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Soundscape cost index: a case study in Aachen

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ABSTRACT

Soundscape studies are showing the importance and the benefits regarding the sonic the environment in our daily lives. Through the soundscape paradigm shift, not just negative aspects, common on environmental noise studies, are highlighted, but also how the sonic environment can be recovering to the welfare of communities. Thinking of the valuation of environments, past studies focused mainly on how much the environmental noise does cost for society. This kind of valuation followed several methods like hedonic pricing, contingent valuation, and benefits transfer methods, which are based just on economic factors involving socio-economic aspects. The aim of this study is to show a new approach which fits better with the soundscape paradigm shift, highlighting the valuation of positive and negative aspects of the evaluated soundscape, together with the interaction of socio-economic and socio-cultural aspects, as well as aesthetics, thermal-comfort and, air quality, which are other stimuli who can influence our general environmental perception.

Keywords: Soundscape, Cost, Sound Perception.

1. INTRODUCTION

Acoustics is defined as the science of sound. A good definition and explanation of the scope of this science can be found in the book Springer Handbook of Acoustics, edited by Thomas D. Rossing, as follows: "The sound has become an interdisciplinary field that encompasses such disciplines as for example physics, architecture, psychology, communication and neuroscience. As branches of acoustics can be cited: architectural acoustics, physical acoustics, musical acoustics, psychoacoustics, electroacoustic, noise control, vibration and shock, underwater acoustics, speech, physiological acoustics, etc." (Rossing, 2007, p.1). Physics studies the phenomenon of sound itself and its propagation medium; psychophysics studies the physical reactions that stimulate the psychological part of the individual and through these, there are the interpretation of sound in the ecological, sociological, psychological and physiological aspects.

The sound reaches the auditory system of an individual, whose sound perception is affected by the situation and the cultural environment, among other factors, and as a consequence, this noise can affect people´s welfare, health and to the economy of the region where they live giving rise to the so-called "environmental costs" (Lercher, 2013).

In the year of 2012, Engel, through her master thesis entitled "Characterization of the Noise Pollution, Through Measurements, Mappings and Sound Perception Interviews at the Green Line in Curitiba – Paraná "led to several conclusions. One of them concerns the need for investigations in greater depth about the socioeconomic influence on the perception responses of soundscape and its impact on the quality of life of the involved communities.

Interested in economic issues related to noise, several scholars have proposed different methods for the calculation of its economic cost. In 2011 the state of the art on the subject was exposed by Restrepo et al. in "Valoración Económica del Ruido: Una Revisión Analítica de Estudios". This environmental contaminant has a low cost of generation and its economic value is difficult to measure because it is influenced by the perception of the community and affects individuals (Regecove and

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Rellevora, 1995), there are some methods of monetization of noise, but these all have their limitations. Among them, the following can be highlighted: the method of hedonic pricing, which establishes a relationship between the price of a good and the marketable attributes associated with it; in the case of noise, we evaluate the impact caused by the noise in the dwellings next to the sources. A second method is a contingent valuation, which is based on the allocation of value to individual preferences established by direct feedback from consumers; to this end, the researcher may ask individuals how much they would be willing to pay to reduce noise. A third method is called benefits transfer method when the information of an original study is applied in a different context; for example, the averages of data from a study area calculated and then applied to another area.

Currently, there are several publications that address the environmental costs associated to noise, which use the method of hedonic pricing (Brandt and Maenning, 2011; Püschel & Evangelinos, 2012; Bréchet & Picard, 2012). However, this method, although widely used, considers only objectively measurable variables, leaving out important factors, such as the commitment of families to their old home and neighbourhood, which was identified by Odling - Smee & Whitehead (1975) in the pricing of a property; in addition, there are also omitted subjective variables that influence the decision of the valuation and devaluation of properties. On the other hand, the contingent valuation method or marginal cost (Carlsson et al., 2004; Galilea & Ortúzar, 2005; Andersson and Ögren, 2006) uses socioeconomic research to identify consumer preferences in relation to the costs he is willing to take to stay in an area with a particular soundscape. Few studies have reported the benefit transfer method (Navrud, 2002; Rosenberger and Loomis, 2003), since it is difficult to apply a method that uses averages of objective variables easily measured in a certain location; these data cannot always be applied in different locations, since each study site has its geographical, cultural particularities and specific soundscapes, which influence the habits of its residents.

A more detailed analysis of these methods leads to the conclusion that they focus only on the aspect of the economic costs caused by noise, omitting several important aspects such as: cultural, physiological, psychological, geographical, architectural, landscape, as well as, the sound quality and acoustic comfort, which all influence people's health, the wellbeing and aggregate value in urban spaces" (Engel, 2013 - Original dissertation project).

These aspects are in line with the concept of soundscape, which over time leaded efforts to establish an international standard about the conceptual framework for soundscape studies (ISO/FDIS 12913-1:2014). The aim of this study is to present a soundscape cost index that considers sociocultural, geographical, architectural, sound and air quality, as well as thermal comfort aspects.

2. METHODS

Environmental studies have shown that the soundscape of urban areas is an important aspect for the comfort of people in general (Raimbault et al. 2003): The association between the sound quality of the environment and comfort has been often debated in the last decade. Initially only sound levels indicators were analyzed and, over time, the concept of sound quality was expanded, as people became aware of the new dimensions of sound, such as (1) the compatibility of response to stimuli (2) to what extent sound is pleasing, (3) the possibility of identifying sounds or sound sources (Guski, 1997,).

Psychoacoustic magnitudes, such as loudness, roughness, sharpness and fluctuation strength (Zwicker and Fastl, 1999), have proved to be useful concepts for the evaluation of sound quality.

To assess the soundscape quality, descriptors (Aletta et al. 2016), frameworks (Jennings & Cain, 2013), and methodologies for data collection, such as soundwalks (Adams et al. 2008), listening tests (Susini et al., 2012), interviews (ISO/TS 15666, 2003, Simmons, 2014) and focus groups (Bruce & Davies, 2014), were developed.

This study is presenting data collected though soundwalks in three areas in Aachen -Germany, called: Stadtgarten-Farwickpark (CA), Theaterstrasse (TE) and Westpark (WP). The first area, CA, is a residential area with a great urban park, which includes a conference venue, casino, playgrounds, sports courts, pools and spa, as well as a historic graveyard. The second area, TE, is a busy street, with access to the main train station, as well to the principal theatre from the town. The third area in another urban park, inside the student quartier from Aachen. There are a pond, several sports courts and playgrounds inside the park.

It was established some objectives which help us to understand better the environment interaction and its perception, as well as socio-economic aspects and users' preferences related to the sonic environment. For the development of the index, the main associations with sound conditions and its perception are:

- Microclimate and thermo-comfort;
- Air quality;
- Users' profile in terms of context, demographic information, socio-cultural aspects, preferences related to the sonic, visual, thermal environment, air quality and its valuation;
- Landscape, urban morphology, habits about the use of urban spaces;

To understand how those aspects can influence the soundscape perception, some concepts will be explained in the sequence with the addition of current work in the soundscape field of study.

A) Microclimate and Thermo-Comfort

According to Tromp (1980), Biometeorology is the science which investigates direct and indirect irregular, fluctuating or periodic influences from physical, chemical and physiochemical micro and macro environments namely the Earth's atmosphere and similar extraterrestrial factors, physic-chemical systems in general, and living organisms such as plants, animals and humans, in particular. It is common to compare bioclimatology to biometeorology, analogous to the use of the terms micrometeorology and microclimatology or the current convergence of meteorology and climatology.

Human Biometeorology is divided into physiological, pathological, spatial and urban, as well as sociological Biometeorology. Faust (1976) distinguishes the (photo) actinic, the thermal and the air-hygiene / air-chemical interaction. The actinic complex of action comprises the influencing factors of the radiation, Infrared and UV radiation as well as the visible light (German Weather Service). This effect complex incorporates solar and atmospheric radiation, according to the global radiation. Significant parameters are therefore short- and long-wave radiation. The actinic activity complex is influenced by the degree of cloudiness, which is recorded manually in the measurements, as well as by industrial evaporation, the altitude above the normal altitude and the time of day. The effects on humans are, for example, the delivery of radiation energy via the skin (depending on the outside temperature), health risks due to infrared heating, the absorption of vitamin D, pigmentation of the skin and effects on the state of mind.

The thermal effect complex includes all the climatic factors influencing the heat balance of the human, i.e. all conditions "that have an influence on the heat exchange of the human body with its surroundings" (Turowski, 2002). The thermo-physiological important factors are air temperature, air humidity, radiation and air movement. Therefore, in addition to the radiation, the measurements include the air temperature (and the temperatures of the globe thermometer, which is more affected by solar radiation) and the humidity.

Different heat balance models were developed, which form the basis for evaluation methods of the thermal effect complex. These include the comfort equation according to Fanger (1972), which is used to calculate the Predicted Mean Vote (PMV).

Few studies investigated the joint combination of thermal and acoustic stimuli and its perception, and most of them focused on controlled indoor studies (Fanger et al. 1977, Clausen et al. 1993).

B) Air quality

Some studies have started to investigate the association of walkability with health conditions and environmental factors, including air pollutants like particulate matter (Bereitschaft, 2015; James et al., 2017). Even how the type of transportation mode can influence personal exposure to ultrafine particles has been assessed (Kaur and Nieuwenhuijsen, 2009). The perception of air quality by pedestrians is also a major concern, with investigations being carried out in German and Mediterranean outdoor environments to discover how particulate matter (PM10), nitrogen oxides (NOx) and carbon monoxide (CO) are perceived by the public (Nikolopoulou et al., 2011, Paas et al., 2016; Pantavou et al., 2017). Dust and grime, as well as the smell can be perceived by the population (Forsberg et al., 1997), affecting behaviour and it is normally associated with traffic (Klæboe et al., 2000).

The association between air quality and sound perception was investigated some years ago by Nikolopou et al. (2011). This study realized filed surveys about microclimate, sound pressure level and particulate matter (PM) perceptions. Their findings suggested that the perception of particulate matter occurs with the help of visual effects, due to the significant negative correlation with solar radiation.

C) Users' profile

It was used in terms of context, demographic information, socio-economic conditions, socio-cultural aspects, preferences related to the sonic environment and its valuation

According to the International Organization for Standardization (ISO/FDIS 12913-1:2014), the soundscape is defined as “acoustic environment as perceived and, or understood by a person or people, in context”.

The context includes all non-acoustical components of a place, related to persons, between the interaction of person-place and the motivation for undertaking an activity in this place (Brown et al, 2016). It is also shaped by visual stimuli, knowledge accumulated on the place and cultural meanings (Botteldooren et al, 2016).

As mentioned above, persons and their preferences play a significant role in the soundscape evaluation, thus it is important to know the profiles of users who are evaluating the soundscape, making understandable the interaction person-place and the influence of the sonic environment on their everyday lives (Engel et al., 2016).

In Engel et al. (2016), perception responses from residents and park visitors related to soundscape indicated a clear difference in the importance of acoustic attributes. Visitors highlighted that restoration; nuisance; comfort and intensity of the sonic environment were important sound quality attributes. Residents indicated that nuisance, intensity, comfort and finally restoration were important attributes for the sonic environment. Related to socio-cultural aspects, the most important predictors on the soundwalks were: age, gender, profession; and on the interviews with residents: motivation to live in Aachen, gender and profession.

In Jeon et al (2018) a cross-national comparison assessment about soundscape perception was conducted with data from France, Korea and Sweden. The findings indicated the importance of the selection of attributes using proper wording which will lead to the same semantic interpretation in different countries.

D) Landscape, urban morphology, habits about the use of urban spaces

Various studies are showing recently the association between soundscape and landscape, which by an analogous view, these terms are representing the interaction of natural and human factors (Brown et al. 2016). The concepts of soundscape and landscape are based on human perception (ISO/FDIS 12913-1:2014). This study collected landscape data considering , the method developed by Barton and Tsouro (2000) entitled “Healthy Urban Planning” approach, considering the following indicators: healthy lifestyle, social cohesion, housing quality, access to work, accessibility, local food production, safety, equity, air quality & aesthetics, water and sanitation quality, quality of land or mineral resources, and climate stability.

All objective and subjective data were tabulated, classified, transformed into composites with averages, as well as standardized to have a similar scale, allowing complex statistical analysis. When it was required, imputations with predicted values were realized, completing possible missing data. This procedure were analyzed and realized with the help of IBM SPSS Statistics ®. After the data pre-processing, it was calculated through linear regression a predicted model of the Soundscape Cost Index, considering “Soundscape Wish” as the dependent variable and the following parameters as independent variables:

- Demographic composite 1 (Gender, categorized age, categorized nationality);
- Demographic composite 2 (Time living in Aachen, motivation);
- Standardized Mean of Noise Controle (NC) Perception (need of NC; NC need street or area, NC need building)
- Standardized Mean of Soundscape Quality Perception (intensity, comfort, nuisance, welfare recovery);
- Standardized Mean of Soundscape Acceptance and Cognitive Aspects (acceptance, emotions, memories, special feature – soundmark);
- Standardized average Loudness;
- Standardized average Sharpness;
- Standardized average Hearing Model Roughness ½ Bark;
- Standardized average Fluctuation Strength ½ Bark;
- Standardized average Tonality;
- Standardized average Sound Pressure Level A-weighted;
- Standardized Mean of Air Quality (AQ) Perception (Feel overall AQ, Pureness AQ, Visualize Particulate Matter, Pleasantness AQ, Impression AQ);

- Standardized average Particulate Matter (PM) PM_1;
- Standardized average Particulate Matter (PM) $PM_{2.5}$;
- Standardized average Particulate Matter (PM) PM_{10};
- Standardized Mean Thermal Comfort (Perception of weather perception, temperature, the heat of the sun, humidity, wind speed and wind speed comfort);
- Standardized average Predicted Mean Vote (PMV);
- Standardized Mean of Liked aspects related to Landscape (Healthy lifestyle, social cohesion, housing quality, accessibility, local food production, safety, air quality and aesthetics, water and sanitation, quality of land or mineral resources)
- Standardized average of landscape distances (Healthy lifestyle, social cohesion, housing quality, accessibility, local food production, safety, air quality and aesthetics, water and sanitation, quality of land or mineral resources).

The SCI regression model will be compared with actual empirical data of real state (square meter values) from the investigated areas, collected at the website of Stadt Aachen, showing its efficiency.

3. RESULTS AND DISCUSSION

Considering all mentioned parameters above reported, the first version of the model presented R = 0.585 with p-value 0.00, but several parameters were not significant for the construction of the model: Standardized Mean of Soundscape Quality Perception (p-value: 0.249), Standardized Mean of Soundscape Acceptance and Cognitive Aspects (p-value: 0.494), Standardized average Loudness (p-value: 0.236), Standardized average Sound Pressure Level A-weighted (p-value: 0.132), Standardized Mean of Air Quality (AQ) Perception (p-value: 0.168), Standardized average Particulate Matter (PM) PM10 (p-value: 0.432) and Standardized average of landscape distances (p-value: 0.806). These parameters were removed from the independent variables list and the model was calculated again.

The new SCI model presented R = 0.58, R Square = 0.337, with df (12) and p-value = 0.000. The new independent variables list showed the significance for all parameters as shown in Table 1.

As resulting Soundscape Cost Index (SCI) we have:

$$SCI = 0.827 - 0.389\, X1 + 0.055\, X2 - 0.093\, X3 - 0.153\, X4 - 0.427\, X5 + 0.181\, X6 - 0.086\, X7 - 0.432\, X8 + 0.603\, X9 - 0.078\, X10 - 0.137\, X11 + 0.213\, X12 \quad \text{(eq.1)}$$

Comparing the index to real estate actual empirical data (monetary value per square meter), it is possible to see in Figure 1, that the mean at each evaluated point followed well the real estate values expected for the two park areas (Stadtgarten-Farwickpark and Westpark). Positive impressions about “soundscape wish” at CA1, CA2, CA4, CA6 and CA7, as well as negative impressions at W1, W4 W5 and W7 are consistent to the real estate values of these areas. At Theaterstrasse, due to commercial speculation, the real estate values are overrated and showed no consistency compared to the SCI model.

Table 1 – Coefficients of the Soundscape Cost Index Model

Model		Unstandardized Coefficients		Standardized Coefficients		
		B	Std. Error	Beta	t	Sig.
1	(Constant)	.827	.160		5.156	.000
	Demographic composite 1 (X1)	-.389	.046	-.259	-8.400	.000
	Demographic composite 2 (X2)	.055	.028	.061	1.959	.050
	Standardized Mean of Noise Controle (NC) Perception (X3)	-.093	.030	-.093	-3.114	.002
	Standardized average Sharpness (X4)	-.153	.031	-.153	-4.964	.000

Standardized average Hearing Model Roughness ½ Bark (X5)	-.427	.039	-.427	-10.913	.000
Standardized average Fluctuation Strength ½ Bark (X6)	.181	.035	.181	5.202	.000
Standardized average Tonality (X7)	-.086	.032	-.086	-2.677	.008
Standardized average Particulate Matter (PM) PM_1 (X8)	-.431	.112	-.431	-3.836	.000
Standardized average Particulate Matter (PM) $PM_{2.5}$ (X9)	.603	.122	.603	4.941	.000
Standardized Mean Thermal Comfort (X10)	-.078	.030	-.078	-2.588	.010
Standardized average Predicted Mean Vote (PMV) (X11)	-.137	.036	-.137	-3.821	.000
Standardized Mean of Liked aspects related to Landscape (X12)	.213	.031	.213	6.927	.000

Dependent Variable: Standardized Mean (soundscape wish)

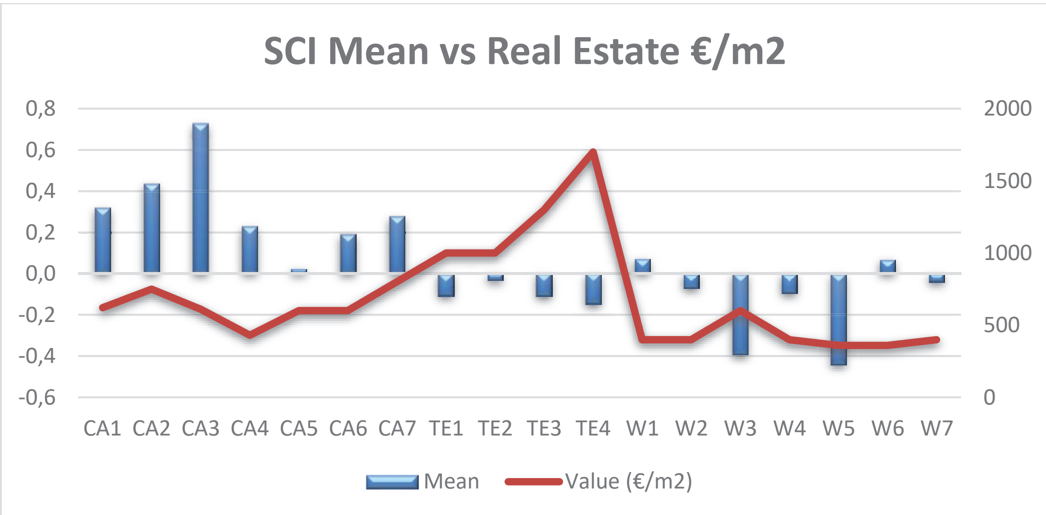

Figure 1 – SCI Mean vs Real Estate €/m2

4. CONCLUSIONS

The aim of this study was to show a soundscape cost index that considers sociocultural, geographical, architectural, sound and air quality, as well as thermal comfort aspects.

Through this study was possible the development of a soundscape cost index based on subjective data of "soundscape wish", which is showing the expectancy of soundwalkers regarding the evaluated sonic environments.

This index presented an explanation of 58% of the evaluated data, showing consistent results for residential areas near to urban parks. Commercial areas with busy streets presented a bad rating according to the SCI, but in reality, they presented overrated real estate values, not fitting well with our prediction.

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