Framework and Potential Implementations of Urban Sound Cartography

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ABSTRACT

The objective of this survey is to attach importance and attention to the acoustic geography of cities and to analyze the spatial reference of urban sounds. This approach encompasses both current environmental noise policies and common soundscape research. In this context it is necessary to create an appropriate and effective instrument to document and communicate spatial components and references of urban sounds. In order to accentuate and display the spatiality of city acoustics, methods of traditional, digital and multimedia cartography as well as the integration of characteristic audio sequences in common 3D city models (auralization) are intended to be incorporated into the urban sound cartography, underlying the overall concept of audio cartography. Methodically, audio cartography enriches and increases knowledge in the fields of geovisualization and visual analytics. Some of these prototype concepts and visualization layouts will be introduced in the following.

1. GENERAL BACKGROUND

Environmental and anthropogenic sounds are ubiquitously present in modern societies nowadays. The acoustic emission and exposure of increasing traffic (road, rail and air), industrial facilities, construction sites, busy neighborhoods and leisure activities surround city dwellers in modern cities constantly and exert wide influence on their quality of life. It is generally known that noise exposure has strongly increased in the last decades and has become a well-known ecological, social and medical problem in metropolitan areas – not only talking about disturbance of our ecological system, encouragement of social segregation and medical surveys which document serious damages to the human body in cities with high noise levels. The list of potential effects documented in literature and research is alarmingly long and encompasses among others hearing impairment, high blood pressure, communication disablement and the loss of environmental orientation (Lercher 1998). Additionally, extreme noise exposure can harm social behavior, reduce helpfulness, neighborly contact and the ability to cope with complex social incidents as well as fear and nervousness can turn into aggression (Cohen et al. 1986).

Aural perception is based on subjective evaluation and depends similarly on technical acoustic variables such as sound pressure, frequency, time flow and sound propagation, direction and distance as well as psychoacoustic factors. Regarding acoustics it is of particular importance that sound propagation in the atmosphere strongly depends on geographic conditions, e.g. atmospheric absorption, wind, temperature, ground effects and so forth (Rossing et al. 2002, Heckl and Müller 1994). Determining factors taken from psychoacoustics encompass among others the intensity of perceived loudness, pitch, sharpness, roughness and fluctuation strength (Zwicker and Fastl 1990). For instance, psychoacoustic analyses resulted in frequency-selective hearing and prove high-frequency and impulsive sounds to be more annoying than deep-frequency sounds or broadband noise (railway noise is experienced less annoying than road traffic noise). Major annoyance is caused by sudden sounds or bangs which may cause shock-alike reactions (Lercher 1998). However, Guski (1996) states that further environmental conditions have to be taken into account when the acoustic impact on our quality of life is to be comprehensively evaluated. Likewise, Lercher (1998) emphasizes that spatial and urban parameters have strong influence on the human attitude towards the sonic environment, specifically the contentment with the living space, the residential area, the importance of the sound source or when other environmental aspects are perceived negatively.

By now, the high social and environmental risk of a dense population being exposed to noise levels above recommendation in metropolitan areas became a matter of common knowledge and governments are starting to react to this pressing urban problem. For this reason, in 2002 the EU passed the Directive Relating to the Assessment and Management of Environmental Noise 2002/49/EC to reduce noise levels in European cities with over 250 000 inhabitants. The policy defines noise indicators and their assessment methods, demands strategic noise mappings from the respective communities every five years and if necessary the realization of action plans. Taking measures of noise reduction forced in this directive mainly depends on the indicator L_{DEN} which marks the overall noise level during day, evening and night in decibel (dB) which is not actually measured but calculated or estimated (European Commission 2007). However, it is generally known that this guideline and its indicators are being strongly criticized by many scientists, acousticians, politicians, decision makers and persons concerned for not being technically or cognitively precise, sufficient or rather comprehensible.

Against the background of the aforementioned immediate relations and definite dependencies of subjective sound perception and situational spatial circumstances, it is remarkable that beyond technical measurements and public noise guidelines and regulations the qualitative influence, correlation and interaction of acoustic parameters and spatial conditions of our urban environment have been barely analyzed in spatial geographic disciplines yet. But exactly this close connection and interaction is particularly needed to fully grasp the significance of our sonic environment in urban centers.

2. ACOUSTIC GEOGRAPHY

There are some scattered theories, initiatives and projects referring to the spatial implication of sounds in rural or urban areas. To name only a few, already in 1929 the Finnish geographer Granö treated the environment as a sensuously perceivable complex of events and objects as the actual geographic research subject. In this approach aural events play a major role to scientifically describe certain spatial situations. However, it is admitted that the concrete localization of aural events in space is hardly possible (Granö 1929). In the 1970s the Canadian composer and scientist Schafer initiated an international large-scale survey to describe our sonic environment systematically. The results of the World Soundscape Project have a lasting effect and notions like (hi-fi/lo-fi) soundscape, acoustic ecology, soundmarks etc. have been defined here explicitly for the first time (Schafer 1977). Unfortunately, this pioneering work brings out only few capable links between acoustics and space. In the end Rodaway scientifically discusses an aural and sonic geography whereas the latter refers to the spatial organization of sounds and sonic characteristics of places. These ideas are embedded in a theoretical concept of a sensuous geography similar to Granö's approach (Rodaway 1994). Recent research activities on a theoretic scientific and public level are taking place at a national level in Europe and beyond (e.g. Acoustic City Linz, Linz Charter, International Noise Awareness Day and dozen ambient sound online archives) but mostly each of these projects deals with particular spatial scientific aspects of soundscape research. Fortunately, the European Cooperation in the field of Scientific and Technical Research (COST) just granted a broad action dealing with the Soundscape of European Cities and Landscapes to bundle loose soundscape research projects. The action's initial position is that current research works in soundscape are still at the stage of describing and identifying the problems and it is implicitly needed to go significantly beyond the current state-of-the-art (COST 2008). The initiation of this campaign once more demonstrates clearly the urge and necessity to consider sounds as a basic, vital and interacting component of our environment. However, even this huge program does not fully attend to the spatial reference and scale of acoustics. So what is still missing is an extensive exploration of the geography of sounds.

In this context a holistic and scientifically founded concept of acoustic geography is proposed which has promise and goes far beyond current attempts due to its strong focus on geographic scientific objectives (Kornfeld 2007, 2008). Developed from the recent research project 'Soundslike', acoustic geography as a division of geography holds great potential to enrich spatial sciences epistemologically by investigating the interaction of acoustics and space very closely. It is built on a multidisciplinary store of knowledge and unifies diverse scientific expertise. To mention just a few examples acoustic geography uses and paraphrases geography's regular scientific interest and testifies what kind of sound occurs where, when and why so that distinct spatial patterns and correlations can be deduced from these conclusions. Relying on acoustic principles this approach acts on the assumption that analyzing ambient sounds allows remarkable conclusions to be drawn about a certain environmental condition; strengthened by the fact that acoustic emission is always accompanied by informational transmission. Also integral parts of the EU environmental noise policy are being attached to this concept as well as ecological, meteorological, social, architectural and urban frameworks and so forth. This knowledge is used and incorporated into the idea of acoustic geography so that a considerable library of significant indicators can be provided to fully detect any spatial acoustic situation:

- *Geographic* indicators depict reciprocal influences of sounds and space and are essential to measure basic condition, setting and structure of the area to be analyzed. These indicators are taken out of human and physical geography divisions such as urban, transportation, economic, population, cultural, social and time geography as well as biogeography, climatology and landscape ecology respectively. Geographic indicators play a key role in acoustic geographic research.

- Indicators extracted from *soundscape research* are among others hi-fi/lo-fi soundscapes (soundscapes differing in their inner sound quality and structure), the identification of (dominant) soundmarks (sounds silhouetting against the audible environment and providing assistance in spatial orientation and identification; dominant soundmarks mask other sounds completely) and sound events (single sound objects distinctly associated with actual events in space).

- Measurable indicators derived from *acoustics* are ranking from sound pressure (level), velocity, intensity, source, wave and propagation in the atmosphere and frequency (also infrasound) etc. and are significantly shaped by geographic, environmental and urban conditions, e.g climatology, architecture and so on.

- *Psychoacoustic* indicators expand the field of acoustic variables in acoustic geography by labeling loudness, pitch, sharpness, rhythm, annoyance, melodiousness, roughness and fluctuation to cover the human perception of sounds.

- Finally, acoustic geography incorporates parameters considered in the legal EU *noise* policy including frequency-selective noise levels in dB(A), differentiation and description of the sound sources, (sensitive) persons, institutions and areas concerned, high potential areas of conflict and places with noise peaks excessing a certain value; thus providing the opportunity to complement the directive with further considerable results and knowledge and to assure that noise is only one of numerous sound characteristics.

All these parameters are closely connected to each other, but were only handled unidimensionally in their respective branch of science yet. Acoustic geography brings together these different variables and establishes a stable relationship between them to create an integrated view on our sonic environment. However, acoustic geography emerged to be an independent and sustainable scientific concept and analysis tool. In order to make allowance for this awareness in relevant use cases, e.g. urban planning, architecture, tourism, culture and industry, it is absolutely necessary to create an appropriate and effective instrument to represent and communicate the spatiality of the aforementioned indicators and to document spatial references of urban sounds comprehensively.

In order to accentuate and display city acoustics spatially, cartographic methods as well as geovisualization and information visualization techniques are intended to be incorporated into the concept of urban sound cartography, underlying the overall idea of audio cartography. First leads in design an implementation as well as some prototypical visualization concepts will be presented and described in the following.

3. URBAN SOUND CARTOGRAPHY

The incompatibility of senses poses great challenge in illustrating acoustic phenomena and activities due to natural contrary perceptual patterns and handling of visual and acoustic information. Moreover, complex technical and scientific issues, e.g. loudness, frequencies or (dominant) soundmarks, have to be factored into visualizing and localizing sounds in space in an understandable manner. Traditionally, spatial information and processes are treated effectually within the discipline of cartography.

3.1 Previous Works

Unfortunately, the graphic visualization of sounds has been almost neglected here and not many attempts have been made so far. To name only a few previous works Southworth in designing event maps gives priority to the visualization of (strong or weak) visual and acoustic spatial identity. These maps outline areas of temporal continuity and areas of distracting/uninformative or responsive/reflecting sounds with simple black-and-white point, line and polygon graphic objects (Southworth 1969). In the 1990s the University of Nantes, France, worked on the qualitative exploration of the sonic environment and showed urban districts with predominant sounds on a city map. These districts are presented as ordinary monochromatic color coded polygons (Scharlach 2002). The National Institute of Applied Sciences (INSA) in Lyon, France, set up an information system for urban soundscape to provide decision-makers a handy tool to compare the city's noise levels with their public reception and to model the auditory effects of urban developments. Here, smileys are applied as a graphic semiology to describe soundscapes (Laurini and Servigne n.d.). In Melbourne, Australia, the Spatial Information Architecture Laboratory (SIAL) launched the project City Sounds and integrated sounds into a 3D city model to provide an audio-visual simulation of downtown in real terms (SIAL 2006). Above all, various noise maps produced by European communities or engineering offices in the course of the EU directive have to be mentioned here as well. The (historic) cartographic presentation of noise maps have been intensively analyzed by Glück and Scharlach which both on their part designed alternative noise maps, too (Glück 1973, Scharlach 2002). To summarize, there have been some cartographic ambitions to visualize our sonic environment sporadically. Unfortunately, every single approach caters only one certain spatial aspect of sounds and various possibilities of cartographic representations with all their variations have hardly been utilized. It has to be acknowledged that even studies in other disciplines, e.g. in graphic and information design, already brought out very promising conceptual designs (compare works by artist Nicolai and projects Digital Acoustic Cartography or Much Ado About Nothing by information and graphic designers). But neither scientific, spatial or acoustic accuracy is assured here, though.

3.2 Framework for Urban Sound Cartography

Previous efforts are obviously lacking an unambiguous (carto-) graphic style of communication and an intuitively graspable design. Either the acoustic parameters are not transferred into adequate cartographic variables or the map is not entirely expressing the complexity of the spatial acoustic structure.

But a suitable, stable and reliable *audio cartography* as an innovative cartographic approach has been elaborated recently (Kornfeld 2007, 2008). It is to be classified methodologically between the disciplines visual analytics, geovisualization, information visualization and cartography to highlight its explorative, geospatial, analytical and descriptive capacity. Audio cartography successfully undertakes the task of spatial processing, documentation and communication of any acoustic information and intends to prepare, create, compose and construct diverse sound maps types. *Urban sound cartography* is thereby to be specialized regionally in the cartographic visualization of urban soundscapes. Both audio cartography and urban sound cartography fulfill the following conditions:

- Acoustic geographic indicators have to be converted into suitable graphic variables where further variations can be applied, e.g. analog to Bertin's system of graphic variables (Bertin 1974).
- Abstract and technically complex information, e.g. frequencies, have to be conceived unproblematically without any previous or expert knowledge by each target group, e.g. public and experts.
- Urban sounds and their properties have to be spatialized precisely with graphic means (Figure 1).
- Spatial implication and coherence of sounds have to be discovered unmistakably and immediately.

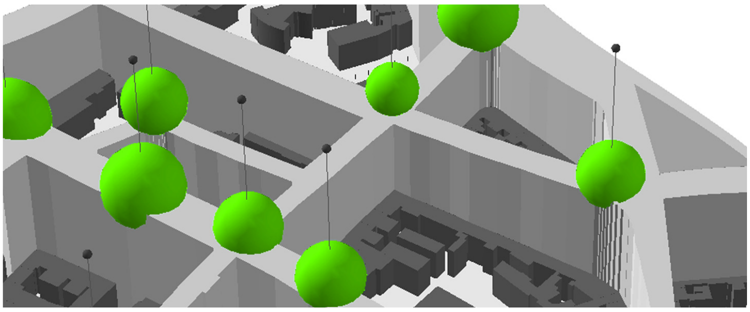

***Figure 1**:* With regards to the spatialization of urban sounds this 4D map animation marks precisely local maximum dB-values and their interpolation in an urban area (Kornfeld 2007).

3.3 Potential Implementations

It is recommended that before starting the design process spatial information has to be closely analyzed regarding its visual representability to explore the range of possible graphic and cartographic options. Thus, a previous cartographic information analysis prepares stylistic and methodical tools for a solid urban sound cartography and derives a style guide for an efficient sound map design. Methodically, visual descriptive notation systems, e.g. thematic cartography, as well as acoustic notation systems, e.g. auralization, are intended to be incorporated into this concept. In detail according to the current state of knowledge the following implementations are reasonable:

Visual descriptive notation systems include methods of traditional, digital and multimedia cartography and information design. The application of graphic utilities provides the opportunity to describe abstract information and data very clearly. Conventional cartographic techniques like classification, abstraction, generalization and symbolization serve here very well to communicate acoustic information spatially (Figure 2). Whereas digital and multimedia cartography expand accessibility and interactivity of maps specifically and adjust urban sound cartography to the current state-of-the-art. As regards content interactive layer-based maps also depict spatial acoustic complexity and dependencies.

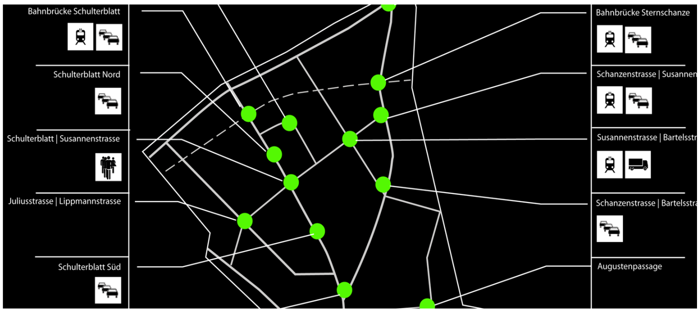

Figure 2: With regards to visual descriptive notation systems this print map uses meaningful pictograms to illustrate (dominant) soundmarks which suppress other sounds in their immediate vicinity (Kornfeld 2007).

Acoustic notation systems integrate abstract or characteristic audio sequences in interactive maps or 3D city models. Talking about auralization and acoustic visualization urban sound cartography bridges the gap between the aural and visual sense (Krygier 1994). Using aural perception to describe our environment helps to communicate spatial acoustic coherences and attracts attention of the map reader. For instance, acoustic visualizations of spatial developments in dynamic processes emphasize the chronological progress (ascending or descending tone) or give acoustic references (traffic noise levels compared to familiar loud sounds, e.g. a jackhammer).

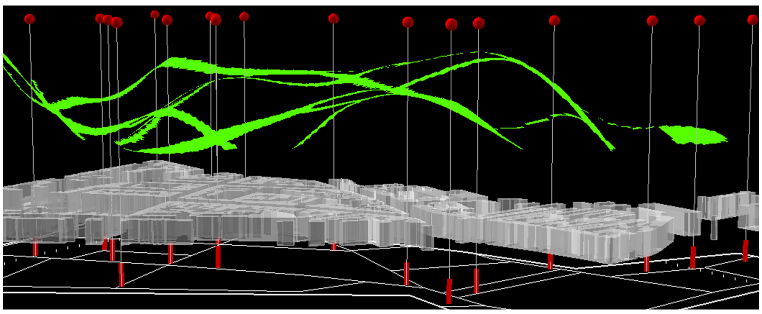

Figure 3*:* With regards to 3D/4D visualizations this 4D map animation shows the spatiotemporal propagation and intensity of diverse urban sound sources, e.g. sounds of traffic and sounds of human activity etc. (Kornfeld 2007).

Spatial patterns, chronological and periodical courses of actions and dynamical behavior and processes of acoustics can be communicated by *spatiotemporal animations*. Animated day and night rhythms and changes over time demonstrate their temporal progression. Furthermore, with means of animation modifications in the acoustic spatial profile within a predefined interval of time can be reflected visually.

3D/4D visualizations of sounds enable a completely different view on our sonic environment. Actual 3D sound propagation in the atmosphere and noise levels on façades can be presented as well as acoustic geographic issues can be integrated into contemporary 3D city models (Figure 3).

There are many more implementations possible in urban sound cartography and this selection depicts only few ideas. But they give a small insight into up-and-coming mapping instruments of an acoustic geography. In the meantime further prototype concepts and layouts are in progress (Kornfeld 2008).

4. CONCLUSIONS

Although acoustic exposure on city dwellers are ubiquitous in modern cities nowadays, urban sounds are highly neglected in spatial sciences and in graphic presentations of our built environment until now. It is remarkable that beyond technical measurements and public noise guidelines the interaction of acoustic parameters and our urban environment has been practically disregarded so far. This survey attaches importance to the *acoustic geography* of cities and analyzes the spatial reference of acoustics in urban phenomena. For this purpose it is necessary to create an appropriate instrument to document and communicate spatial references of urban sounds. *Urban sound cartography* as part of *audio cartography* is based on both subjectively interpreted acoustic phenomena and technically measured acoustic data. Furthermore, socioeconomic and geographic information are taken into account and are correlated with acoustic occurrences. Input data for the cartographic visualizations range from sound source differentiation, distance, dominance, distribution, etc. as well as population density and meteorological data. All these acoustic and non-acoustic variables shape our urban neighborhood directly or indirectly and are therefore to be considered as an essential part of our environment. Nevertheless, the incompatibility of senses challenges traditional cartography and geovisualization in representing our sonic environment in the cities.

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