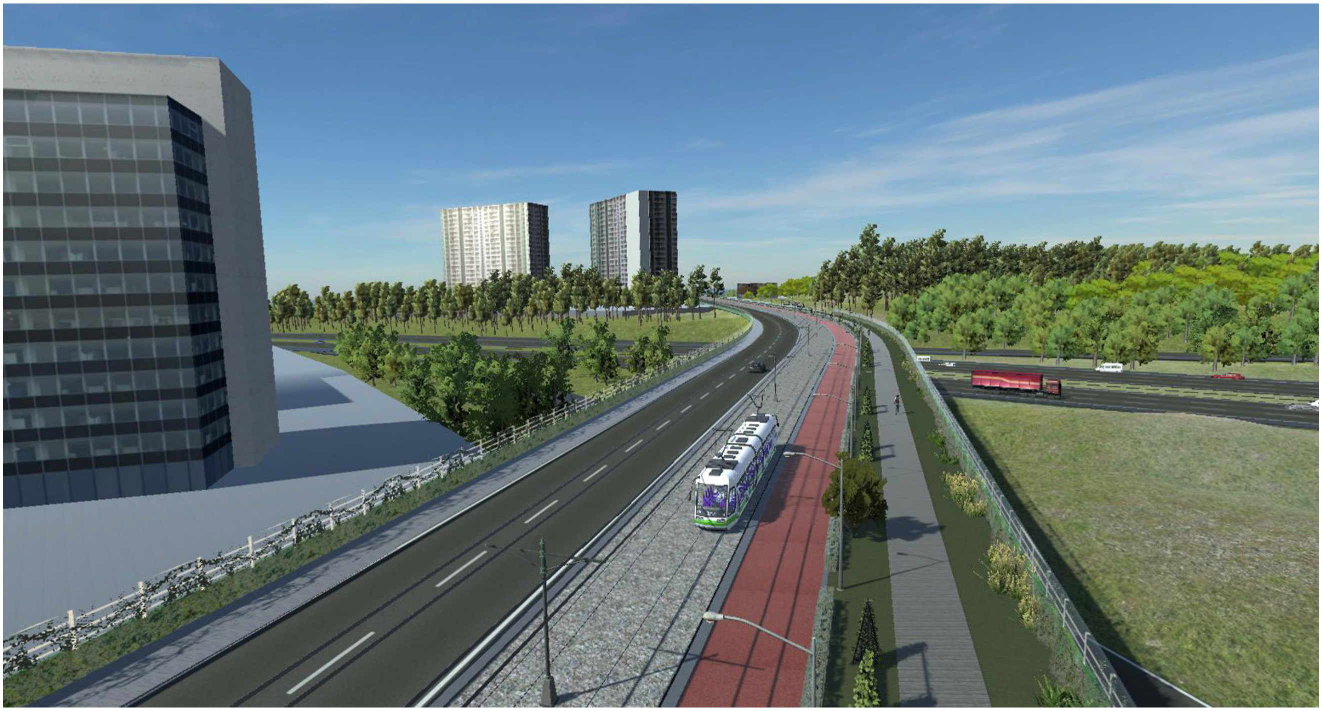
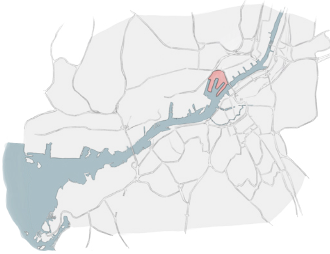


Figure 9. Virtual reality applied to improve the urban sound environment at Turnhoutsebaan bridge

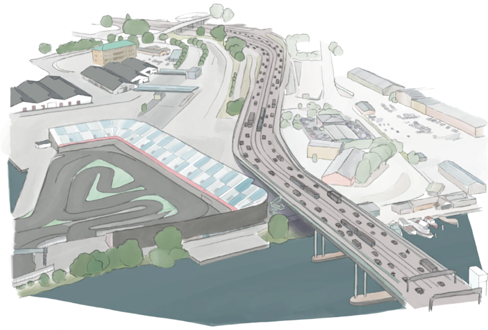
sensorial (especially, the visual sense is related to the auditory sense) and such interactions can have an important effect on people's noise perception. As an example, the effect of the noise barriers is not only a noise reduction at the ear of the pedestrian. It also partially hides the sound source from sight, and the visual design of the barrier may help to improve the overall perception of the environment.

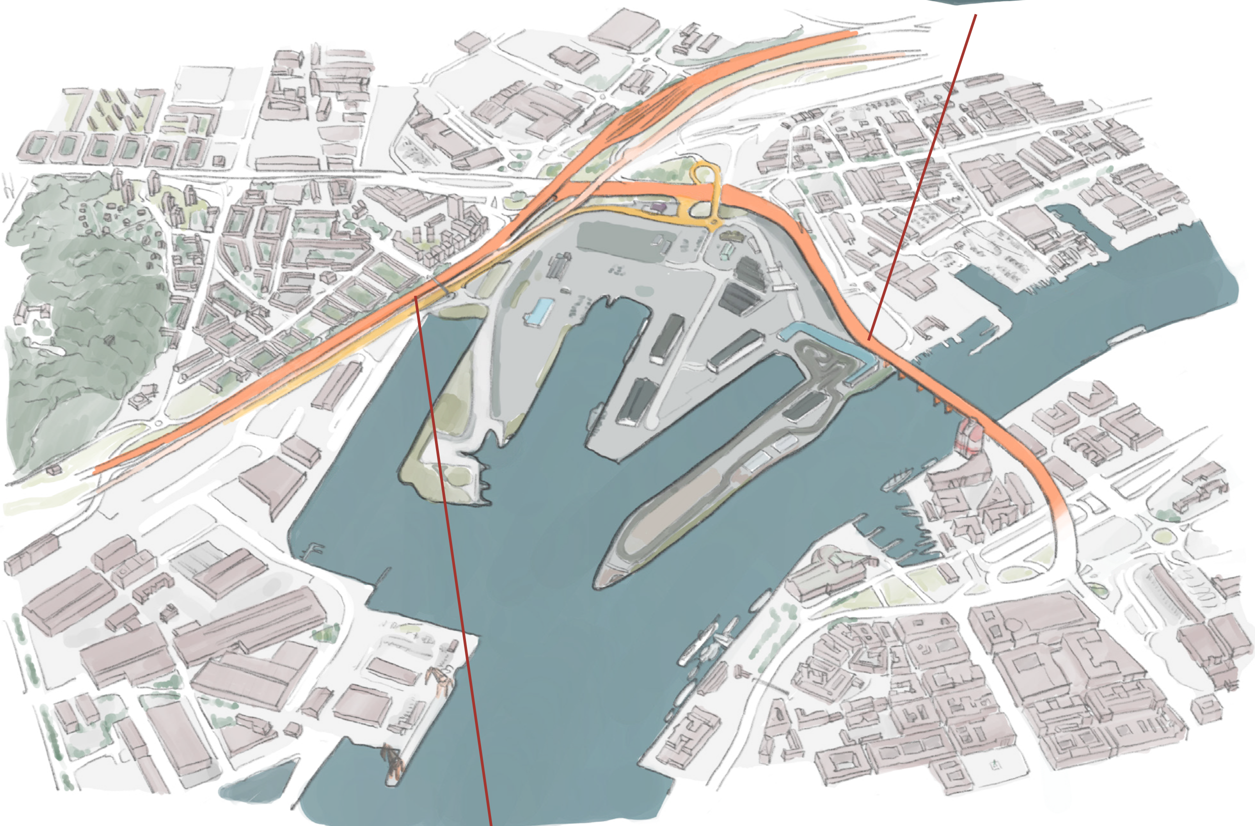
This demonstrates that noise control in the context of soundscape design should not only consider reducing levels of unwanted sounds, but also improve the audio-visual perception of the urban environment. Consequently, architects and urbanists play an important role in the perception of the urban environment and the participation of an urban sound planner is recommended as an integral part of future urban planning.

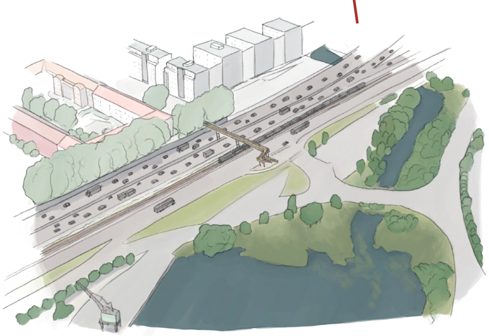


Map of Gothenburg (Frihamnen area marked in red)

Götaälv bridge to the northeast of the area







One pedestrian bridge links the Frihamnen area with the north side. The bridge goes over the highway and railway that run along the northwest side of the area.

GOTHENBURG, FRIHAMNEN AREA

PLANNING GOAL: Recover and transform a central area with residential purposes, including a large city park.
MAIN RESEARCH TOPIC: Controlling the sound environment through noise prediction methods.

Mesoscale level

OUTPUT: Development of a tool to study the impact of future road traffic scenarios on the sound environment through microscopic traffic alternatives based on real situations.

Description

The city of Gothenburg is located at the mouth of the river Göta in west Sweden. It is the second largest city in Sweden, with 550 000 inhabitants in the urban area.

The study area of the SONORUS project is Frihamnen (Freeport). It was built in the 1920s as the most inner harbour located in front of the city centre. The freeport was closed in 1996. Since then, this area of around 100 ha (the same size as the city centre) has been enduring a severe transformation. The area presents a unique opportunity to improve and test new ideas within the urbanization process. This unique occasion is presented by the city in the way of a long-term project to be finished by 2040, transforming it into a dense-mixed area with around 15 000 people and the same number of working places.

However, Frihamnen is a challenge from the environmental point of view, where the list of aspects contain rising water levels, contaminated soil and water, and air and noise pollution coupled with the infrastructure problems.

Frihamnen within SONORUS

SONORUS working group got the task to analyse the acoustic situation and understand the impact of future developments on the sound environment from a holistic perspective. In this regard, Frihamnen presents a great potential to become a pleasant area. However, the project needs to look at a long-term perspective under a holistic approach, where retrofitting might be avoided due to the increase in costs and technical complexity. Frihamnen is a project largely driven by the need of densification. Moreover, the complexity is increased by the interest it has generated among the city offices, the citizens and the building companies around it.

Our concern is on how to obtain a good sound environment, attending to the above described interactions. To exploit all potential benefits of obtaining a good sound environment, guideline values may be a first approach, but certainly not the final answer within an

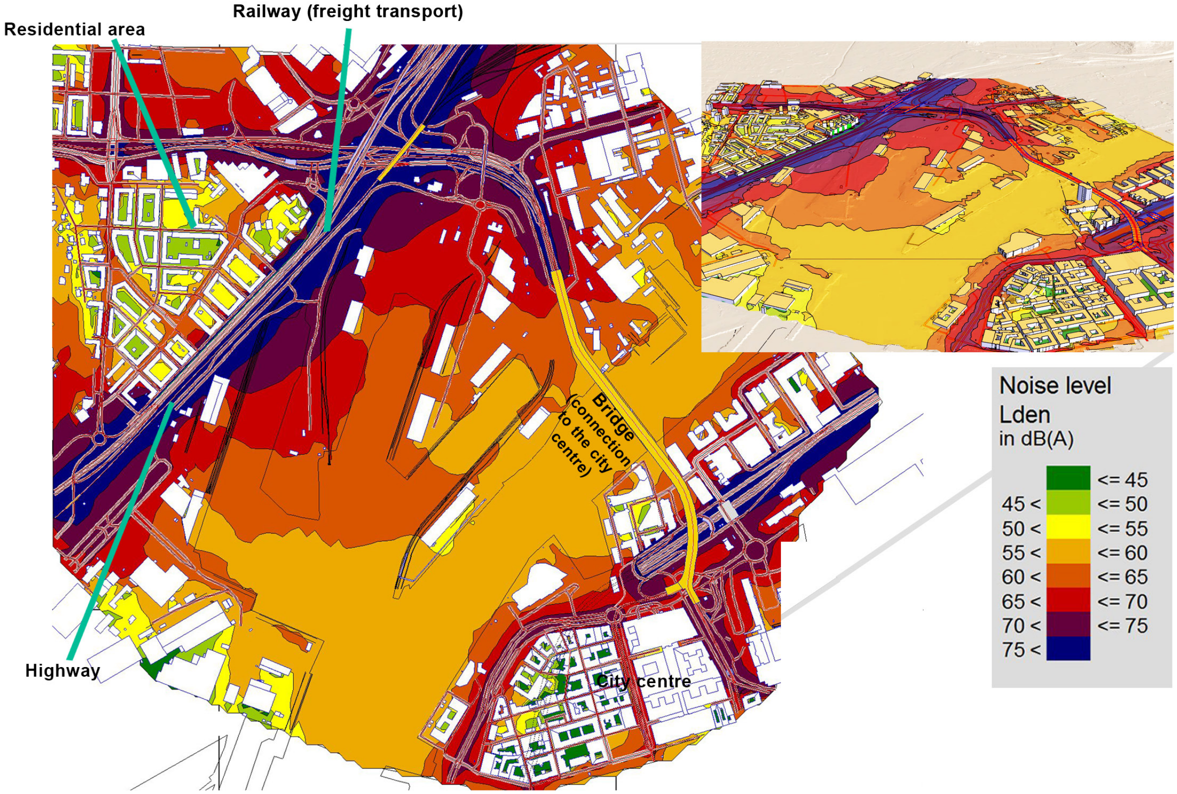


Figure 10 – Noise map of Frihamnen area. Day-evening-night noise levels

urban sound planning approach.
To get a glimpse of the current noise situation, a noise map reflecting the day-evening-night equivalent level (Lden) is already assessing the problematic environment (see Figure 10). The whole area is submitted to levels above 65 dB, calculated according to the Swedish standard. The World Health Organization (WHO) stated in the Good practice guide on noise, that Lden values around 50 dB would represent a good sound quality in a residential area. The Swedish legislation considers the LAEq,24h limit to be 55 dB. However, this limit level is raised in the case the noise levels at the quiet side are below 55 dB, in at least half of the living rooms and bedrooms.

The main noise source in Frihamnen is the road traffic. Nevertheless, a high contribution is also coming from the trains traveling northwest-northeast.

However, as we stated in the previous Chapters (see "Controlling the urban sound environment" Chapter), these type of maps, which are mainly based on static traffic situations, are not adding enough information about how the sound power of sources is varying along the roads and over time, where vehicles are constantly braking and accelerating. Such noise maps are not giving enough information about how to improve the area embracing a view that places sound quality on the urban planning agenda.

Transport management and traffic design are decisive if one wants to start talking about qualities in the sound environment. To study these types of projects, the assessment includes a macroscale perspective, focusing on how the city works. The building and transportation structures comprise a cascade effect within the rest of the urban scales. Infrastructures such as the train line and highways are affecting the overall sound environment (to know more on this type of scales and the implications it has on the sound environment, read the introduction of the Chapter on "Controlling the urban sound environment"). This type of scale is tackled from a long-term perspective, looking at all agents involved. In the study of Frihamnen, the focus is on looking toward the next scale affected by this macroscale planning design, i.e. the mesoscale, capable to give enough answers to improve the sound environment of large areas.

Within the mesoscale, the appropriateness of the sound environment to the desired planned activities and functions in the area is one of the main ideas to explore. However, certain proper conditions are needed. In an area dominated by high exposure to noise, the spatial functions and uses that this part of the city could offer to its inhabitants is practically none. With such high exposure to noise, the idea to, for example, sit in a park to read a book not being disturbed by traffic noise or rest at home without noticing the high noise levels coming from the road traffic all the time, etc., will be extremely difficult to realise, unless a careful plan of the sound environment is included in the decision-making process. If this is not addressed at the planning stage, it is very likely that in order to mitigate the noise and increase the sound quality of the area, the resulting design will end up being a patchwork design, e.g. with noise proof windows, standard noise barriers and suboptimal use of spaces due to their high exposure to noise. This will also have enormous long-term consequences on complexity and costs. The SONORUS vision tries to avoid this retrofitting state, where everything becomes complex and expensive.

The city is making a large effort by

creating several workshops and activities about the area. However, acoustic aspects are generally not present in those activities. As part of the Urban Sound Planning approach, SONORUS organised a workshop with members of the city's Planning Office and Environmental Office (see section "Urban Sound Planning workshop").

As mentioned previously, the transport management and traffic design is key if one wants to start talking about qualities in the sound environment. For this purpose we started to study the traffic scenario proposed by the Traffic Office (this model has been modified in the latest project reviews).

In general, noise mapping software work with static traffic, which may lead to underestimations. Therefore, a dynamic assessment tool, representing the kinematics of the vehicle is developed within the SONORUS project. The purpose is to study those plausible strategies that could improve the sound environment of the area. These strategies seek to address the appropriateness of the sound environment to the place (closeness to water, the location of residential areas, the influence of major infrastructures, etc.).

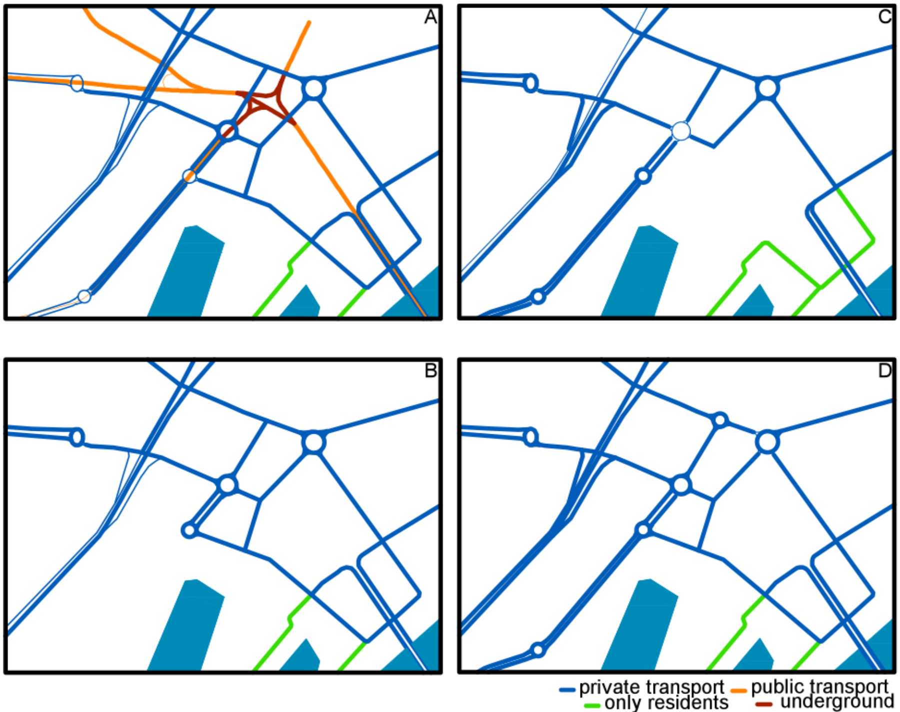
Urban Sound Planning in praxis: traffic strategies, noise emission tool and results in Frihamnen area, Gothenburg

The tool is understood as a dynamic assessment composed by microscopic traffic simulations including the vehicles' kinematics, which are computed to obtain single-vehicle noise emission (see the Chapters on "Controlling the urban sound environment" and "Prediction and auralisation of urban sound environments").

The study focuses on nine alternative traffic strategies. Five of the strategies are related to speed reductions or acceleration effects based on the first scenario (the one proposed by the Traffic Office). The rest of scenarios present different layout transformations (see Figure 11). The models are made to assess the worst traffic demand situation (peak hour). The requisite is that all scenarios have to allocate the same traffic, for example, the same number of vehicles traveling from one point should be able to reach their destination in all scenarios

We selected 11 receiver points distributed among the area to see how the acoustic properties are changing among them (see figure 12, scenario 1). The sound power level of all individual vehicles during the peak hour is estimated.

The influence of vehicle dynamics is



Scenario	Description	Model layout
1	Base scenario with adaptations	A
2	Remove parallel road to highway	B
3	Remove roads close to piers	C
4	Transform intersection with traffic lights into roundabout	D
5	Reduce speed on highway to 50km/h	A
6	Reduce speed on bridge to 50km/h	A
7	Reduce speed on road close to piers to 30 km/h	A
8	Remove medium-heavy and heavy vehicles	A
9	Acceleration set to 0	A

Figure 11 – Studied scenarios

already shown in scenario 9 in Figure 12, (acceleration noise omitted) in comparison with base scenario (1), with differences around 1-3 dBA for the selected receivers. Also, scenario 8, without heavy vehicles, is giving differences in terms of equivalent sound pressure level (1-2.5 dBA).

With this type of tool is also possible to see the contribution to the equivalent sound pressure level, for e.g. 15 minutes (LAeq,900s), from each road segment to a certain study point (e.g. receiver), creating a kind of contribution noise map. The same way, the largest LAeq,1s value during the period, here denoted Lpeak, is analysed. (See Figure 13, top, for equivalent as well as peak levels.) To study data through maps, roads are grouped into segments (here ca 150 segments in total).

In general, when assessing LAeq,1h the most favourable scenarios are 3, 5, 8 and 9. Speed reduction in the highway (scenario 5) might be a good solution to reduce noise levels in the majority of the study points. Keeping only light vehicles (scenario 8) reduces levels up to 2.5 dBA. A study on time patterns should be made to give further information about the test site opportunities (to see more about time patterns and number of

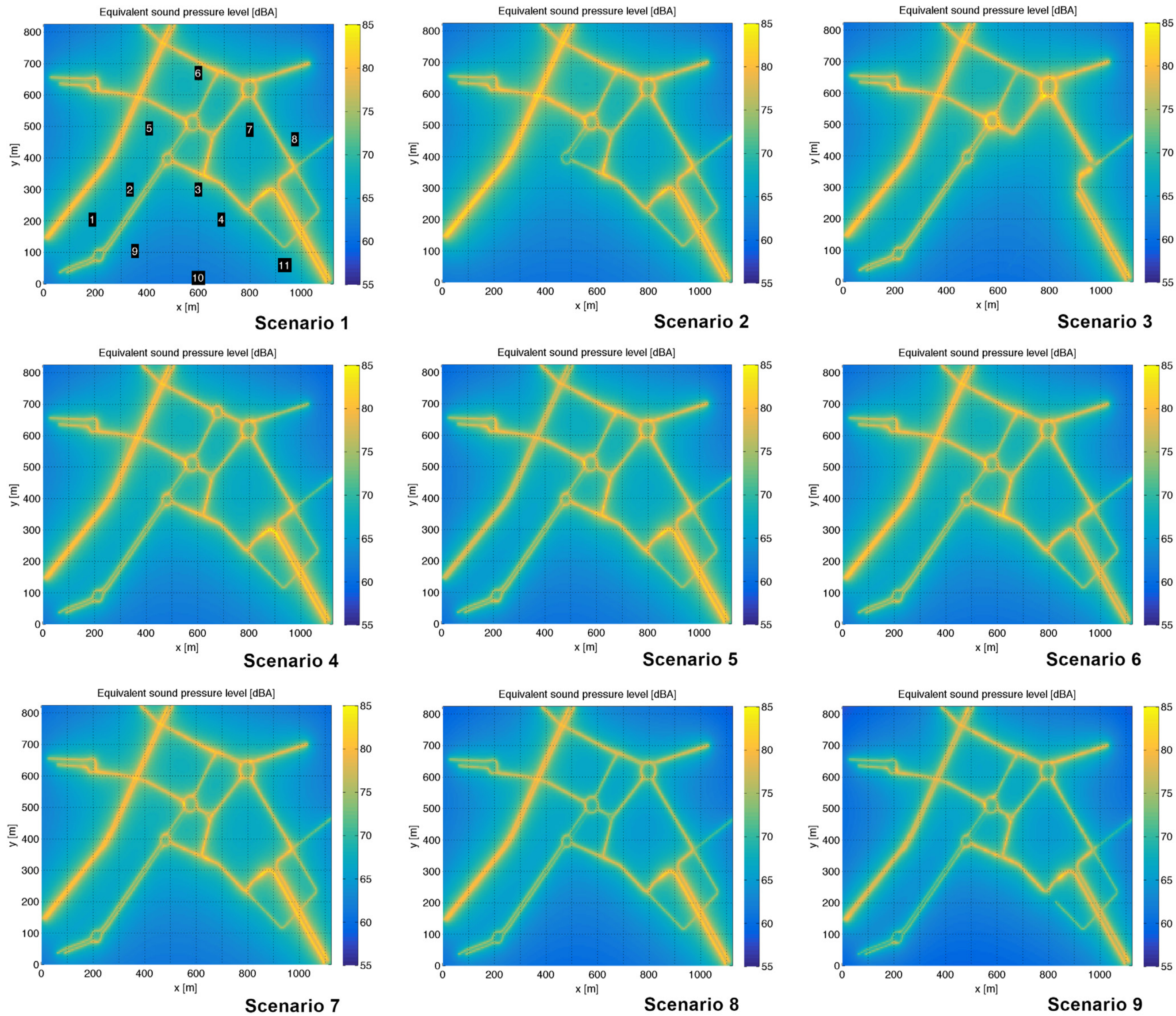


Figure 12 – Dynamic noise maps for the second simulated quarter hour reflect the equivalent sound pressure level for the second quarter hour (LAeq,900s)

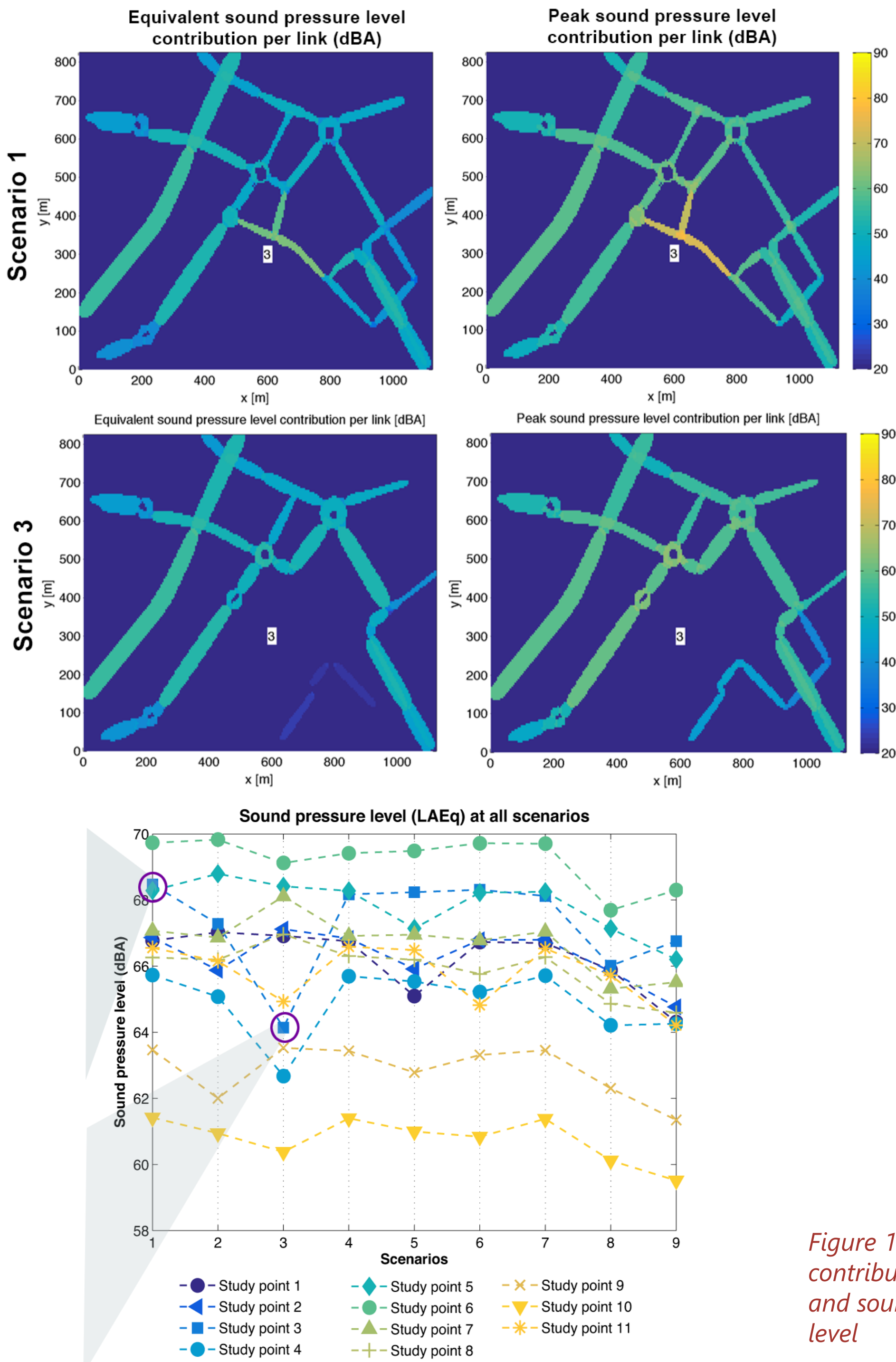


Figure 13 – LAEq,900s contribution per link and sound pressure level

events go to the Chapter on “Controlling the urban sound environment”).

From this work, we have concluded that there is a need to confront the project under a multi-perspective scenario, letting the urban planning process meet the requirements of the city, while offering concrete proposals from a holistic point of view. The SONORUS working group has been developing the research in parallel to the development of the project. Our aim has been to show different alternatives that can be considered by the city, but also to develop a tool that might be used as part of the design process in other urban developments.

Some recommendations proposed are looking toward:

- The reinterpretation of the transport system: controlling the sound environment through transport management and traffic design strategies focusing both on a macro and microscopic traffic study;
- Interest on time patterns with a large impact on nuisance: study through dynamic traffic situations;
- Rethink the opportunities to improve the sound environment through the study of the activities and functions that each particular site is demanding;
- Avoid complex and expensive solutions through the application of the urban sound planning approach as part of the decision-making design stage.

BRIGHTON, VALLEY GARDENS

PLANNING GOAL: Regain a park area for pedestrians.

MAIN RESEARCH TOPIC: Soundscape of urban parks including urban sound environment control.

Microscale level

OUTPUT: Characterization of the sound environment by integrating a detailed traditional noise mapping and soundscape maps through the perception evaluation of the sonic environment appropriateness. First assessments show that this integration may be an effective methodology in the analysis stage, supporting city planners with adequate information and strategies to plan future urban interventions.

Description

Brighton & Hove is a city of 250 000 residents and is one of the main seaside destinations in the UK, both for national and foreigner tourists. It receives around 400 000 visitors per year. Brighton & Hove city has a wide range of restaurants and cafes, and offers a varied nightlife, which, along with the numerous art and cultural events have created a thriving city.

The drawback of being such a vibrant city is the added pressure in terms of road traffic and human activities resulting in excessive noise and annoyance therefrom.

The Valley Gardens site within SONORUS

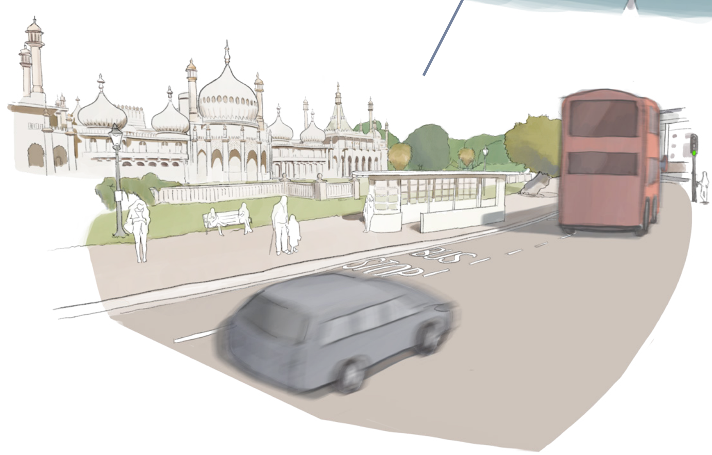
The Valley Gardens site is a green area located in the city centre, which stretches from the seafront roundabout (Brighton Pier) to approximately 1.5 km into the city.

The area constitutes a relevant access for entering and leaving the city and for accessing the seaside. Consequently, it is largely affected by the high noise levels from road traffic. The residents do not use the green areas along the site for their leisure activities.

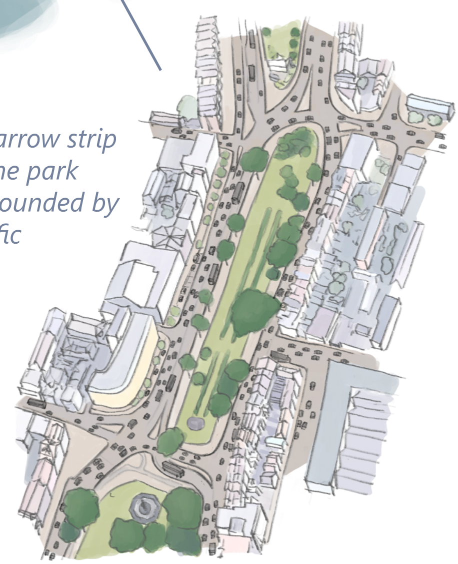
Added to the problem of noise, there are also mobility issues: some road sections have a total of four lanes, narrow sidewalks and almost non-existing cycling lanes which make it difficult for people to move around.

In order to solve these problems, the city of Brighton & Hove started a project with the purpose of improving the area and transform it into a safe and flexible place that will attract residents and visitors. This way, the area will become a meeting place, connecting the city efficiently and safely however people travel. The Valley Gardens project's aim is to upgrade the public spaces and improve routes for pedestrians, cyclists, drivers

Map of Brighton
(Valley Gardens
marked in blue)



View of the Royal Pavillion



A narrow strip
of the park
surrounded by
traffic

and public transport. This project seeks to minimise intrusive/unwanted noise whilst at the same time introduce positive sounds. According to the city partner, the intention for this site is to use sound as a valuable resource rather than a "waste product of poorly designed areas".

Nevertheless, the current situation is deeply affected by noise problems. The entire Valley Gardens area is being exposed to high noise levels (Lden≥65 dBA and Ln≥60 dBA), which are above the recommended levels by the WHO. One of the first challenges proposed by the city to the SONORUS working group was to tackle this problem in a holistic way, improving the soundscape of the park area.

Urban Sound Planning in praxis: soundscape design strategies and results in the Valley Gardens, Brighton

In order to have a solid background for future proposal and design, it was essential to have a good acoustic characterisation of the current Valley Gardens situation. Thus, two main strategies were defined: producing a more detailed road traffic noise map of the Valley Gardens area characterizing the sound environment both from the acoustic metrics and the individual perceptions point of view. The noise map for the day-time level (Ld) was generated based on fifty-five selected receiver points, calculated according to the CRTN method (used in the UK).

A noise survey and a soundwalk campaign were carried out at eight selected locations close to and within the Valley Gardens; (1) Seafront, (2) The Old Steine, (3) Royal Pavilion, (4) Victoria Gardens South–Victoria Statue, (5) Victoria Gardens South–Mazda Fountain, (6) Victoria Gardens North, (7) St Peter's Church and (8) The Level.

For each location, 21 participants were asked to listen to the sound environment for 2 minutes and fill in a structured questionnaire. The questionnaire included questions about: participant's demographic information, expected social or recreational activities, noticeability of different sound source types, semantic scales of perceptual attributes related to the sound environment, and overall quality and appropriateness of the sound environment. Two sets of questions on a ten-point scale were further considered to assess:

- Soundscape quality: two questions considered the perception of the sound environment, ranging from "very bad" (0) to "very good" (10), and the appropriateness of the sound environment, ranging from "not at all appropriate" (0) to "completely appropriate" (10).

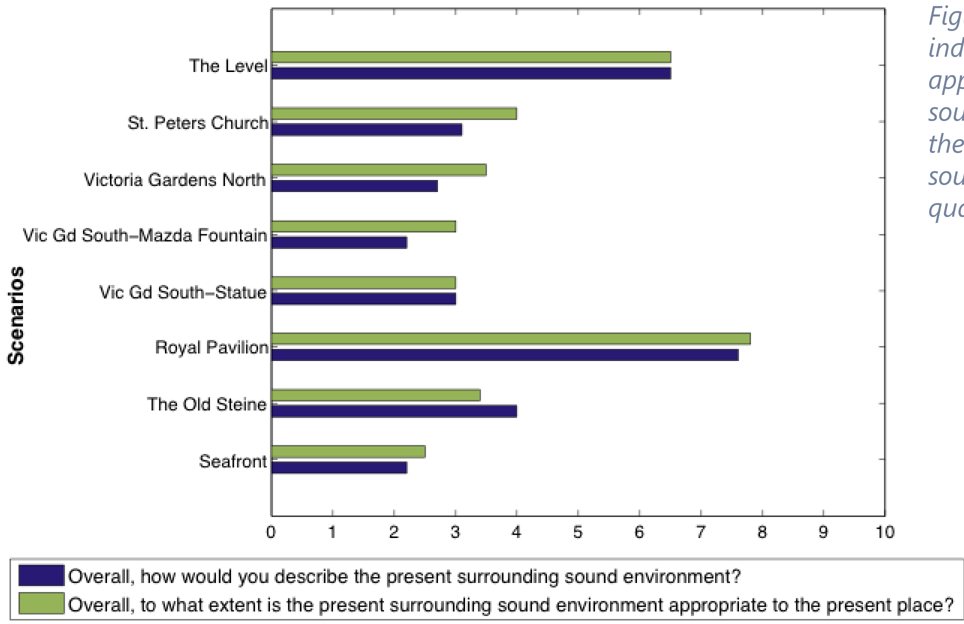


Figure 14 – Median individual responses for appropriateness of the sound environment to the place and overall sound environment quality

- Sound source profiles, to evaluate to what extent different urban sound sources were present: traffic noise, other urban noise sources (sirens, construction noise, etc.), sounds of individuals or natural sounds. The scale ranged from "do not hear at all" (0) to "dominates completely" (10).

The results (see Figure 14) show that only two of the selected locations had high scores both on the overall sound environment quality and appropriateness of the sounds environment to the place: The Royal Pavilion and The Level. This is likely due to the fact that those are the only two sites that are not directly exposed to road traffic noise, which has been found to be the main cause of noise annoyance in the investigated area.

A "sound sources dominance map" was also produced by implementing the mean individual scores for the sound source profiles question into a Geographical Information System (GIS) platform, generating a prediction surface for the study area, using the Kriging interpolation method (Figure 15).

The results show that road traffic noise sources dominate the area and that "sounds of individuals" had low scores, which suggests the absence of perceived sounds from human activities throughout the park.

A combination of noise mitigation actions and different soundscape

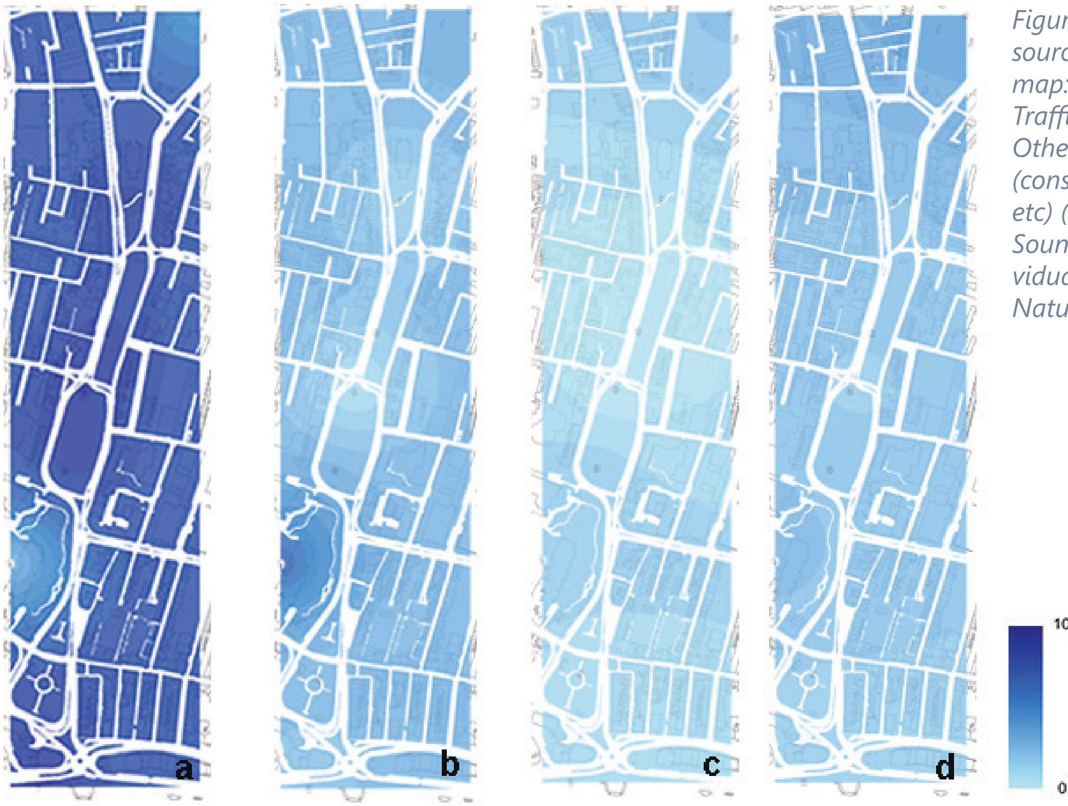


Figure 15 – Sound source dominance map:
Traffic (a),
Other urban sounds (construction, sirens, etc) (b),
Sounds of individuals (c),
Natural sounds (d)

strategies has been proposed in order to assess potential benefits of an overall solution aimed at improving the Valley Gardens sound environment. For this, 15 study points were selected (see Figure 16 and Table 1).

Different noise mitigation actions were proposed and discussed with the city planners. The most effective ones for the majority of the study points are the banning of heavy vehicles and the introduction of a continuous absorbing noise barrier around the park. However, the noise barrier solution will need a further study in order to be adapted to the several particularities of the urban layout, such as crossings, bike lanes, etc.

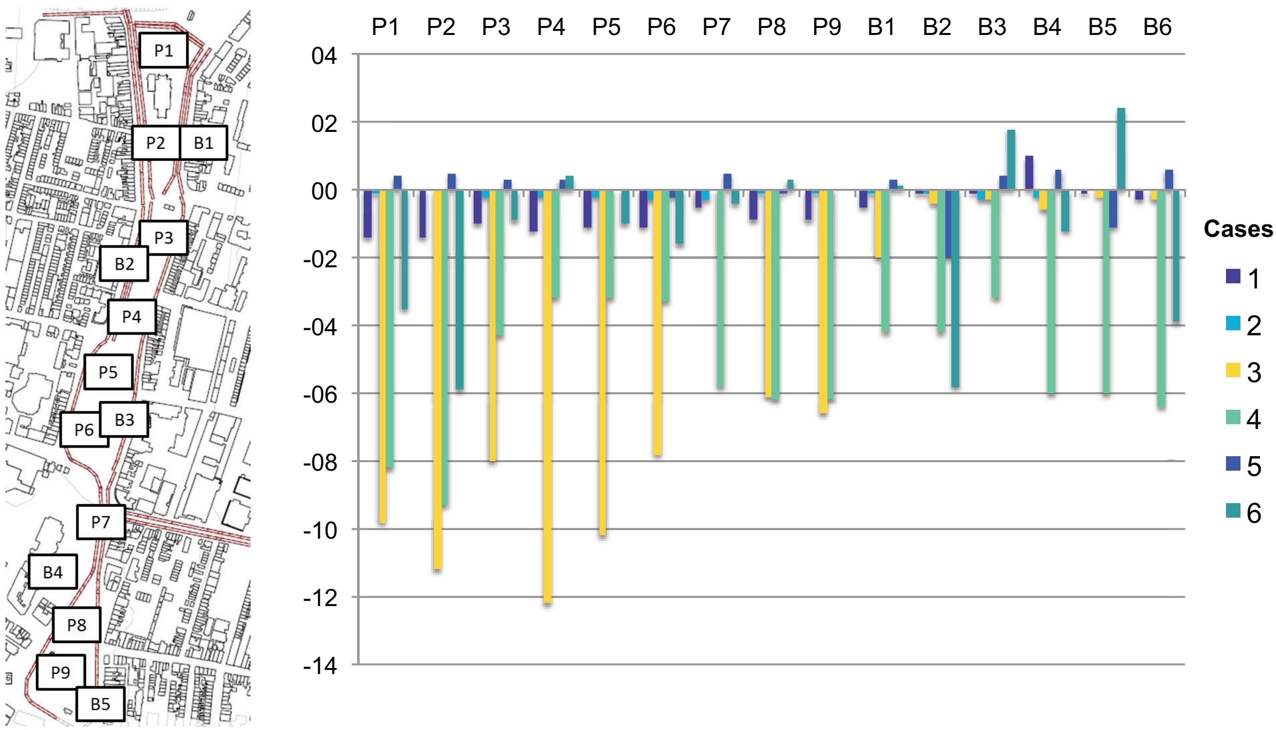


Figure 16 – Noise mitigation actions (Attenuation in dBA)

Table 1 - Noise mitigation actions

Case	Description
1	No reflections from buildings
2	Speed limit set to 20 km/h
3	Continuous absorbing noise barrier (1 m. height) around the park
4	No heavy vehicles
5	Buses on the West bound and remaining traffic on the East bound
6	All traffic to the East bound

In an attempt to improve the urban sound environment, soundscape strategies may be used in the case noise reduction measures were not feasible. However, for noisy environments, it is strongly recommended to reduce noise levels previous to the inclusion of soundscape measures. For the present study, the proposed soundscape strategy aimed to achieve attentional auditory masking for hot spots (suitable places to improve the sound environment due to its relevance and its high noise exposure). The sound-pressure level of a sound from walking on a platform covered with gravel was compared with a 15-second excerpt of traffic noise recorded at a crossroads in Valley Gardens. A simulation of the comparison between the walking sound on gravel and a typical background noise recorded on site during the soundwalk is shown on the next page. Figure 17 shows that the level of the walking sounds has the potential to exceed that of a typical road traffic noise as recorded on site. Therefore, it seems reasonable to assume that this solution could provide energetic as well as attentional masking for the unwanted sound source.

Data collection at the test site (both objective measurements and individual responses) confirmed that road traffic noise is the most relevant noise source while being perceived as inappropriate to the Valley Gardens area.

In summary, the traditional approach provided by the road traffic noise map was extended by including results of research featuring the overall sound environment characterisation, in both acoustical and perceptual levels, and showed that the sound environment of the site is not adequate to the visitors' expectations. Together, the three tools implemented by the working group (noise maps, sound maps and soundscape maps) proved to constitute an effective methodology at the analysis stage, as well as for the planning of the future site. The methodology supported the city planners with adequate information to plan urban interventions toward an improved urban solution.

The main acoustic goal was to promote sound environments that can foster health and wellbeing for citizens. In order to implement the holistic concept, the issues related to the sound environment of the test site were approached from both a conventional noise control perspective and a soundscape perspective.

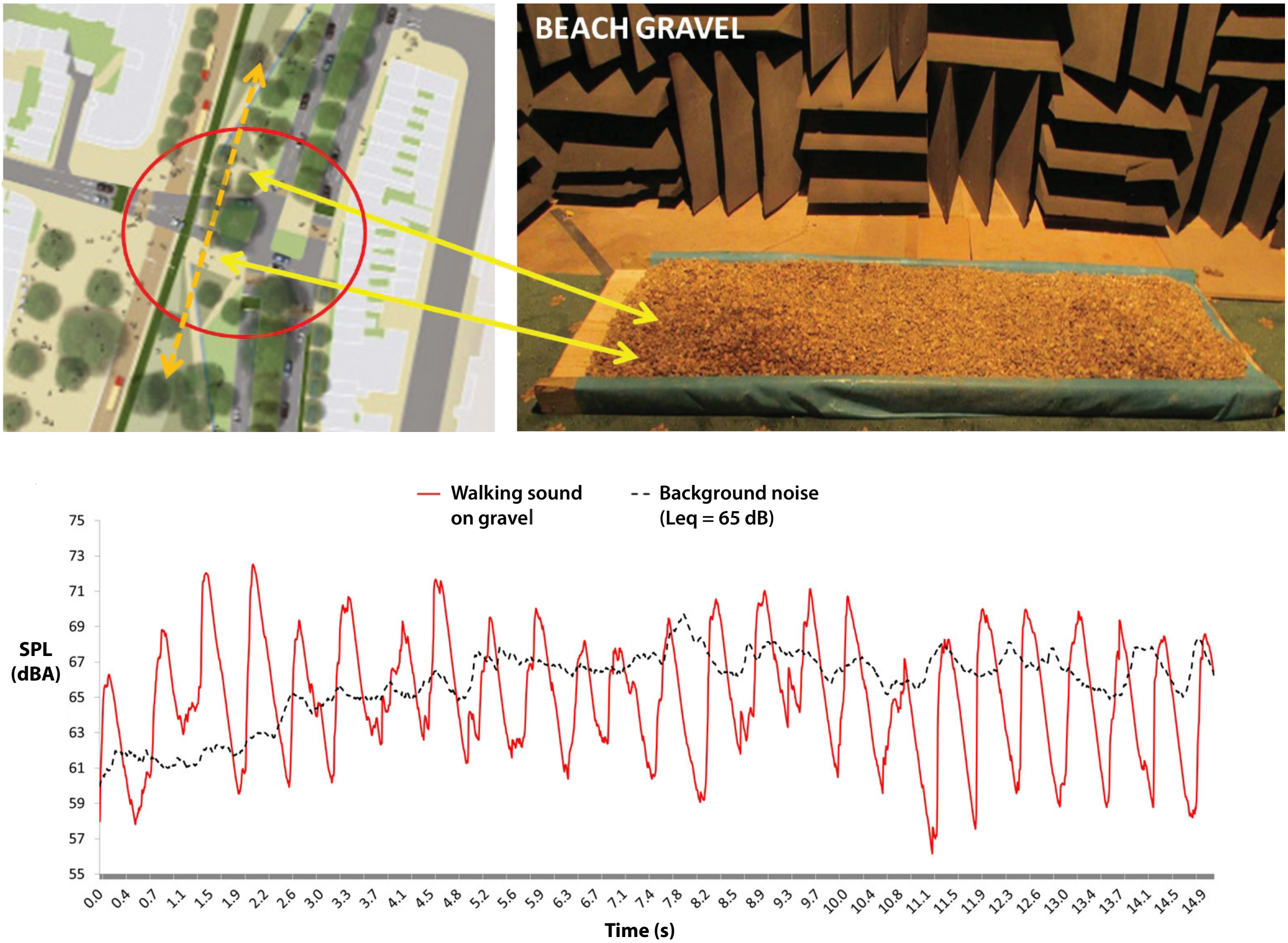


Figure 17 – Results of masking effects of proposed solution

ROME, THE COLOSSEUM, PALATINE AND ROMAN FORUM AREA

PLANNING GOAL: Improve the perceived quality of an archaeological area for visitors.

MAIN RESEARCH TOPIC: Controlling the urban sound environment through noise mitigation actions and soundscape within an archaeological area.

Microscale level

OUTPUT: Integration of noise maps and acoustic measurements with a perceptual analysis to characterise the current situation. First assessments indicate that poorer general judgements are related to low ratings of soundscape quality.

Description

Rome is well known for its historical and archaeological heritage, where the most important monuments are the Colosseum and the Roman Forum area, with 6,5 million visitors in 2015. This situation suggested the emergence of new strategies to approach to heritage interpretation, improving the liveability of the space and the surroundings, while enhancing the experience and site's identity. The site is immersed in the urban structure with an area of around 40 ha. Busy roads and high human activity are surrounding the area.

The Colosseum, Palatine and Roman Forum area within SONORUS

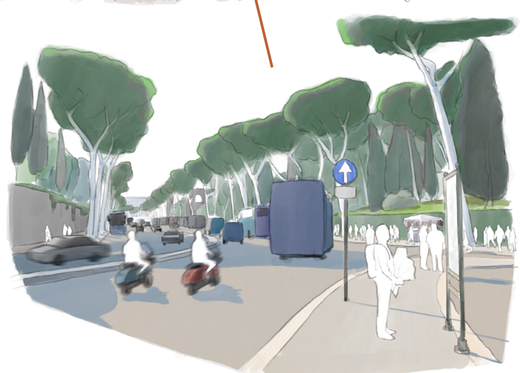
In terms of its sound environment, the area is considered a highly protected environment where quietness is a basic characteristic for its use. Despite all the regulations, the sound environment is not appropriate to the activities and uses of the space. Road traffic noise levels above 65 dBA (LEq) are generally present in the area. The municipality has taken some actions to reduce the noise exposure by banning private traffic from around the Colosseum in the Fori Imperiali street. Due to this, around 1300 veh/h in the peak morning hour are removed from the area. Moreover, construction activities are currently present in the surroundings of the area, to enable a new metro line.

The area confronts a wide range of challenges in order to protect, understand and value the archaeological area. These challenges cover a broad perspective, including: the improvement of quality and attractiveness of outdoor spaces, the need for protection of certain areas whilst guaranteeing tourists' access, and integration in the city as a crucial part of the cultural, societal and economical development, promoting a participative process including all interested stakeholders.

Map of Rome (Roman Forum, Palatine and the Colosseum marked in orange)

View of the Colosseum and pedestrian area

Via Celio Vibenna and Via di San Gregorio passes to the east of the Roman Forum, Palatine and the Colosseum, exposing the areas to the sounds from noisy mopeds and turist buses



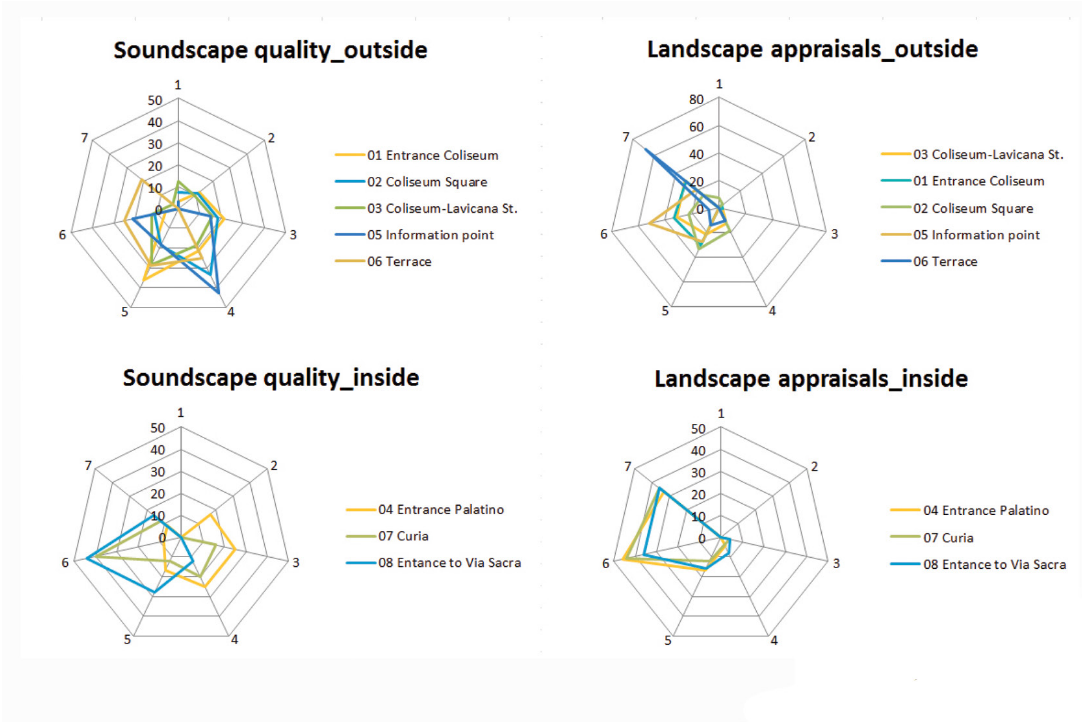
The SONORUS working group got the task to evaluate the factors that can affect the sound environment of the area. In this area we find a battlefield in which the needs of residents and tourists are largely confronted. Tourists' and residents' demands are evolving over time, making it harder to state a unique intervention. A multidisciplinary approach requires both considering the problems and enhancing the potential of the area. In this study, the focus is mainly on the tourist perspectives and expectations, however, it has an effect that will help to improve the overall quality of the area.

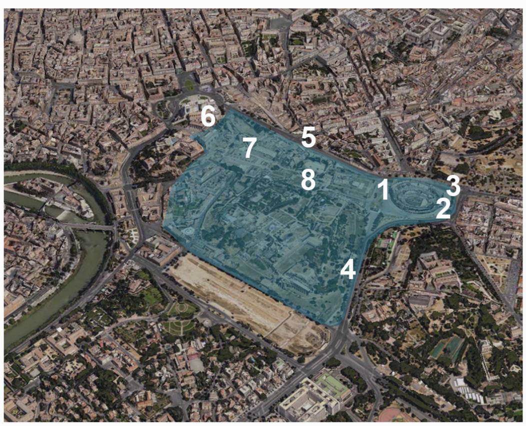
Urban Sound Planning in praxis: soundscape and landscape strategies and results: quality perception in the Colosseum, Palatine and Roman Forum area

The first attempt is to analyse the sound environment of the area and to study the soundscape and landscape quality perception. Four steps were taken, including data acquisition, data analysis, conclusions and proposals.

In the data acquisition stage, the archaeological, cultural and historical values are considered, including measurements and survey campaigns made at different periods throughout the year. To get this type of data, a series of sound measurements, field surveys including soundwalks, traffic counts, traffic recordings, and people density estimates were included. In the survey campaign, the questions involved sound and visual aspects as landscape quality, soundscape quality, overall analysis, etc. A 7-point scale was used, rating them from 1 (very bad) to 7 (excellent). All data collection was made inside and outside the limits of the Roman Forum and Palatine.

The results in Figure 18 confirm that the area is visually very attractive for the visitors. However, sound quality was not rated in the same way. The study points 1, 2 and 3, located at the surroundings of the Colosseum, present a low mean score. In this area, controlling the sound environment is extremely needed. The main source at points 2 and 3 is road traffic, however, at point 1 people become the main source, which may lead to a different approach, trying to improve the overall impression and attract their attention to other qualities of the area. It is also interesting to observe the correlation between the lower general judgements of the landscape quality with low general judgements of soundscape quality. However, this might be due to other aspects influencing the soundscape appraisal, and needs further study. Semantic differential analysis was performed using bipolar scales where different adjectives are able to characterize the sound environment. These adjectives





1 Entrance to Colosseum
2 Intersection between Fori Imperiali St. and Labicana St. Level of Colosseum Square
3 Intersection between Fori Imperiali St. and Labicana St. Level of Labicana St.
4 Entrance to the Palatine (San Gregorio St)
5 Tourist information point (Zetema)
6 Terrace. Sight of the Roman Forum
7 Curia, Temple of Antonio and Faustina
8 Entrance to Via Sacra. Arch of Tito

Figure 18 – Soundscape and landscape quality perception inside and outside the Roman Forum and Palatine area

have been pointed out in several research works: eventful, exciting, calm, pleasant, chaotic, unpleasant, uneventful and monotonous. (See Figure 19.) As a result, the soundscapes of the areas 3 and 4 (intersection between Labicana and Celio St., and the Palatine entrance) are considered the more unpleasant ones by more than the 60% of the interviewees. On the contrary, the entrance to the Roman Forum and the gardens near Campidoglio Square are the more pleasant ones. The Colosseum Square, the Constantine Arch and the Garden nearby the Campidoglio Square, although being pedestrian areas, are considered chaotic by approximately 45% of the interviewees.

Considering the results related to the unpleasantness of the sound environment, several measures should be implemented based on a combination of different approaches, looking first to control the sound environment, i.e. reduce noise levels, and then to integrate these measures with soundscape design approaches. For that, prediction methods and auralisation techniques might improve the assessment and increase the opportunities of the area. (See previous Chapters to know more about different tools that can be used.)

In summary, high noise exposure levels are constraining the area and due to the uniqueness of the place, the measures need to go beyond the sound aspects, looking to all characteristics involved in the conservation and value of the area, including the social, economical and cultural values. The municipality of Rome is very interested in improving the acoustic quality of the archaeological area, but is also conscious of the complexity of the interventions due to the different authorities involved in the decision process of this area.

Some recommendations proposed to the municipality are looking towards:

- Reinterpretation of the perimeter of the area, including strategies of urban renewal aspects;
- Establishment of a monitoring system in the area to acquire objective and subjective data of the sound environment;
- Controlling the sound environment through transport management and traffic design strategies;
- Provision of information to tourists about the archaeological area, directing their attention towards other aspects such as information on the set, observation of the landscape, discovery through time, etc., rather than towards the presence of disturbing noise.

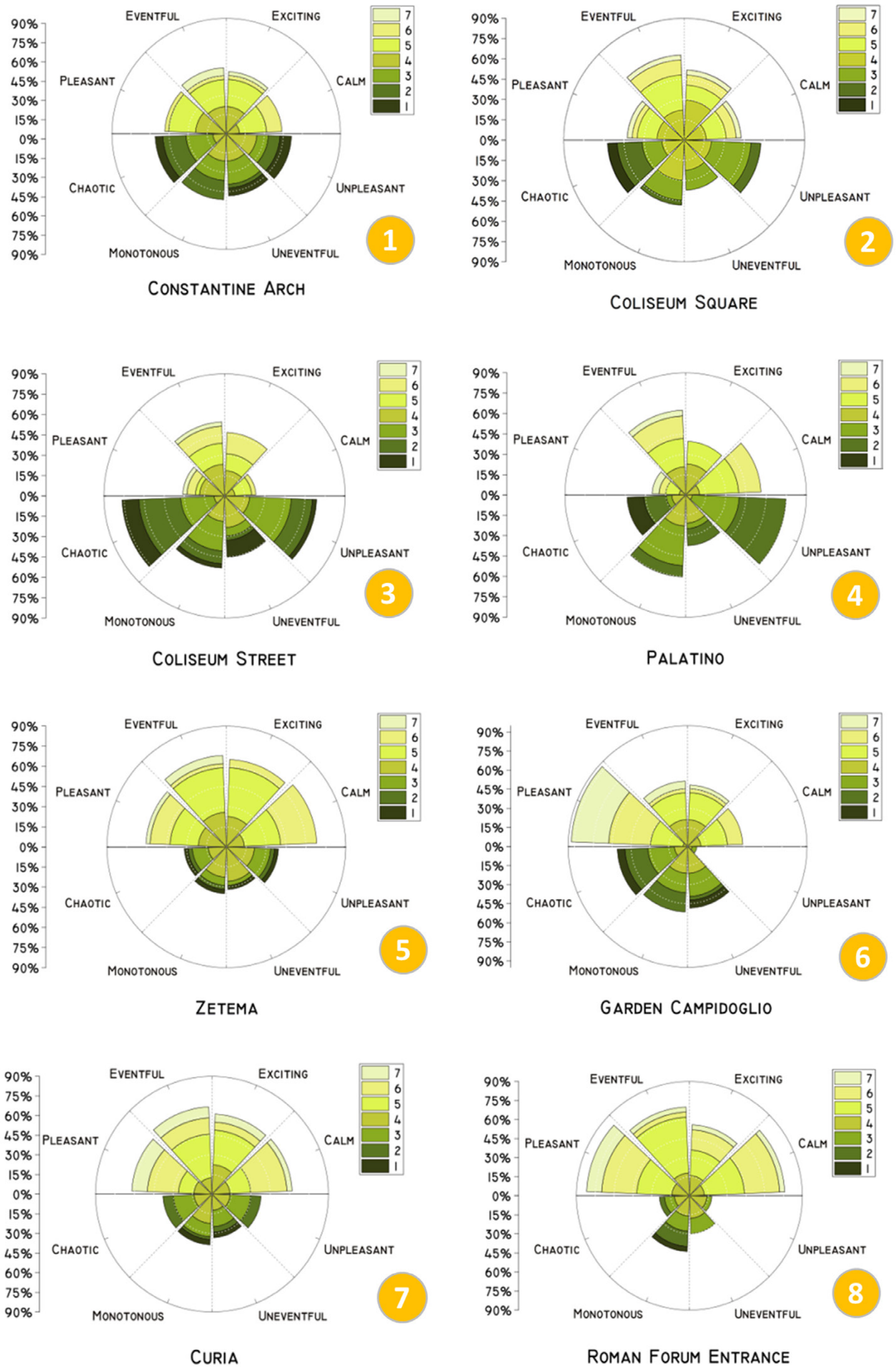


Figure 19 – Semantic differential analysis of the eight areas under study. The radial magnitudes represent the percentages of subjects that have given a certain score on each of the following 7 points bipolar scales of the sonic environment:
1=Unpleasant
7=Pleasant,
1=Uneventful
7=Eventful,
1=Monotonous
7=Exciting and
1=Chaotic
7=Calm.
Half of the neutral scores (4) have been represented in each positive or negative sector of the bipolar scales.

Figure 20 – SONORUS Workshop Frihamnen

Urban sound planning workshops - a tool to improve interactive and participative processes

In order to embrace an integrated approach to urban sound planning, every test site organised a workshop with the different stakeholders and city representatives. In practice, it is an opportunity to exchange opinions and ideas among those directly involved in the project, for example, between the city's planners and working groups and the SONORUS members. The intention is to acquire knowledge about the project for an attempt to provide solutions that may improve the urban sound environment with an integrated approach.

This type of study will increase awareness among the people involved in the urbanisation process as well as among the citizens, which are constantly demanding an improvement in the environmental quality. These demands require innovative solutions to cope with the agents and systems involved in urbanization processes. Although several solutions to reduce the impact of noise have been looking through a retrofitting perspective (increase of sound insulation in buildings, noise barriers, etc.), the goal of the SONORUS project is to avoid such types of solutions. Our aim is to initiate the urban sound planning study and its practical implementation one step before the urban decisions are made. This will avoid expensive and complex solutions and will further avoid overall physical modifications that could end in a retrofitting patchwork. To succeed in this holistic methodology, a comprehensive approach and a continuous dialog between the interested partners is needed.

The Urban Sound Planning workshop pointed at several challenges that the areas are confronted with. Selected steps in this methodology include the study of the site, understanding its scale and area of influence, the incorporation and comprehension of the several urban systems involved in city planning and their potential impact on the sound environment, and the overall quality and its perception. The study methodology needs to go a step further by the constant exchange of ideas with the different actors involved in the project.

In this Chapter two workshops are presented: the one realised at the Valley Gardens site in Brighton & Hove and the one at Frihamnen area in Gothenburg.

VALLEY GARDENS URBAN SOUND PLANNING WORKSHOP, BRIGHTON & HOVE

This workshop consisted of a project update from the Valley Gardens project manager, a site walk-about, and a summary of the current design proposals. There was general agreement that the background noise levels in Valley Gardens test site need to be reduced by at least 8 dBA before any enhancements to soundscape experienced in the space would be sufficiently beneficial.

After the site walk-about, the participants (including the SONORUS network) were split into three groups for a brainstorming session. From the workshop, a strategic approach (Table 2) was suggested to condensate in two inter-related key types of proposals for the test site: controlling the urban sound environment and providing positive soundscapes.

Table 2. Recommendations for different problems in the Valley Gardens, Brighton

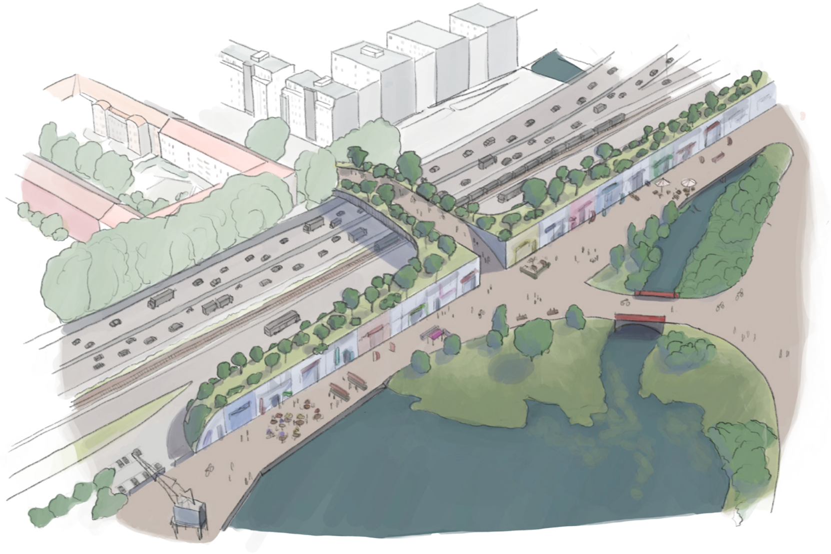
Topic	Problem	Applying Urban Sound Planning: recommendations
Controlling the urban sound environment	Noise levels exceeding the WHO guidelines	As the most dominant noise source was the road traffic noise, the recommendations of the workshop participants focused on actions: 1. AT THE EMISSION: • Low-noise road surfaces • Limit the vehicles speed • Promote awareness actions among the bus • drivers • Reduce heavy traffic by goods distribution centres 2. AT THE PROPAGATION: • Low vegetated barriers next to the roads • Soil embankments surrounding the noise hotspots of the park • Encourage profiled/textured building facade profiles rather than flat reflective surfaces • Vegetated roofs or facades • Moveable screens for music events 3. AT THE RECEIVER: • Create acoustic 'shadow' areas at ground level using physical barriers, level changes, topographic modelling within the park • Creation of different areas according to users and existing noise levels (e.g. sports activities, children parks, resting areas etc.)
Provide positive soundscapes	Perceived sound environment as bad and not appropriate to the site	• Introduce 'natural' sounds through elements such as wind in vegetative foliage or flowing water • Allow for 'artificial' sounds via infrastructure such as new lampposts • Encourage bird song by adequate planting • Encourage positive activity such as children's play

FRIHAMNEN URBAN SOUND PLANNING WORKSHOP, GOTHENBURG

The workshop started with a visit to the site by the working group. During the second day, together with city representatives, a series of presentations about the city, the area, the challenges, future plans, environmental issues and current sonic environment gave the opportunity to the participants to get to know more about the area. Afterwards, the participants formed five teams to work on the situation and its possible solution alternatives, mainly through sketches and discussions, aided by maps and models (see Figures 21 and 22). The outcomes of the workshop are condensed into three main topics: controlling the urban sound environment, the acoustic quality and the soundscape design, and the economic aspects (Table 3). These topics are concatenated and interpretations must be made with this integrative approach.

Table 3. Recommendations for different problems in the Frihamnen area, Gothenburg

Topic	Problem	Applying Urban Sound Planning: recommendations
Controlling the urban sound environment	Time scale of the project: construction will last 20-25 years. Impact on visitors and residents.	• Different kinds of noise maps able to reflect the construction process and its acoustic impact are needed • Build some kind of temporary acoustic screen during the construction period
	High noise levels in the entire area, both indoors and outdoors with a large number of sensitive areas	• Introduction of noise reduction treatments: noise abatement in the propagation path through the implementation of greener solutions • Buildings and sound absorbing solutions: shifting building positions between the two rows of buildings next to the railroad could form a barrier to the Jubilee park, located in the northern pier. Incorporating vegetated roofs, especially in the lower buildings, as well as green or sound-absorbing facades will increase the acoustic quality throughout the area. Sensitive areas, such as schools and hospitals, may, in case of maintaining the current plan, require special noise abatement treatments, including material aspects. • Introduction of green and screening objects through the use of low-height acoustic barriers that could protect pedestrians and cyclists from noise



Proposal for the northern part of Frihamnen

Railway infrastructure: the proximity to the railway is already causing high noise levels and vibrations	• Reduction by screening is the primary effect, for example through the construction of a sloped roof/building, which could also be designed as a pedestrian path. Presumably, this would facilitate the crossing to the other side of the motorway, in an attempt to erase the “urban scar” that this road is drawing in the northern part of Frihamnen.
Road traffic infrastructure, transport management, road design and connectivity: avoid noise abatement measures in the future that will become difficult and expensive 1) Distributing traffic throughout the area will result in a larger zone with high noise levels 2) High noise levels coming from the south due to the bridge	• Concentrating traffic and applying preventive solutions in surrounding limited areas will not only reduce the costs, but also attend to the spatial configuration, bringing acoustic quality as a response to the functions and uses • The road parallel to the motorway will have a large impact in terms of noise levels at the three piers. This road could be allowed for residents with electric vehicles and electric buses only • The introduction of an electric shuttle bus and the promotion of cycling and walking routes could improve the sound quality of the entire area. This entails a careful study about the connectivity and accessibility. • To avoid high noise levels at the south part, the new bridge requires a careful design, incorporating a good shielding through the use of screens. Finally, the noise coming from the city centre should be considered in the analysis of the sound environment of the area.

Acoustic quality and soundscape design	The high noise levels will constrain the popularity of the area, especially during the constuction period	• Promotion of the area among residents: ideas on possible compensations, such as attractive activities that make the best out of the acoustic quality
	Accessibility and sound attractiveness: access to both the city centre and the north area is one of the key sets in this project	• The passage through the area should be attractive and accessible. For this, the city could use sound to connect the space as a kind of heritage, reflecting the possibilities to keep and recall its past as a former industrial area and harbour. • Build a landmark/soundmark throughout the piers. Taking advantage of the positive sounds that water features may bring to Frihamnen, incorporating the waterfront history (e.g. sounds of waves on resting boat hulls), floating bridges and shipyard sculptures as a variation of the sound environment as well as different pavements capable to reduce attention to road traffic noise.
	Park area and piers: to cope with the uses and functions of this area as a park, special acoustic qualities are needed. The area will be submitted to high noise levels during the construction period, which will be around 20 years.	• The park activities could be oriented according to the noise exposure of the area. Possible functions might be a recreational park with a large number of activities e.g. concerts, playground, sports, etc. • Topography as an alley through the construction of a railroad-oriented slope, incorporating the attractive idea to Gothenburg citizens of a running track in the park, which could block the noise from the northern infrastructures
Economic aspects	The impact of the low attractiveness of the area due to its high levels of noise	• Careful study on the impact of future measures intended to act only at a single city system. For example, the traffic can be planned as a deterrent, providing a design difficult to drive through. However, this approach might drive the area and its surroundings to a higher noise exposure as a consequence of the spread of traffic and the increase in the distance travelled.

Figure 21 – Working process and outcomes. Focus on controlling the urban sound environment.

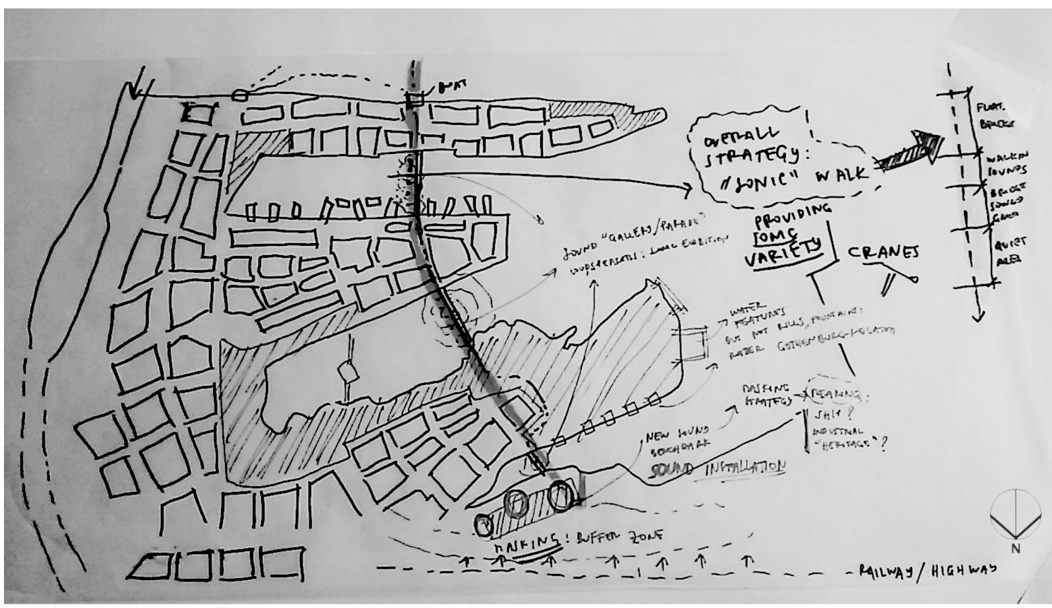


Figure 22 – Working process and outcomes. Focus on soundscape design.

Implementing a holistic approach in urban sound planning

Within this project, the research made has intended to start a process of interaction with stakeholders through the development of tools to minimize the gap between urban planning practice and current situations in cities.

From the beginning of the work with the city partners, a holistic approach has been intended, where the problem and methodology is approached from a broader perspective including the concept of urbanisation processes as a problem-solving method. The main goal is to avoid unnecessary costs and complexity where retrofitting is avoided as an option. However, the way is still long and here we have just attempted to take some steps toward the inclusion of sound as a self-evident part of the urban planning process.

Aligned to this, a SWOT analysis for each test site was performed where the strengths (S) relied on assessing the project characteristics that give advantage over others, the weaknesses (W) are the aspects that place the project at a disadvantage relative to others, the opportunities (O) are the elements that the project could exploit to its advantage, and the threats (T) are the ones that could cause trouble to the development and success of the project (Table 4).

One of the main concerns in the working groups is the inability to see the proposals realized. This has mainly to do with the limited awareness that different stakeholders and actors involved in the current urban planning of our cities might have related to the sound environment management.

Liveability of spaces has become more relevant in recent decades, and the role of urban sound planners and their incorporation in the decision-making process is extremely needed. In this sense, the holistic urban sound planning approach shares its scope with the urbanization processes to make spaces more liveable while efficient, integrating all systems and stakeholders in the process and avoiding to tackle “noise issues” as an independent entity.

The results presented in this Chapter are intended to be an application of the previous Chapters, showing that there is a wide range of possible approaches to a holistic planning that embraces sound in the urban development agenda with

Table 4. SWOT analysis for the four areas of analysis

Test site City	S	W	O	T
Antwerp	Several professional backgrounds in the working group	Indirect contact with the city planning office	Interventions made previous to urban decisions, observation of consequences due to the short-term accomplishment	Sensitive areas related to noise annoyance with possible public opinion and news media repercussions
Gothenburg	Freedom to implement innovative urban sound planning proposals since they are running parallel with the city project	Project complexity and scale with a considerable existing environmental deterioration: sonic quality is not in the current planning agenda	Include the urban sound environment in the planning process defining acoustic capacities in order to improve liveability	Inconsistency between current project and proposed vision: risk of increasing environmental degradation. The group is not part in the decision making process
Brighton	Different professional backgrounds in the working group; direct contact with the city council project manager and design team	Sound is only a small fragment of the overall picture; the time scale of the research project is different to that of the design scheme	Proposing local solution for critical issues within the current design	Recommendations provided by urban sound planners not eventually considered in the final proposal
Rome	Indirect participation within the first phase of the decision making process	Acoustic interventions are limited due to the protective legislation, despite that high acoustic standards are defined for the site	Authorities are aware of the noise problem and are open to introduce noise mitigation actions to improve the sonic quality of the area	The group is not an active part in the decision making process

successful results.

For example, in Antwerp the urban sound planning praxis intended to restore a damaged sound environment, protecting pedestrians and cyclists. Results from calculation methods have shown that including adapted noise abatement solutions in the propagation path may result in large improvements to the sound environment. Also, the study goes beyond traditional ones through the development of a model for human perception of environmental sounds and its translation to an artificial sound perception model, with very interesting applications in the study of human perception. Also the Valley Gardens site in Brighton & Hove targets a damaged sound environment. Outcomes in this case show that the combined tool of road traffic noise maps, soundwalks and "sound source dominance maps" may enhance the possibilities to intervene in the sound environment of an area on a broader perspective. The Frihamnen project in Gothenburg used a different approach mainly due to its scale with a large new urban development of great importance due to its strategic location. The tools used in the holistic approach studied the sound environment from the traffic planning perspective. This dynamic noise map tool is capable of analysing traffic time patterns and noise events, rethinking the traffic layout and studying different possibilities to improve the future sonic environment and its demanded qualities. The Rome archaeological area confronts a very particular situation, where social, economical, and cultural values are confronted. Moreover, tourist and residential demands are leading to different problem approaches. In order to understand its particularities, sound measurements and surveys have been carried out and a series of recommendations for improving the sound environment of the area have been given.

Throughout the urban sound planning workshops, together with the tools developed in the project, the SONORUS working group attempts to facilitate the process of understanding the importance of incorporating acoustic quality aspects in the designing process, as a self-evident part of city planning.

Reflection on the future of urban sound planning

The idea of SONORUS was born out of the vision that it is possible to achieve a paradigm shift in the handling of sound environments in our cities. A shift to a holistic approach to sound environment planning, as a natural part of the overall planning of our cities from the very beginning, instead of traditional noise control applied late in the planning process. It is self-evident that a project such as SONORUS alone never can achieve such a change during its limited lifetime. It can, however, be the beginning of that change.

For this paradigm shift to take place, we are depending on the young researchers from SONORUS who worked hard during the last years to approach the vision behind SONORUS. They will hopefully have the chance to implement their ideas, knowledge and skills during their future professional careers.

This booklet is written by the SONORUS young researchers for acousticians as well as for architects, planners and all professionals and stakeholders involved in the development of our cities. The lines of research and the philosophy and ideas of a holistic approach, including its complexity in real applications, are documented. The booklet demonstrates the potential of the paradigm shift, but it also shows that we are far from offering final tools, recipes and solutions for urban sound planning. Despite this long way left to go, it is an encouraging documentation.

Inside the acoustics community, urban sound planning has become a relevant topic due to SONORUS. By combining noise control engineering, soundscape approach and prediction and auralisation schemes, embracing city and traffic planning, SONORUS established urban sound planning as a new field of research. This field offers innovative tools and a better understanding for designing the sound environments in our cities.

We also observe that urban sound planning has started to attract architects and planners. It is this attraction we have to work further for. A good urban sound environment should not only be a question of fulfilling regulations, but a self-evident part of designing our future cities.