Urban soundscape: the relationship between sound source dominance and perceptual attributes along with sound pressure levels

Bachelor Thesis

BSc Spatial Planning and Design

Faculty of Spatial Sciences
University of Groningen

by

Emilis Navickas

Under supervision of

Dr Efstathios Margaritis

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Summary

Urban acoustic environment and sound implications on human health are increasingly receiving more attention in public and academia. Such as soundscape approach where the acoustic environment is analysed “as perceived by people in context” (ISO, 2017). Some implications of dominant sound sources, such as adverse impacts of traffic noise, are well known. However, there may be possibilities for empirical evidence on other sound sources. Therefore, this study aims to grasp to what extent urban acoustic environment could be evaluated by assessing the associations of dominant sound sources with perceptual attributes and sound pressure levels. To achieve this, data on sound sources, perceptual attributes and acoustic parameters were collected using Method A as defined in ISO 12913-2:2018 (ISO, 2018). The perceptual attributes separately and as the collapsed model of Pleasantness and Eventfulness were studied in correlative analysis. As a result, only weak relationships could be found. Findings add evidence to existing soundscape knowledge on the Pleasantness of natural, repulsiveness of traffic and Eventfulness of human dominant sound sources. It seems that different statistical variations of sound pressure measurements correspond to acoustic environments of certain sound dominance. The research provides with an empirical standing that the quality of urban acoustic environment could be explained by assessing the associations between dominant sound sources and perceived affective quality.

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1. Introduction

1.1 Background and societal relevance

Sound plays a vital role in our daily life. Humans are exposed to sound wherever they go: at home, streets or parks. For instance, traffic noise is one of the most dominant sources of sound in urban areas (Paviotti & Vogiatzis, 2012). However, noise pollution that was caused by traffic has an adverse impact on public health (Bravo-Moncayo et al., 2017). It is estimated that around 113 million people of 33 member countries of the European Environment Agency are exposed to Lden (day-evening-night) noise levels from road traffic equal or above 55 dB (EEA, 2019). Noise pollution is a significant public health issue, and it was reflected in the "Environmental Noise Directive" (European Council, 2002), which aims to reduce the harmful effects of environmental noise through the integrated noise management approach. Sound importance is, therefore, highly recognised by society. However, there is still space for improvement regarding the empirical understanding of noise implications.

Most of the practical approaches use physical sound parameters, such as sound pressure levels, to make inferences on the effects of sound. While it is a practical measure for environmental standards, perception of sound plays a vital role in the overall evaluation of an acoustic environment (Marry & Defrance, 2013). According to Brown (2010), sound sources are the key representative element of an acoustic environment. Therefore, sounds of different origins, for instance, anthropogenic or natural, make an auditory environment which is then being experienced by the people. Likewise, the number of studies on sound through a perceptual, soundscape prism is increasing. The soundscape is "acoustic environment as perceived by people in context" (ISO, 2014). Thus, soundscape studies can examine the acoustic urban environment more adequately while combing perceived affective quality with knowledge of multiple disciplines.

Sounds do not necessarily have an adverse effect on humans. Aletta et al. (2018), in their literature review, suggest that environmental sound could be regarded as beneficial from a health-related perspective. Hence, there may be undiscovered properties of the urban acoustic environment and its sound sources. The audio-visual and perceptual data on soundscapes collected in Groningen will be an addition to the development process of soundscapes indices (SSID) (Kang et al., 2019). Such projects and soundscape research contribute to gaining of new analytical knowledge on the urban acoustic environment. With a coherent understanding of soundscapes, the living environment could be improved. Urban planners, policymakers could take into consideration soundscape features in decision-making processes. As a result, exposure to the harmful effects of noise could be minimised. At the same time, a more pleasant and attractive sound environment could be introduced, making public spaces in settlements more hospitable, enjoyable, and finally - healthy.

1.2 Problem statement

The urban acoustic environment is complex, and it affects the well-being of people (Aletta et al., 2018). Some sound sources are more dominant in the environment than others. Henceforth, an in-depth understanding of sound source dominance is needed. This paper seeks to be an empirical addition to the soundscape research, combining perceptual attributes and physical parameters of the acoustic environment. Therefore, the aim of the research is to see how the dominant sound sources of the urban acoustic environment are being perceived by the people, concurrently considering sound pressure levels (SPL). The following research question has been formulated:

To what extent perceptual attributes and sound pressure levels can be associated with sound source dominance in the urban acoustic environment?

To answer the main research questions, the following secondary questions are proposed:

1. What are the most dominant sound sources in the selected urban areas?
2. What is the perceived affective quality of those urban areas?
3. What is the relationship between the most dominant sound sources and perceptual attributes?
4. What is the relationship between sound pressure levels and perceptual attributes?

1.3 Thesis structure

After concluding this introductory chapter, the theoretical framework with essential concepts and current academic knowledge is discussed. In the third chapter of the thesis, research methods, data collection and analysis techniques are explained. Consequently, the findings and discussion of data analysis could be found. Lastly, the answers of secondary research questions will be combined to answer the main question in the conclusive part of the thesis.

2. Theoretical framework

2.1 Urban acoustic environment

The soundscape of the urban environment could be fundamentally understood by analysing sound sources, their level of presence and perceptual attributes given by the people (Marry & Defrance, 2013). With this regard, identifying sound sources and investigating how people perceive them may be a basis for understanding the urban acoustic environment. Since people are not only experiencing the sound environment; they are also an active part of it (Liu et al., 2007). Individual collects visual and auditory information from the environment, and then a symbolic representation of it is generated by the central nervous system (Shapiro, 2019). This way, noise can induce stress and health-related problems (Bravo-Moncayo et al., 2017). Thus, a person is bounded to be experience repercussions, whether positive or adverse, of the acoustic environment. Consequently, when investigating the human experience of the environment, it is essential to understand what feelings and attributes the person applies.

Moreover, the in-situ data collection method enables to gain more immersive and holistic knowledge (Cadena et al., 2017). Individuals who participated in questionnaires or interviews in the field were experiencing not only auditory information; other senses and subjective attachments were apparent as well. Through soundscape approach, urban acoustic environment can be analysed not only by measuring physical acoustic parameters of sound but also including and correlating people's subjective opinions on them in contextual settings.

2.2 Context of an acoustic environment

Context of the urban acoustic environment plays an essential role in the understanding of a soundscape. Margaritis et al. (2015) suggest that spatial variation of sound sources relates to urban contexts and their activities. While Hong & Jeon (2015) propose that perceptual factors change correspondingly with the functions of the urban areas. For example, sounds of human activities were more significant than other factors in commercial areas wherein residential areas – traffic was the most dominant factor. Kang et al. (2019) also consider physical-contextual factors, such as the physical appearance of the environment as noteworthy in the soundscape assessment. Besides the physical factors, according to the authors, participant's cultural background and emotions may influence soundscape perception. Moreover, visual scenery, lightning is also a dominant factor in soundscape perception (Yong Jeon et al., 2011; Aletta & Kang, 2018). The mentioned research suggests that non-acoustic elements of the environment can have a significant influence on soundscape perception, including perceptual attributes used in this research.

2.3 Perceived affective quality

A method of describing the perception of an acoustic environment is needed for soundscape research. A term which is used to describe the perception of the acoustic environment is called descriptor (ISO, 2017). There are various fitting descriptors suggested by the researchers as summarised by Aletta et al. (2016), such as tranquillity, music-likeness, appropriateness or others. However, as the authors reason, Axelsson (2015) model of perceived affective quality (PAQ) incorporate the most descriptors in a single method. Moreover, using PAQ, it is possible to represent the perceptive responses in a two-dimensional model. With the first dimension as to how pleasant or unpleasant the environment is or Pleasantness and Eventfulness as the second one – to the amount of human or other activity. The method was adapted to be applied in soundscape research and is described in the latest ISO/TS 12913-3 document (Axelsson et al., (2010), Russell et al., (1981), Cain et al., (2013)). All in all, it would be sensible to use previously confirmed methods of soundscape analysis for this research as standardised techniques enable the build-up of potential research and its comparison.

2.4 Physical parameters of soundscape

There are many ways how to measure the acoustic environment. As it is recommended in ISO/DTS 12913-2:2017 document, classical acoustic indicators, such as SPL and their statistically calculated percentage exceedance levels should be used in acoustic research. However, parameters such as loudness or roughness may be appropriate measures for describing a single sound source, but in a complex acoustic environment, the applicability is minimal. Merely using acoustic parameters is not enough to coherently describe soundscape (Kang et al., 2019; Zwicker & Fastl, 2013). Nevertheless, correlative studies between specific perceptual attributes and acoustic parameters show significant results (Aletta & Kang, 2018). For example, Berglund et al. (1990) conclude that physical sharpness of a sound can be regarded as a causal aspect for unpleasant perceptual attributes, such as annoyance. The previous research suggests that acoustic parameters may be used for describing physical properties of the acoustic environment and investigating relationships between other components of soundscape such as sound sources.

2.5 Sound sources

Sound environment in urban areas is complex and consists of many different sound sources. The distinction between sound sources must be made in order to examine them. They could be defined as sounds generated by human activity or nature (Brown et al., 2011). Kang et al. (2019) in their soundscape indices model classified them into three categories: human, natural and other sounds. They were characterised by their dominance and meaning in the acoustic environment. While Margaritis et al. (2015) grouped sound sources in technological, natural and anthropic categories and then specified them more precisely. The classification used in these papers shares similarities with the ISO/TS 12913-2:2017 standards.

The number of sound sources and their variation may have implications on perceptual attributes. Large spatial variations in a horizontal plane have a significant correlation between perceptual attributes. (Hermida & Pavón, 2019). It may imply that busy streets and squares could be linked to the eventfulness and for some, it may be overly full of activity; hence it would become unpleasant.

2.6 Natural against anthropogenic sound sources

Natural sounds are a vital component in urban areas. It seems that in the majority of studies on soundscape sources, the most variance could be explained by traffic and natural sounds (Kogan et al., 2018). Romanowska (2018) (n = 309) and Tse & Chau (2012) (n = 732) suggest that people prefer natural and human sounds over anthropogenic (mechanical and traffic sounds). Hence, it could be assumed that most public space users favour natural sound origins in cities and generally are perceived as positive.

Natural sounds contribute to positive health benefits (Aletta et al., 2018). Moreover, it also brings positive emotions and more pleasant and exciting feelings. (Medvedev et al., 2015; Ulrich et al., 1991). A natural soundscape may enable cognitive states of tranquillity and creativity (Andringa & Lanser, 2013). What is interesting that SPL in urban parks often exceeds the level what is defined for “quiet” areas (Brambilla et al., 2013). Thus, the significance of nature auditory and visual aspects for humans is evident from the research.

However, positive aspects of natural areas, such as tranquillity, decreases with the loss of natural sounds and the introduction of anthropogenic sources (Pheasant et al., 2010, Li et al., 2018, Kaplan, 1983, Herzog, 1989). As an effect traffic noise, for instance, could contribute to the surge of stress levels (Grahn & Stigsdotter, 2003). This is genuinely noticeable in places where anthropic sources dominate natural sounds. It may be hypothesised that in natural sampling locations in this research, traffic or other humanmade sound sources will be perceived as more unpleasant as in other non-natural areas.

2.7 Concluding the theoretical framework

The essential concepts and theories that are relevant to this thesis are urban acoustic environment and its contextual factors, sound pressure levels and perceptual attributes. Also, it is important to consider the human factor in the research. In soundscape, a person is an active initiator as well as the experiencer of the sound environment. Their perception of sound sources may differ thorough shifting urban contexts where visual aspects may change and contribute as well. Dominant sound sources in one location may be perceived differently as in the other. Hence, the conceptual model of the theoretical framework and their interrelatedness is shown in Figure 1. In addition, it shows which variables will be used in further analysis.

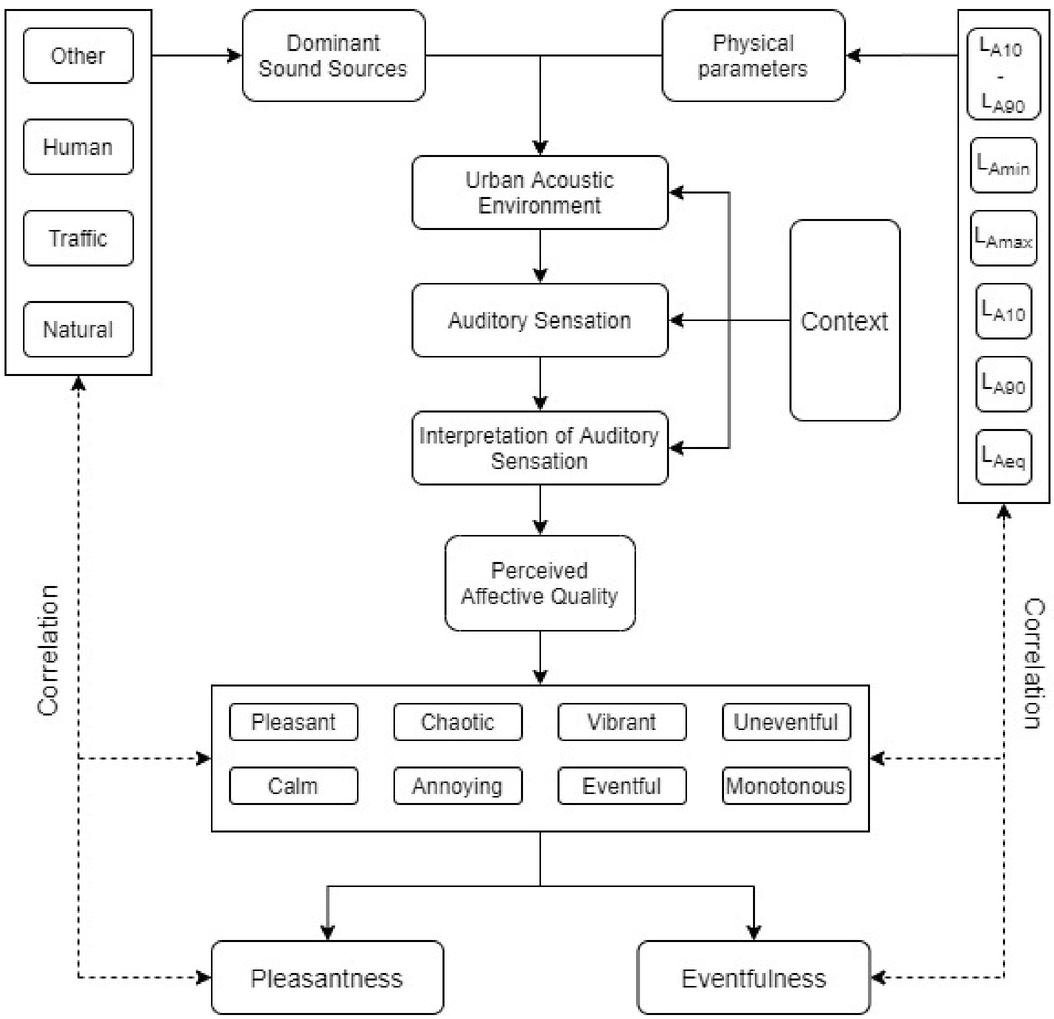


Figure 1. Conceptual model of the theoretical framework. Variables grouped in a squared rectangle symbolise input variables that are used in this research.

3. Methodology

This thesis is based on a combination of quantitative primary and secondary data. The source of secondary data is the database of the SSID project (University College London), while primary data were collected in Groningen.

3.1 Locations

The sampling took place in 14 locations in Europe. Table 1 shows all study locations, the number of participants and the sound source composition. Multiple sampling locations allows collecting data with diverse sound origins, varied visual and contextual cues. All locations are publicly accessible squares, parks on streets from several European cities. Most of the data collection process took place in London. While Venice refers to St. Mark's Square (Piazza San Marco) and in Granada, the survey took place in a residential street.

The sampling location for primary data is Noorderplantsoen in Groningen. It is one of the most visited parks in Groningen, where people with different backgrounds and age groups gather. On top of that, the park has a vibrant acoustic environment with natural visual aspects and water elements.

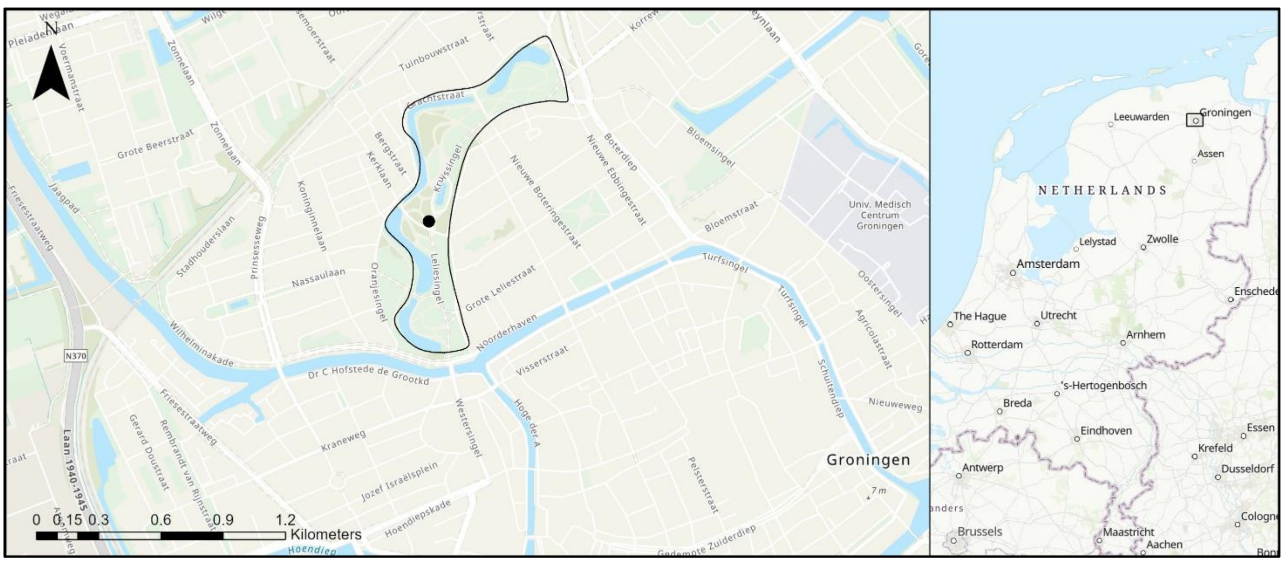


Figure 2. A map of sampling location indicated by a point in Noorderplantseon (marked area).

Figures 3 & 4. Data collection process, Humalda (2020) and the typology of Noorderplantsoen, de Waal (2019).

Table 1. Case count and sound source composition of studied locations; mean values of natural, traffic, human and other sound sources represent the proportion of sound sources in a soundscape.

Locations	n	Natural	Traffic	Human	Other
Camden Town	87	1.33	3.7	3.25	2.61
Euston Tap	104	1.68	3.7	2.58	2.96
Granada	54	3.31	1.65	3.44	1.56
Marchmont Gardens	108	2.57	2.69	2.69	2.46
Noorderplantsoen	97	3.16	2.79	2.88	1.79
Pancras Lock	98	2.35	2.49	2.54	3.3
Regents Park Fields	94	3.06	2.49	2.86	1.85
Regents Park Japan	97	3.98	1.91	2.57	1.54
Russel Square	151	3.26	2.73	3.06	2.14
St. Pauls Cross	68	2.32	2.59	3.32	2.1
St. Pauls Row	72	1.76	2.61	3.5	2.26
Tate Modern	139	2.58	2.46	3.63	2.13
Torrington Square	122	1.95	3.16	3.27	2.79
Venice	63	2.3	1.43	3.76	1.9

3.2 Participants

Participants of the study are the randomly selected visitors of public spaces in Groningen and other locations. It is worthwhile to mention that public space users with headphones were not included in the study since their auditory perception might have been disturbed. In total 1354 participants, mean age 34.9, males 604 (44.6%), females 721 (53.2%) were recruited. 97 participants mean age 35.75, male 40 (41.2%) females 57 (58.8%) are from Groningen.

3.3 Data collection

The quantitative data on perceptual attributes and the dominance of sound sources was collected via questionnaires that are designed according to Method A of ISO/TS 12912-2:2018 protocol (ISO, 2018). An equivalent questionnaire with variable coding information can be found in Appendix 1. Considering that both primary and secondary data follow the same requirements, secondary data is used as complementary data with primary data to increase the sample size.

Simultaneously, objective data on the acoustic environment and 360° video recordings were recorded. This study has used only a small part of the overall data that was collected. Primary data is stored in the SSID database for other research projects. For example, audio and 360° video recordings could be used in the recreation of the environment in virtual reality settings. For exact data collection method for variables unrelated to this study, refer to the SSID protocol (Mitchell et al., 2020).

3.4 Measurements

To answer the research questions, the data on sound sources, acoustic parameters and perceptual attributes are needed. The following sub-sections below describe the way data on these variables were processed.

3.4.1 Sound sources

The participants assessed the composition of an acoustic environment by establishing the most dominant sound sources. The respondents have evaluated each source on a 5-point scale from 'not at all' to 'dominates completely'. Four categories of sound origins were present for evaluation: 'natural', such as running water, 'human', – conversation, 'traffic' – cars passing by and 'other', such as construction works. Using the ordinal Likert scale, it is possible to establish the proportion of each type of sound source within a location. The most dominant sound source will be determined by finding the highest mean values. It is assumed that a sound source with the highest mean value represents the most distinguishable and dominant sound source in the soundscape.

3.4.2 Acoustic parameters

In each sampling location SPL were recorded using Sound Level Meter. 1-second logging period was used, and the total measurement duration is approximately 3-4 hours. The results of all locations are shown in the table below.

Table 2. SPL recorded at every study location using Sound Level Meter.

Location	L_{Aeq}	L_{A90}	L_{A10}	L_{A10} - L_{A90}	L_{AFmax}	L_{AFmin}
Camden Town	69-84	62-72	70-90	7-25	92-100	55-62
Euston Tap	69-73	63-64	70-73	7-10	92-104	58-60
Granada	58	69	66	6	92	53
Marchmont Gardens	56-58	48-51	57-62	7-12	83-94	45-46
Noorderplantsoen	55	71	62	5	97	51
Pancras Lock	59-61	55-56	62-63	7	87-104	49-50
Regents Park Fields	53-64	45-46	55-61	9-16	82-88	42-44
Regents Park Japan	62	60	62	2	83	57
Russell Square	66-73	64-72	69-74	2-5	87-95	59-68
St. Pauls Cross	61	56	62	6	84	53
St. Pauls Row	62	59	64	6	81	55
Tate Modern	62-63	55-58	64-65	8-9	85-88	51-53
Torrington Square	64-68	57-58	66-67	9	92-106	51
Venice	61	70	64	6	93	60

3.4.3 Perceptual attributes

In this study, the perceptual attributes will be regarded as an ordinal variable, containing five response categories, based on the perceived affective quality (PAQ), Swedish Soundscape Quality Protocol (ISO, 2018). It includes a question 'to what extent they agree/disagree that the present surrounding sound environment is …'. Pleasant, chaotic, vibrant, uneventful, calm, annoying, eventful, or monotonous are the adjectives that are used to evaluate the quality of the acoustic environment. Similarly, the questionnaire answers are ordinal variables represented in a 5-point Likert scale, ranging from 'strongly agree' to 'strongly disagree'.

3.5 Procedure

At sampling locations, participants were randomly approached and asked whether they would like to participate in the study. All information regarding the study, including the confidentiality of research data, was presented to the participants. Informed consent was signed electronically or on paper stating that participants understand the information and goals of the research. Through the data collection process, objective measurements on the acoustic environment were simultaneously collected through binaural recordings, a calibrated sound level meter and environmental meter.

This procedure was conducted in Noorderplantsoen in Groningen as it was taken in an exact manner by other researcher teams while collecting secondary data.

3.6 Statistical analysis

The data on the dominance of sound sources, perceptual attributes and objective measurements of the acoustic environment was analysed using correlation techniques on IBM SPSS Statistics (version 26.0) (IBM Corp, 2019).

Before conducting statistical analysis, data collected in before mentioned data collection methods were checked for normality using analytical Kolmogorov–Smirnov/Shapiro– Wilk's normality tests and visual inspection using Q-Q plots. All ordinal variables were found to be not normally distributed; therefore, non-parametric statistical testing techniques were used.

3.6.1 Collapsed model of Pleasantness and Eventfulness

In addition to perceptual attributes, the soundscape data were analysed using the dimensional model as described in ISO/TS 12913-3:2019 (ISO, 2019). Perceptual attributes collected through questionnaires were used to calculate coordinates for Pleasantness on the x-axis and Eventfulness on the y-axis. When plotted on scatter plot, Pleasantness and Eventfulness ratings can be represented as an 8-dimensional model, see Figure 5. Eight dimensions correspond to perceptual attributes used in this study.

The formula for Pleasantness P coordinate:

$$P = (p - a) + cos45° \cdot (ca - ch) + cos45° \cdot (v - m)$$

The formula for Eventfulness E coordinate:

$$E = (e - u) + cos45° \cdot (ch - ca) + cos45° \cdot (v - m)$$

where

a is annoying;
ca is calm
ch is chaotic;
e is eventful;
m is annoying;
p is pleasant
u is uneventful;
v is vibrant

The resulting coordinates have a range of ± 9.66.

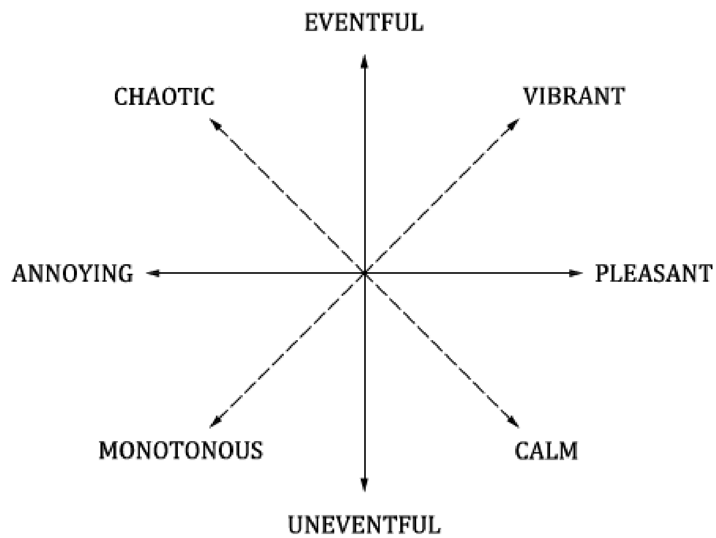


Figure 5. Graphical representation of Pleasantness and Eventfulness formulas (ISO, 2019).

3.6.2 Hierarchical clustering analysis

Sound source variables are in ordinal scale and highest values are taken to represent the dominance over the other sound sources. With the mean response for each sound source question, it is suitable to group them to represent a group of locations with similar, in this case dominant, sound features. The hierarchical clustering analysis was carried out using Ward's method with squared Euclidean distance as a measurement interval.

$$\sum_{j=a}^{n}(x_a - y_a)^2$$

In the equation, x and y refer to the two cases being equated on a variable, where n is the total number of variables included in the clustering analysis (Blei & Lafferty, 2009).

This way, a single distance value for all variables is calculated while calculating the distance between two cases or clusters. With every step, the pair of cases with the smallest squared Euclidean distance are merged, forming a new cluster. At each step, the pair of cases or clusters with the smallest squared Euclidean distance will be joined together (Yim & Ramdeen, 2015). This process is repeated until there is no further option available.

The differences in the distribution of Pleasantness and Eventfulness ratings for population among all clusters were investigated using a Kruskal-Wallis analysis.

3.6.3 Correlative analysis

Spearman's rank-order correlation analysis with a significance level of 5% was used for analysing the relationships the dominant sound sources as grouped in homogenous sound source clusters and perceived affective quality and SPL as an independent variable. The analysis was conducted separately among sound sources (independent variable) and perceptual attributes, then Pleasantness and Eventfulness ratings (dependent variable).

3.7 Ethical considerations

During the primary data collection, but also throughout the entire research, ethical considerations were made. Throughout quantitative data collection using questionnaires, participants were informed before surveying on how their data will be used, processed and stored. The anonymity of participants identity is ensured. Interviewees were told that all the questions are optional and it up to them to decide whether answer or not to a question. The consent form agreeing on the conditions of the research and how the data will be used was signed. Refer to Appendix 2 for the information sheet and consent form. The study was approved by the local ethics committee of the University of Groningen.

4. Results & Discussion

In this section, results of hierarchical clustering analysis, Kruskal-Wallis and correlative tests between dominant sound sources and perceptive affective quality are presented. The results of statistical analysis are discussed through a theoretical prism.

4.1 Hierarchical clustering analysis

The results of clustering analysis are depicted in a dendrogram of Figure 6. On the vertical axis, Location ID's with their corresponding cluster ID can be seen. On the horizontal axis – rescaled squared Euclidean distance.

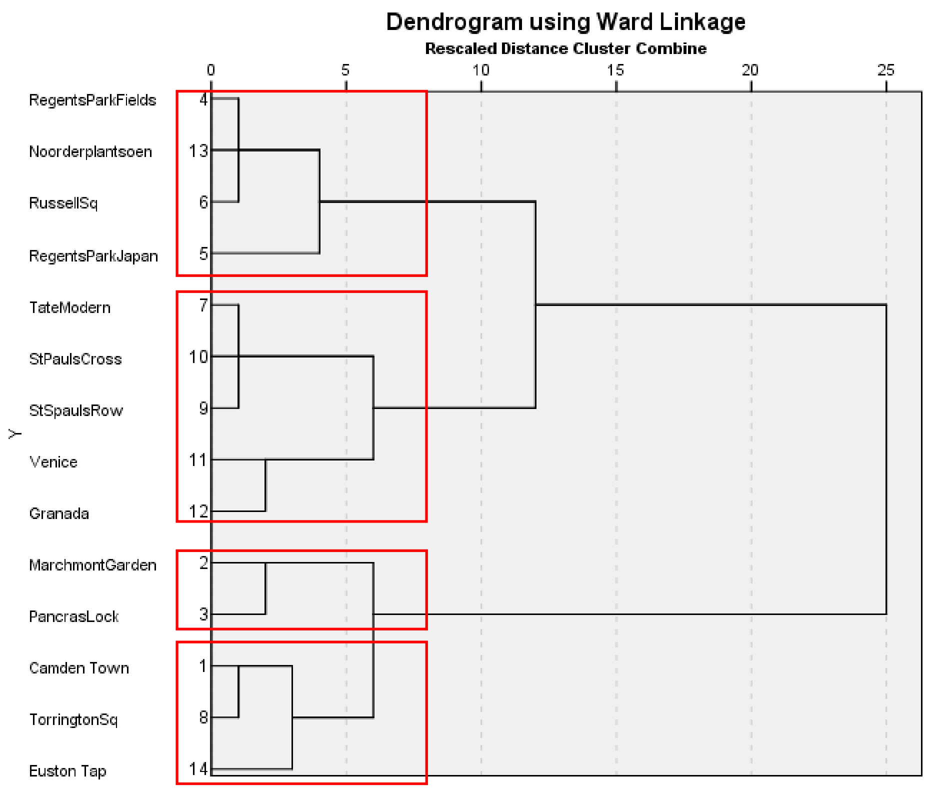


Figure 6. Dendrogram of hierarchical clustering analysis. Nature, human, other and traffic dominant clusters are shown from top to bottom, respectively.

Ward's linkage coefficient was used as the main selection criterion. The coefficient is the value of the distance or similarity statistic that was used to form the clusters (Ward, 1963). Since dissimilarity measures are used in the clustering analysis, small coefficients assume the homogeneity of clusters. The similarity of clusters should be sought when forming the dominant sound source clusters since similar dominant sound source composition is wanted.

In Figure 7 below, the agglomeration schedule of clustering analysis with Ward's linkage coefficients plotted on the y-axis and stages of clustering on the x-axis. The dual numbers on a chart illustrate which sampling locations were merged into a cluster. The numbers of sampling locations correspond to the Cluster ID's depicted in the dendrogram. For example, in the first stage of the clustering process, RegentsParkFields (4) was merged with Noorderplantsoen (13) because it is the most homogenous locations in terms of sound source composition. The similarity corresponds with low coefficient value and short rescaled distance (horizontal lines) in the dendrogram. In the final stages, the coefficient surges, implying that clusters formed in those stages are becoming too heterogeneous. In this sense, stages from 10 to 13 were dismissed, leaving four clusters with relatively homogenous sound source composition. This way, the objective validity of a rather subjective cluster selection manner is increased.

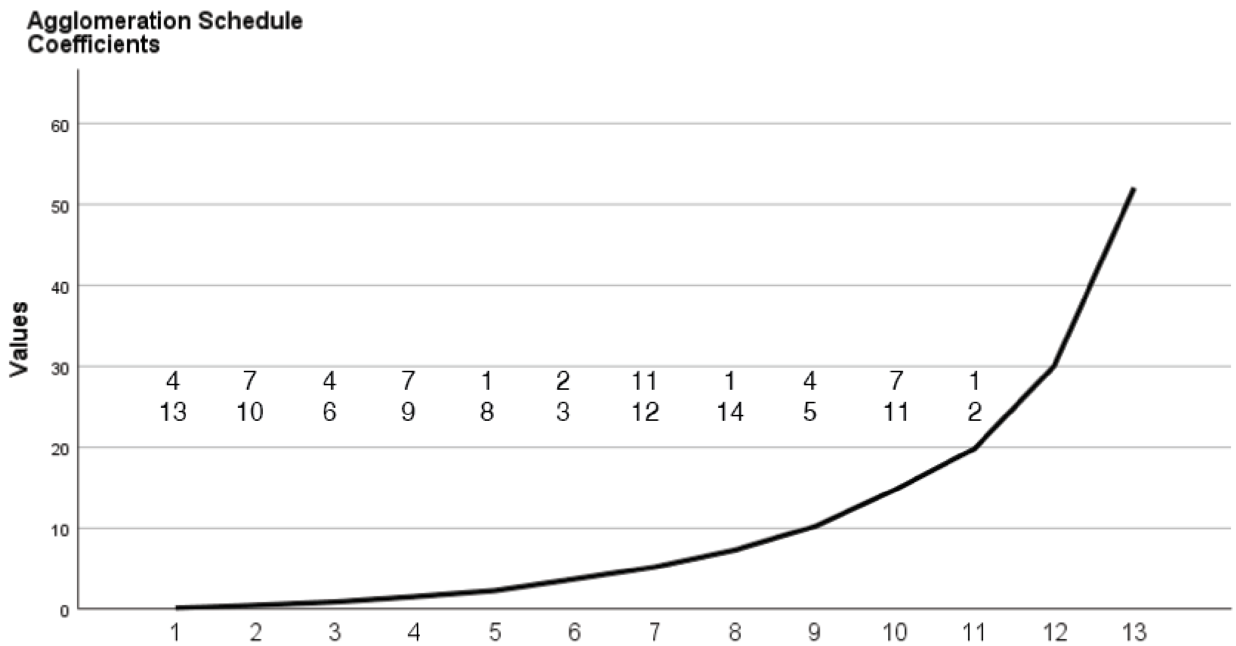


Figure 7. Agglomeration schedule of clustering analysis.

The final selection of clusters can be also argued by functions and typologies of sampling locations that form the clusters. 'Nature' cluster (n = 439) is consists of urban parks where visual elements are dominated by greenery. 'Traffic' cluster (n = 313) consists of locations with high traffic areas in London. While 'Human' (n = 396) cluster involves mainly pedestrian only areas. Lastly, 'Other' cluster does not have conspicuous dominant sound sources and could be characterised as with locations of mixed functions. This is clear from sound source composition in clusters, Figure 8.

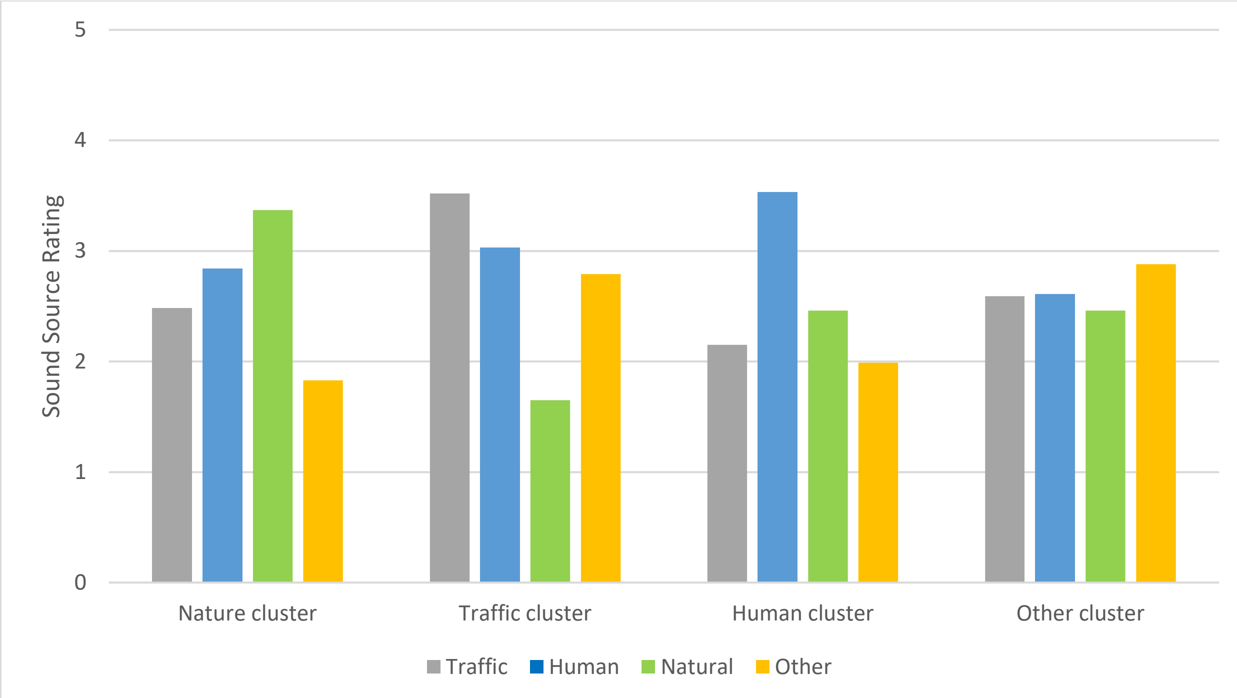
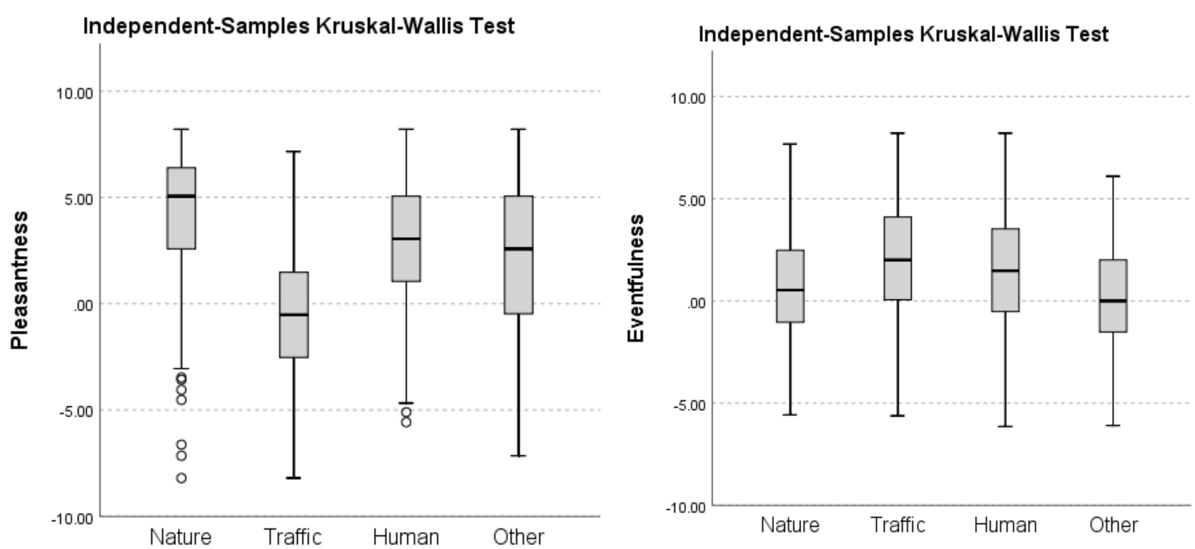


Figure 8. Sound source composition of Nature, Traffic, Human and Other clusters.

4.2 Differences among clusters in the population

To determine whether there are statistically significant differences in the Pleasantness and Eventfulness ratings of all clusters, the Kruskal-Wallis H test was conducted. As a result, in the population, there is a significant difference in Pleasantness rating between Nature, Traffic, Human and Other clusters, x^2 = 373.55, $p < 0$. Moreover, there is a significant difference in Eventfulness rating between latter mentioned clusters, x^2 = 72.8, $p < 0$.



Figures 9 & 10. Boxplot of Kruskal-Wallis tests for Pleasantness and Eventfulness differences among four clusters.

By looking at the boxplot of Pleasantness and Eventfulness ratings among four clusters, differences and similarities between distributions are visible. Nature and Traffic clusters are the most distinguishable from each other in Pleasantness ratings. However, besides latter differences, distribution of Pleasantness and Eventfulness ratings of all clusters are similar. Moreover, some outliers of the data are visible in the Nature and Human clusters of Pleasantness ratings.

4.3 Relationship between dominant sound sources and perceived affective quality

Spearman's rank-order correlation was run to determine the relationship between the dominant natural, traffic, human and other sound sources with perceptual attributes, namely pleasant, chaotic, vibrant, eventful, uneventful, calm, annoying and monotonous. The results are shown below:

Table 3. Results of Spearman's correlation between dominant sound sources and their perceptual attributes.

		Pleasant	Chaotic	Vibrant	Uneventful	Calm	Annoying	Eventful	Monotonous
Natural	r_s	0.338	-0.236	0.088	-0.074	0.296	-0.254	-0.025	-0.141
	p	0*	0*	0.066	0.123	0*	0*	0.601	0.003
	n	439	439	438	438	438	437	438	438
Traffic	r_s	-0.377	0.323	0.054	-0.112	-0.3	0.24	0.111	0.038
	p	0*	0*	0.343	0.047	0*	0*	0.05	0.502
	n	313	313	313	313	313	313	313	313
Human	r_s	-0.083	0.239	0.209	-0.186	-0.259	0.008	0.231	-0.058
	p	0.1	0*	0*	0*	0*	0.869	0*	0.249
	n	394	394	393	391	392	391	394	394
Other	r_s	-0.353	0.27	-0.086	-0.047	-0.373	0.279	0.179	0.15
	p	0*	0*	0.222	0.508	0*	0*	0.01	0.032
	n	205	205	205	205	204	205	205	205

*p < 0.01

Moreover, Spearman's rank-order correlation was run to investigate the relationship between the dominant sound sources and Pleasantness and Eventfulness ratings or collapsed perceptual model.

Table 4. Spearman's correlation between dominant sound sources and Pleasantness and Eventfulness ratings.

		Pleasantness	Eventfulness
Natural	r_s	0.334	-0.53
	p	0*	0*
	n	435	435
Traffic	r_s	-0.331	0.202
	p	0*	0*
	n	313	313
Human	r_s	-0.9	0.348
	p	0.76	0*
	n	388	388
Other	r_s	-0.373	0.255
	p	0*	0*
	n	204	204

*p < 0.01

As a result, only weak relationships could be identified. As expected, dominant natural sound sources positively correlate with positive perceptual attributes, such as Pleasant ($r_s = 0.338$, $p < 0$), Calm ($r_s = 0.296$, $p < 0$) and overall Pleasantness ($r_s = 0.334$, $p < 0$). While there is negative correlation with unpleasant attributes: Chaotic ($r_s = -0.236$, $p < 0$) and annoying ($r_s = -0.254$, $p < 0$).

On the contrary, relationship between traffic dominance and unpleasant attributes can be identified: negative weak relationship with Pleasant ($r_s = -0.377$, $p < 0$) and Calm ($r_s = -0.3$, $p < 0$) and overall Pleasantness ($r_s = -0.331$, $p < 0$). Also, positive a correlation with Chaotic ($r_s = 0.323$, $p < 0$), Annoying ($r_s = 0.24$, $p < 0$) and Eventfulness ($r_s = 0.202$, $p < 0$).

Human sound dominance significantly correlates with Eventfulness ($r_s = 0.348$, $p < 0$); however, there was no significant relationship with Pleasantness ratings.

Other sound dominance indicates negative perception with Pleasantness ($r_s = -0.373$, $p < 0$) but also there is an indication for Eventfulness ($r_s = 0.255$, $p < 0$).

Overall, the results suggest a basis for reasoning that the quality of soundscape could be explained by analysing the relationships between the dominant sound sources and the perceived affective quality. The distinction between natural and traffic sound sources in the sense of their perception that was discussed in Section 2.6 of this thesis is also noticeable. It is clear from the data and previous research that natural sound sources are perceived as pleasant and are favourable in urban environments. In addition, the tranquillity in nature dominant areas is noticeable from low eventfulness ratings.

It also seems true that with the introduction of traffic or other, such as construction sounds, the Pleasantness of soundscape decreases, as other researchers found it. It is also true for Other sounds dominant cluster, although it is the most vaguely explained by the statistical analysis. However, from the data, it is not suitable to say that traffic noise may be perceived as less unpleasant in non-nature dominant areas (see the table in Appendix 3).

Locations with dominant human sounds are distinguishable by the Eventfulness ratings. As it was discussed in the theoretical framework, many activities resulting in multiple sound sources in a horizontal plane may explain why these areas were regarded as busy in terms of sounds. However, it is not clear whether the soundscape of busy locations is pleasant since it is regarded as chaotic but also as vibrant.

4.4 Relationship between acoustic parameters and perceptual attributes

The results of correlative analysis between SPL and Pleasantness and Eventfulness ratings in different dominance clusters are shown below:

Table 5. Spearman's correlation between Pleasantness and Eventfulness ratings (dependent) and SPL (independent) in dominant sound clusters.

Cluster	Component		L_{Aeq}	L_{A90}	L_{A10}	L_{A10}-L_{A90}	L_{AFmax}	L_{AFmin}
Natural	Pleasantness	r_s	0.051	-0.215	-0.020	-0.154	-0.286	-0.020
		p	0.285	0*	0.679	0.001	0*	0.679
		n	435	435	435	435	435	435
	Eventfulness	r_s	-0.223	0.356	-0.033	0.065	0.329	-0.033
		p	0*	0*	0.496	0.176	0*	0.496
		n	435	435	435	435	435	435

Traffic	Pleasantness	r_s	-0.231	-0.256	-0.231	0.138	0.198	-0.338
		p	0*	0*	0*	0.015	0*	0*
		n	313	313	313	313	313	313
	Eventfulness	r_s	0.218	0.218	0.218	0.258	-0.179	0.037
		p	0*	0*	0*	0*	0.001	0.513
		n	313	313	313	313	313	313
Human	Pleasantness	r_s	-0.048	-0.070	0.146	0.128	0.079	-0.139
		p	0.341	0.165	0.004	0.012	0.120	0.006
		n	390	390	390	390	390	390
	Eventfulness	r_s	0.061	0.033	0.025	0.053	0.079	-0.012
		p	0.226	0.516	0.625	0.296	0.119	0.818
		n	390	390	390	390	390	390
Other	Pleasantness	r_s	-0.052	-0.052	-0.052	0.052	-0.052	0.052
		p	0.462	0.462	0.462	0.462	0.462	0.462
		n	205	205	205	205	205	205
	Eventfulness	r_s	0.254	0.254	0.254	-0.254	0.254	-0.254
		p	0*	0*	0*	0*	0*	0*
		n	205	205	205	205	205	205

*p < 0.01

The number of significant relationships is considerably lower in the analysis of SPL. As well, all significant relationships appear to be weak. For example, in nature dominant areas, there is positive relationship between L_{A90} and eventfulness ($r_s = 0.356$, $p < 0$) and a negative with pleasantness ($r_s = -0.215$, $p < 0$).

L_{Aeq} could be regarded as steady, averaged sound levels over the measurement period. As it is only significant in traffic dominant areas, L_{Aeq} could be linked with the overall perception of traffic noise which is unpleasant ($r_s = -0.231$, $p < 0$).

L_{A90} levels count for noise level exceeded for 90% of the measurement period. It could be interpreted as background noise level where sounds are present during the quiet measurement periods. In nature dominant areas, the background noise levels could be associated with overall sound composition since sudden noises are not expected in such locations, as they are supposed to be tranquil. It may be the reason why background levels are associated positively associated with Eventfulness and negatively with Pleasantness. In contrast, in traffic dominant areas, there are associations also with L_{A10} levels, which correspond to sudden noises, such as traffic. Whereas in nature areas such associations could not be found.

Correlative analysis between acoustic parameters and perceptual attributes have similarities with the same analysis with the collapsed model. For the sake of conciseness, the results of the correlation of perceptual attributes with acoustic parameters are not shown. However, there is one interesting finding:

In traffic dominant areas there is a negative correlation between L_{A10} and Pleasant attribute ($r_s = -0.257$, $p < 0$) while human dominant areas, there is a positive correlation between the same variables ($r_s = 0.249$, $p < 0$). Hence, the distinction of appeal between sudden noises in traffic and human dominant areas is visible. Traffic noises are unpleasant in all locations, while in human dominant areas, these SPL levels seem to be favourable.

5. Conclusion

This thesis thrived to investigate urban acoustic environment regarding the associations between sound source dominance with perceived affective quality of sound and acoustic parameters. Data on sound sources, perceptual attributes and SPL, that was collected in Groningen as well as in other locations in Europe was a basis for statistical analysis. The most dominant sound sources are natural, traffic and human, in the sense of the highest proportion as evaluated by visitors of surveyed urban areas. The perceived affective quality of those areas varies, but in general natural areas could be described as pleasant, traffic – unpleasant and human as eventful. Sampling locations as clustered in homogenous dominant sound sources, perceptual attributes given by the participants and measured sound pressure levels were the basis for correlative analysis.

Significant relationships between dominant sound sources and perceptual attributes were found. As expected, the division between natural sound as pleasant and traffic sound as unpleasant is clearly visible. Human sound dominance can be associated with locations bustling with activity. While other sound sources could be regarded as annoying and unpleasant. All in all, the perceived affective quality of urban acoustic environment could be explained by analysing the associations between sound sources and perceptual attributes.

A relatively new method of evaluating the acoustic environment – the collapsed model of Pleasantness and Eventfulness was also used in this thesis. It seems that the model adequately describes perceived soundscape quality, similarly as with perceptual attributes. The model, however, has more applications, such as plotting on graphs or it is more suitable in regression analyses.

The significant relationships were found between soundscape descriptors: statistical variations of SPL and Pleasantness and Eventfulness. It seems that some SPL measurements are more distinct for different sound source dominance areas. Background SPL correlates with nature sound dominant areas, while sudden changes in SPL are more significantly correlated with those locations where many, sudden sound sources are found, such as traffic or human.

It is necessary to note that only weak relationships between variables were found. Hence, the implications on the validity of the research are obvious. It may be that more elaborate research design could be used to increase the internal validity of potential analysis of the data. This could be argued that in this study, a relatively large dataset was used, even when correlating all cases, the relationships were still weak. Besides, no attention was paid to contextual factors of the urban acoustic environment. Visual cues, the behaviour of a respondent play a significant role in the evaluation of soundscape (Blid et al., 2018; Kang et al., 2019; Jeon et al., 2011). Future researchers could incorporate contextual factors and innovative statistical approaches while analysing urban soundscape.

Nevertheless, the findings of this research give empirical evidence that perceptual attributes could explain the quality urban acoustic environment. As it is also clear that natural dominant sound sources are favourable in urban environments and could be associated with positive attributes. Whereas traffic dominant areas could have potential negative health implications (Bravo-Moncayo et al., 2017). Decision-makers in cities should seek to separate such uses from areas where people are present.

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Appendix 1: Questionnaire design

Variable Name	Displayed Question	Response code	Response text
ssi01	Traffic noise (e.g. cars, buses, trains, airplanes)	1	Not at all
ssi02	Other noise (e.g. sirens, construction, industry, loading of goods)	2	A little
ssi03	Sounds from human beings (e.g. conversation, laughter, children at play, footsteps)	3	Moderately
ssi04	Natural sounds (e.g. singing birds, flowing water, wind in vegetation)	4	A lot
		5	Dominates completely
ssss01	Please identify the single sound source which you perceive as the most prominent in the sound environment (e.g. traffic noise, children at play, water sounds, etc.)	(text)	
sss03	To what extent did you hear this sound in the environment?		Slightly Moderately Very Extremely Strongly disagree
w01	From an auditory point of view, how would you rate the water features in this space?	5	Very good
		4	Good
		3	Neither bad nor good
		2	Bad
		1	Very bad
w02	From visual point of view, how would you rate the water features in this space?	5	Very good
		4	Good
		3	Neither bad nor good
		2	Bad
		1	Very bad
w03	How much would you say the water features dominate your field of view (visually)?	5	Not at all
		4	A little
		3	Moderately
		2	A lot
		1	Dominates completely
paq01	Pleasant	2	Slightly
paq02	Chaotic	3	Moderately
paq03	Vibrant	4	Very
paq04	Uneventful	5	Extremely
paq05	Calm	1	Strongly disagree
paq06	Annoying		

paq07	Eventful		
paq08	Monotonous		
sss01	Overall, how would you describe the present surrounding sound environment?	5	Very good
		4	Good
		3	Neither bad nor good
		2	Bad
		1	Very bad
sss02	Overall, to what extent is the present surrounding sound environment appropriate to the present place?	1	Not at all
		2	Slightly
		3	Moderately
		4	Very
		5	Perfectly
sss03	How loud would you say the sound environment is?	1	Not at all
		2	Slightly
		3	Moderately
		4	Very
		5	Extremely
sss04	How often do you visit this place?	1	Never / This is my first time here
		2	Rarely
		3	Sometimes
		4	Often
		5	Very often
sss05	How often would you like to visit this place again?	1	Never
		2	Rarely
		3	Sometimes
		4	Often
		5	Very often
v01	How much would you say that green space features (grass, trees, shrubs, etc.) visually dominate in this area?	5	Not at all
		4	A little
		3	Moderately
		2	A lot
		1	Dominates completely
v02	To what extent do you agree that this area is visually pleasant?	5	Strongly agree
		4	Somewhat agree
		3	Neither agree nor disagree
		2	Somewhat disagree
		1	Strongly disagree
v03	What is the quality of the area as a whole?	5	Very good
		4	Good
		3	Neither bad nor good
		2	Bad
		1	Very bad
v04	How safe do you feel here?	5	Not at all
		4	A little
		3	Moderately
		2	A lot
		1	Dominates completely
who01	I have felt cheerful and in good spirits	5	All of the time

who02	I have felt calm and relaxed	4	Most of the time
who03	I have felt active and vigorous	3	More than half of the time
who04	I woke up feeling fresh and rested	2	Less than half of the time
who05	My daily life has been filled with things that interest me	1	Some of the time
		0	At no time
age00	How old are you?	(integer, Min:18)	
gen00	What is your gender?	1	Male
		2	Female
		3	Non-conforming
		4	Rather not say
occ00	What is your occupational status?	1	Employed
		2	Unemployed
		3	Retired
		4	Student
		5	Other
		6	Rather not say
edu00	What is the highest level of education you have completed?	1	Some high school
		2	High school graduate
		3	Some college
		4	Trade / Technical / vocational training
		5	University graduate
		6	Some postgraduate work
		7	Postgraduate degree
eth00	Please specify your ethnicity.	1	White
		2	Mixed / multiple ethnic groups
		3	Asian / Asian British
		4	Black / African / Caribbean / Black British
		5	Middle Eastern
		6	Rather not say
		7	Other ethnic group
eth01	Please specify "Other ethnic group"	(text)	
edu01	What is the name of the university you study at, if applicable?	(text)	
misc00	Would you consider yourself…	1	A local
		2	A tourist
		3	Other
misc01	Please specify "Other":	(text)	
misc02	How long have you stayed in the Netherlands?	1	Less than 6 months
		2	More than 6 months, but less than 6 years
		3	More than 6 months
misc03	Is there anything else you want to let us know about the sound environment?	(text)	
sessionid	SessionID	(text)	
groupid	GroupID	(text)	
use00	Was the participant…	1	Staying
		2	Arriving
		3	Leaving
		4	Passing through
res00	text	(text)	

Appendix 2. Consent form

1. I have read and understood the information sheet explaining the experiment and I have had the opportunity to ask questions about the project.
2. I understand that my participation is voluntary and that I am free to withdraw at any time without giving any reason and without there being any negative consequences. In addition, should I not wish to answer any particular question, I am free to decline.
3. I understand that my responses will be kept strictly confidential.
4. I give permission for members of the research team to have access to my anonymised responses and I understand that I will not be identifiable in reports that result from the research.
5. I agree to take part in the above-mentioned project.
6. I am over 18 years old and under 80 years old.

Yes. I agree

No. I disagree

Appendix 3: Correlation results between all sound sources and perceptual attributes

Dominant cluster		Nature				Traffic				Human				Other			
Sound source		Natural	Other	Human	Traffic	Natural	Other	Human	Traffic	Natural	Other	Human	Other	Natural	Other	Human	Traffic
Pleasant	rs	0.338	-0.311	-0.098	-0.355	0.307	-0.249	0.069	-0.377	0.293	-0.268	-0.083	-0.268	0.183	-0.353	-0.095	-0.212
	p	0*	0*	0.041	0*	0*	0*	0.225	0*	0*	0*	0.100	0*	0.009	0*	0.176	0.002
Chaotic	rs	-0.236	0.296	0.190	0.348	-0.155	0.278	0.081	0.323	-0.087	0.280	0.239	0.280	-0.079	0.270	0.009	0.291
	p	0*	0*	0*	0*	0.006	0*	0.151	0*	0.086	0*	0*	0*	0.260	0*	0.895	0*
Vibrant	rs	0.088	-0.066	0.106	0.060	-0.024	0.026	0.254	0.054	0.140	0.008	0.209	0.008	0.082	-0.086	0.055	-0.120
	p	0.066	0.171	0.027	0.209	0.667	0.650	0*	0.343	0.005	0.871	0*	0.871	0.240	0.222	0.436	0.087
Uneventful	rs	-0.074	0.128	-0.082	-0.041	0.078	-0.031	-0.161	-0.112	-0.022	0.029	-0.186	0.029	0.005	-0.047	-0.059	-0.111
	p	0.132	0.007	0.088	0.393	0.167	0.584	0.004	0.047	0.663	0.565	0*	0.565	0.941	0.508	0.403	0.114
Calm	rs	0.296	-0.221	-0.137	-0.366	0.246	-0.163	-0.007	-0.300	0.210	-0.255	-0.259	-0.255	0.215	-0.373	-0.116	-0.217
	p	0*	0*	0.004	0*	0*	0.004	0.899	0*	0*	0*	0*	0*	0.002	0*	0.098	0.002
Annoying	rs	-0.254	0.336	0.124	0.315	-0.073	0.263	-0.045	0.240	-0.219	0.271	0.008	0.271	-0.063	0.279	-0.044	0.226
	p	0*	0*	0.010	0*	0.200	0*	0.426	0*	0*	0*	0.869	0*	0.368	0*	0.527	0.002
Eventful	rs	0.025	-0.027	0.069	0.155	-0.021	0.131	0.062	0.111	0.060	0.011	0.231	0.011	-0.040	0.179	0.052	0.010
	p	0.601	0.577	0.152	0.001	0.708	0.020	0.274	0.001	0.238	0.831	0*	0.831	0.572	0.010	0.460	0.887
Monotonous	rs	-0.141	0.252	-0.045	0.065	-0.059	0.067	-0.116	0.038	-0.034	0.129	-0.058	0.129	-0.086	0.150	-0.045	0.030
	p	0.003	0*	0.351	0.175	0.302	0.235	0.040	0.502	0.503	0.010	0.249	0.010	0.220	0.032	0.521	0.671

*$p < 0.01$