Audio Cartography: Visual Encoding of Acoustic Parameters

Anna-Lena Kornfeld, Jochen Schiewe, and Jason Dykes

1 Background and Objectives

Human, cultural, and environmental sciences are concerned with the effects of sound in urban environments. They examine medical, social, and ecological problems of acoustic immission caused by increasing transportation, constructions, and industrial production in modern cities. For example, the World Health Organization (WHO) documents several direct exposure-response relationships between constant noise nuisance and severe medical or psychological damage, such as hearing impairment, sleeping disorder, high blood pressure, communication disablement, or the loss of environmental orientation [1]. In the political arena, the European Union (EU) released the directive 2002/49/EC relating to the assessment and management of environmental noise (END) to attend to the expanding urban noise exposure. Since its introduction in 2002, European agglomerations are legally obliged to conduct noise mappings of main sound sources every five years and to publish the results on noise maps [2].

In physics, improvements in computing and simulation algorithms enable the advanced geometric modeling of micro- and macro-scale sound propagation, such as in streets, squares, or larger urban areas [3]. Psychoacoustics analyzes the subjective perception of sound and emphasizes the influence of urban parameters on the human perception of sound, such as the contentment with the residential area, importance of the sound source or whether other environmental aspects are perceived negatively [4]. With an anthropogenic and sociological background, an international research network recently started working on soundscape analysis where linkages between environmental sound and society are explored [5]. Concurrently, a working group of the International Organization of Standardization (ISO) is developing international standards for the perceptual assessment of soundscape quality and discusses definitions, applications, and methods [6]. Also, planning disciplines developed a conspicuous awareness of auditory aspects of urban and architectural designs in recent years [7]. Some of these research results attracted public interest to the extent of triggering several national and international initiatives, such as local action groups or the *International Noise Awareness Day* [8].

Each of these domains deals with different facets of the sonic environment and whilst each focuses on spatial characteristics of sound they are developing individual means of its description and communication. These might be considered different languages for visually describing properties of sound. Their incompatibility means that, when it comes to an exchange of perspectives and ideas, interdisciplinary discourse is difficult. Appropriate tools or guidelines for supporting this activity do not exist.

The objective of this study is to provide fundamental building blocks for communication, documentation, and presentation based on auditory and visual perception to involve all stakeholders concerned with the sonic environment. This includes systematic visual encodings and mappings of acoustic parameters into distinct graphic variables as plausible solutions for the visualization of sound. Consequently, the codifications lead to the compilation of guidelines according to specific tasks. They are assembled into an extensible visual design guide as the basis for the exploration of audio cartography as a visual communication framework for the systematic and coherent description of the sonic environment.

2 The Visualization of Sound

The human process of external cognition uses graphical representations to describe and exchange mental concepts or images [9]. The creation of visual metaphors for data and information depicting structures and processes of the real world aims to reveal patterns, amplify cognition, and generate insights whereby insight enables discovery, decision-making, and explanation [10][11]. These principles specify the missing components in connecting the diversified knowledge of the sonic environment. The display of sound in varying urban contexts would enable the visual utilization of acoustic data and information and provide a solid common level of communication. Based on extensive research of multidisciplinary perspectives on the sonic environment and their visual communication techniques, the visualization of sound has to meet the following design challenges.

2.1 Envisioning Sound

Envisioning sound involves the fundamental problem of designing visual presentations of information that have no clear relation or association to familiar physical geometries [12]. Sound is an audible and invisible entity and human perception is not familiar with its visual interpretation. Depictions and symbolizations of acoustic data range from musical notations and synaesthetic images as subjective visual perceptions of music to aesthetic visual installations of acoustic input signals in the field of artistic visualization [13][14][15]. Although these concepts mainly relate to musical compositions, they can be assigned to the visualization of sound in large-scale environments. The universality and uniformity of music notations underline the requirement to develop a general and consistent visual encoding of acoustic information. Synaesthetic perception, even when it is rare, suggests the capability to transfer an auditory stimulus to a visual metaphor. Artistic transformations of sound highlight the possibility to visualize abstract data of the sonic environment in an appealing and aesthetic way.

2.2 Mapping Sound

Over millennia, maps have been powerful instruments to represent and communicate geographic spaces that are too large or too complex to be seen directly [16][17]. Existing communication techniques in science and practice indicate that mapping sound as the cartographic display of acoustic data on maps is an appropriate instrument for an integrative and interdisciplinary documentation of the sonic environment. For example, one of the main tasks of the END is the the publication of noise maps to communicate immediate problems of noise exposure to the general public [2]. The EU directive dictates the consistent utilization of colored contour lines to describe and map noise levels. Concepts developed in multimedia cartography add audio visual features to noise maps to facilitate their understanding [18]. Cartographic visualizations within soundscape research highlight strong/weak acoustic spatial identity or auditory effects of the sonic environment by using simple black-and-white points, lines, areas, or graphic semiologies [19][20]. Cutting-edge simulation approaches implement sound propagation based on punctual or spatially extended sound sources. This allows for the graphic representation of sound distribution in relation with other topographical objects, such as buildings or urban canyons [21]. Graphical intersections with other topographical objects are important to provide orientation in the setting, give insight into the spatial dimension, or reveal interactions of the acoustic parameters. Consequently, the visualization of sound demands an integrated map design that suits the perspicuous presentation of both acoustic and topographical objects.

3 APPROACH AND METHODS

The heterogeneity of domains dealing with characteristics of the sonic environment opens up a huge range of involved stakeholders, such as experts, scientists, planners, decision-makers, people concerned with noise, and the general public. Therefore, we need a cross-disciplinary communication framework that is suitable for multiple application according to specific questions or target audiences. This includes a medium- and application-independent concept to guarantee its general qualification and usage.

Furthermore, the design has to operate on a broad range of media formats, such as paper and computer-based, internet, and mobile devices.

Our approach is to develop a simple graphical language that connects the above mentioned knowledge levels. This consists of an appropriate set of fundamental graphical constructs that describes this highly complex topic. Within our methodology, we abstract and classify data and vocabularies utilized by potential target groups and derive discrete acoustic parameters to standardize the description of the sonic environment. Subsequently, we visually encode the parameters by systematically assigning graphic variables based on perceptual and cognitive principles. Hence, we obtain an exemplary set of encoding guidelines that is assembled into an application-independent, multifunctional, and extensible design guide. In the end, we apply our encoding and generate sample maps within two case scenarios.

4 ABSTRACTION

Abstractions help to derive generic descriptions of sound and to simplify the complex structure and dynamic behavior of it. We consider a cross-disciplinary selection of acoustic data and information that are either measured, computed, described, and throughout used in science and practice. They are based on formally structured requirements elicitation with domain experts, specifications by legislature, and field studies [22]. Each parameter describes a particular aspect of an acoustic situation, and although they rely on a specific background, the compilation and combination of them prepare for an integrated view on the relevance of environmental sound. The list is intended to be continued:

- *Geometric shape of sound:* The natural shape of sound is a wave traveling through air. Due to large scales, this is abstracted to a simple geometric shape of sound propagation.
- *Sound source:* The END defines and displays major sound sources primarily responsible for high noise levels [2]. Descriptions in soundscape research also relate to properties of particular sources [23]. Setting up further categories and sub-categories is reasonable but depends on the certain use case.
- *Dominant soundmarks:* Sound sources that silhouette against the audible environment and provide assistance in spatial orientation and identification are expressed as soundmarks. Dominant soundmarks completely mask other sounds [23].
- *Sound energy:* Research concerned with geometric outdoor sound propagation models emitted sound energy of a source. Sound energy serves as a useful linear measure to detect sound intensity which summates all immited sound energy at a particular location.
- *Sound pressure level:* Sound pressure level on a logarithmic scale in Decibel (dB) serves as a common noise indicator. For example, the END calculates A-weighted long-term average sound pressure levels [2].
- *Frequency spectrum:* A sound source emits various waves of different frequencies measured in Hertz (Hz). With frequency on a logarithmic scale the distribution of sound energy over frequency is defined as frequency spectrum.
- *Spatial reach:* Soundscape surveys often map the spatial reach or extent of an auditory perceived sound [23].
- *Noise limit values:* There are regional, national, and international noise limit values that are both recommendations and stipulations by law. For example, the WHO observes adverse health effects, such as sleep disturbance at noise levels above 40 dB in the night [1].
- *Rhythm:* Sound is a four-dimensional phenomenon and undergoes spatio-temporal changes. Soundscape research considers this characteristic by describing sound sources in terms of their rhythm [23].

5 Visual Encoding

With the technique of visual encoding, we systematically assign graphic variables to the previously defined acoustic parameters informed by cartography and information design. We employ plausible codifications according to established practice based on perceptual and cognitive principles [16][24][25][26]. The objective of the encoding is to provide a unique and discernible graphic counterpart for each parameter which matches its physical characteristics and variability. In the case of correct encoding, the graphic variables allow recognition, permit estimation, and exhibit association with the underlying phenomenon. It must be possible to utilize and read the graphic variable alone as well as in combination with other dependent variables. The aim is thus a systematic and modular usage of the variables for reoccurring visualization needs within various domains.

5.1 Geometric Shape of Sound

The encoding of the geometric shape of sound matches the type of its spatial dimensionality and employs basic graphic elements, i.e., points, lines, and areas (Fig. 1). We achieve further variations by applying the variable shape to the graphics [24][27]. Punctual presentations are useful to present locally discrete phenomena, e.g., when sound is modeled as particles. The usage of line segments is suitable, e.g., to delimit areal phenomena, such as contour lines of noise pollution or when sound is modeled as rays. Additionally, spatially extended sources, such as streets are assumed as line segments. Areal presentations indicate the geometric shape of sound as a spatial continuous phenomenon and are commonly used in noise mapping [16].

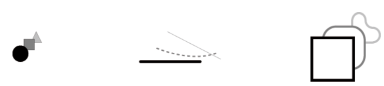

Fig. 1. Basic graphic elements point, line, and area and variations of their shape show the geometric shape of sound.

5.2 Sound Source

The parameter sound source is presented by the graphic variable color hue as it is useable for nominal parameters [24]. By this means, we match the perceptual variation in the referent with the perceptual variation in the phenomenon and allow for qualitative description or comparison of sound sources. With a two-level hierarchy of sound sources we require both an encoding of source categories with equidistant color hues and an encoding of source subcategories with color hues that cluster around the associated category's color hue. We use the CIELuv color model where distances between colors are proportional to perceptual discrimination [28][29]. Additionally, all color hues consist of 100 % saturation to allow a further encoding of this variable. Based on a qualitative analysis of audio recordings, we came up with an exemplary categorization of sound sources (Fig. 2). We transfer auditory stimuli into visual metaphors by associating a source with a color hue and display traffic with blue, economy with yellow, human activity with red, and nature with green.

Fig. 2. Color hues envision (sub-) categories of sound sources.

Blue symbolizes exhaust gases of vehicles that usually come along with the emission of sound. The color yellow indicates artificial or chemical production and serves as a visual equivalent for sources connected to economy. Red associates people and matches sound caused by human activities. In general, green is a symbol for nature and adequately presents environmental sound sources.

5.3 Dominant Soundmark

We present nominal point symbols as possible candidate encodings for the visualization of dominant soundmarks that can be pictorial, associative, or geometric [30]. We provide a set of associative point symbols for dominant soundmarks as they are nominally described discrete phenomena (Fig. 3). The auditory perception of dominant soundmarks and the interpretation of their corresponding symbols are highly subjective and context-sensitive so that our candidate solutions serve as sketches.

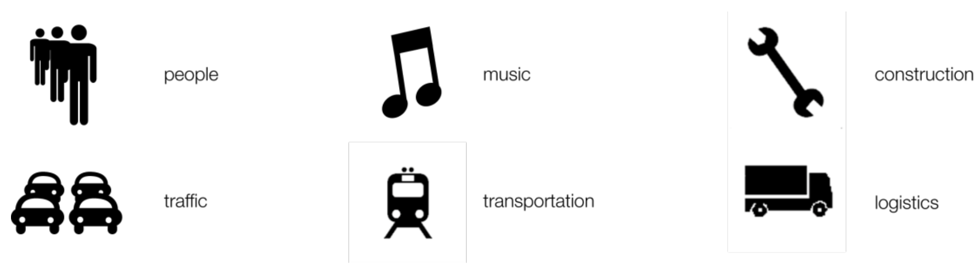

Fig. 3. Associative nominal point symbols present dominant soundmarks.

5.4 Sound Energy

We apply the graphic variable saturation to present linear sound energy [31]. This is achieved by connecting the variable with color hue to simultaneously present sound energy and the corresponding source (Fig. 4). Our visual encoding considers attenuation of emitted sound energy due to absorption and varies the saturation of the color. Perceptual variation in color hue and saturation is non-linear, but using the perceptual CIELuv color model we are able to vary saturation in a perceptually-linear manner [29].

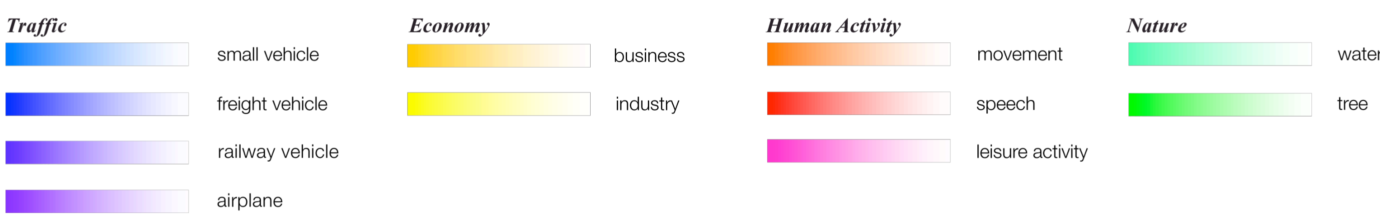

Fig. 4. Color hues are perceptually-linear varied in saturation to present sound energy.

5.5 Sound Pressure Level

Although END noise mapping is standardized the color schemes used for the presentation of sound pressure level differ extremely and particularly lack in an appealing and aesthetic design [32]. Frequently, public authorities apply contrasting or unintuitive colors recommended by ISO standards that contradict established cartographic practice [33]. We suggest an encoding that adopts functional requirements but results in an effective sequential color scheme (Fig. 5). We insert perceptual steps of saturation in contrast to the perceptually-linear codification of saturation to envision sound energy to match the logarithmic nature of sound pressure level. The candidate color schemes are approved and validated by user or usability studies [34]. A sequential color scheme indicates order and qualifies for the presentation of numerical or ordinal parameters. As sound pressure level is a logarithmized and normalized derivation from sound intensity the visual encodings differ concerning their variation of color saturation. We employ sequential schemes consisting of single hues to assure the compatibility with the visual encoding of sound sources.

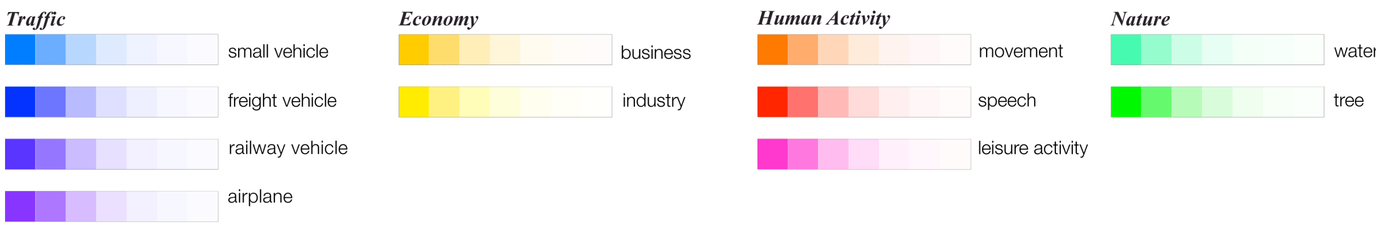

Fig. 5. Sequential color schemes based on single color hues visualize sound pressure levels by integrating perceptual steps of saturation.

5.6 Frequency Spectrum

We encode the parameter frequency spectrum with the graphic variable texture. Textures can be conjoined with other graphic variables much in the way that acoustic parameters are described according to their energy spectrum. Our candidate encoding covers an irregular point texture, and we vary the density of the texture as the ratio of texture units to the background according to the spectrum width (Fig. 6). Thus, a narrow frequency spectrum generates a low ratio of texture units whereas a broad spectrum produces a high ratio of texture units [35].

Fig. 6. Irregular point textures display width of frequency spectrum.

5.7 Spatial Reach

Spatial reach implies the auditory perception of a sound and is usually specified by geographic coordinates. As the parameter relies on subjective perception we consider uncertainties in the underlying information and need a modifiable visualization concerning its clarity. Therefore, we encode spatial reach with the variables size and crispness [24][36]. A possible realization adopts color hue from a specific sound source to qualitatively determine the source and to geographically describe its spatial reach or extent (Fig. 7). The color hue is varied in crispness to selectively filter edges or fills of an object.

Fig. 7. Variations of size and crispness mark the spatial reach of an auditory perceived sound.

5.8 Noise Limit Value

The parameter noise limit value requires a conspicuous encoding to underline the relevance of the underlying information. Blur immediately directs visual attention to relevant areas [37]. Thus, we consider blur as a possible encoding technique to generate sharp areas exceeding critical noise levels while blurring the irrelevant areas. As blurring relies on context to create focus the visualization requires the embedding of the parameter into a spatial setting and the intersection with other topographical objects (Fig. 8).

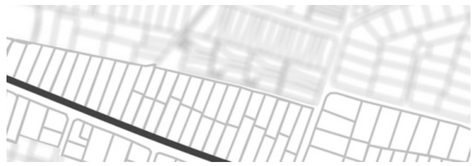

Fig. 8. Sharp display of areas exceeding critical noise limits while unconcerned areas are blurred.

5.9 Rhythm

Concerning the visual encoding of spatio-temporal rhythm, we compose a geometric point symbol as the parameter refers to spatially discrete sound sources. We implement this encoding by accommodating the codification of sound source and sound energy. In our candidate solution we draft an abstracted clock to provide a familiar graphic basis for the geometric symbol and divide its surface into adequate or requested time units, such as one hour or one day. Then, we chart temporal variations of energy on the clock by saturating the source's hue according to the emitted energy at a specific time (Fig. 9). This encoding allows for the static visualization of spatio-temporal rhythm of stationary sound sources and enables their presentation on large-scale maps as point symbols with showing other topographical objects simultaneously.

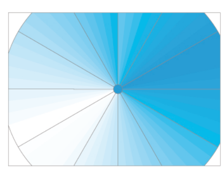

Fig. 9. Geometric point symbols reveal temporal variations of sound energy by employing clock metaphors.

According to our encodings, we build a high-level design guide for the spatial visualization of sound (Fig. 10). Due to different cultural and social contexts, this implementation approves design related modifications of the variables. In particular, the choice of color has to be balanced according to specific framework requirements, such as cultural sensation of aesthetics, potential color blindness, or education and socialization background of target users. Therefore, alternative arrangements are practicable when they stick to the systematic encoding of the parameters.

6 Mapping Examples

Conform to our encoding guidelines we map acoustic parameters and generate two examples of possible large-scale visualization of sound.

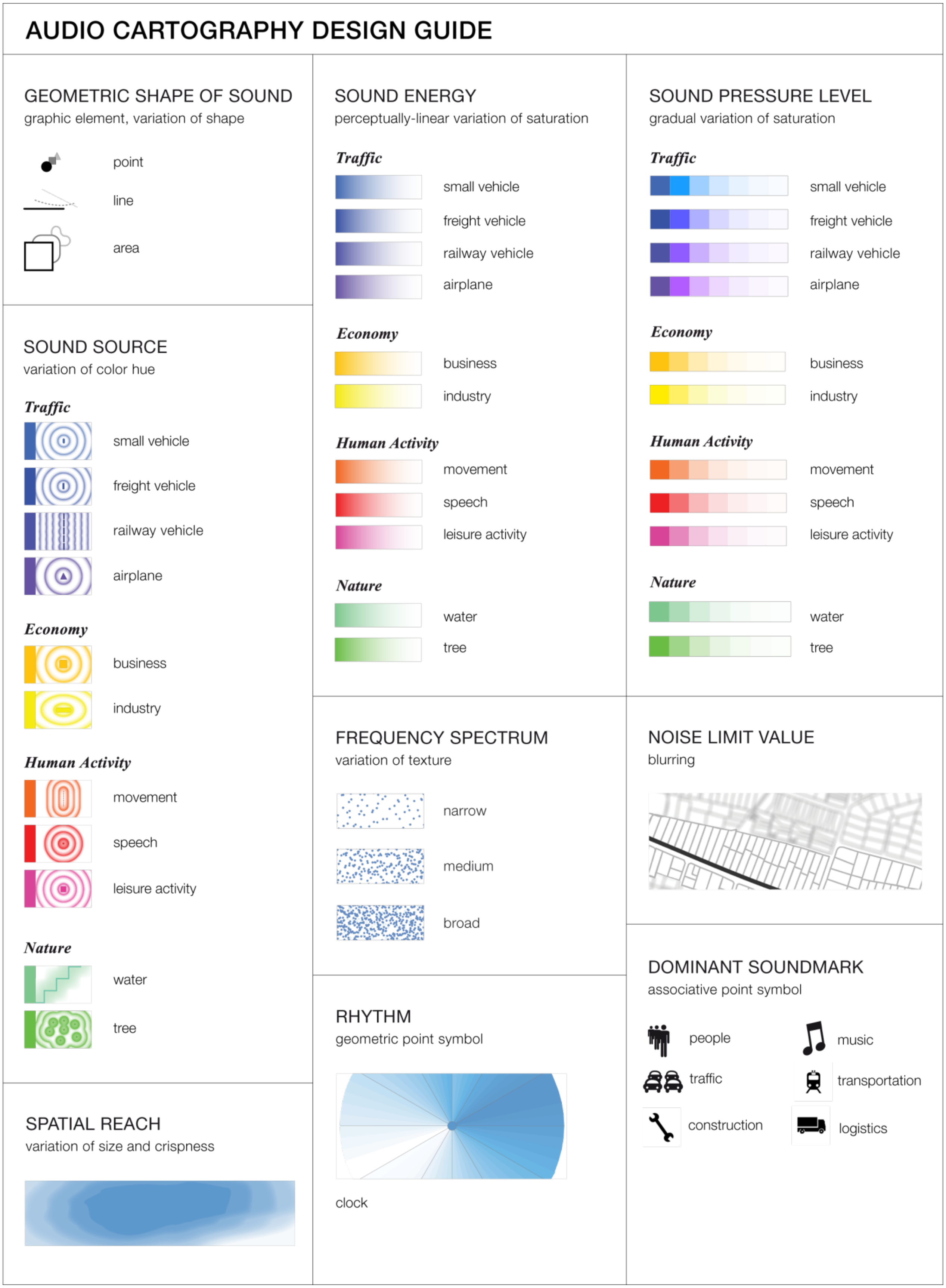

Fig. 10. Design guide for audio cartography contains relevant visual encodings of acoustic parameters.

6.1 Noise Mapping

The map shown in Fig. 11 relies on measured and calculated noise mapping data from the END and presents A-weighted sound pressure levels during the day in an investigation area in Hamburg, Germany. Accessing previous abstractions, we derive geometric shape of sound, sound source, and logarithmic sound pressure level as significant acoustic parameters. Our encoding guideline determines the usage of basic graphic elements varied in shape, color hue, and sequential color schemes to envision them. In this case an areal presentation of sound corresponds with an areal calculation of the sound distribution. The END dictates the separate calculation and presentation of each major source so our map demonstrates traffic emissions with blue as the according category's color hue. As computations merge traffic noise the exhibition of subcategories is not needed. Public authorities are obliged to cover sound pressure levels from 55 dB(A) to >75 dB(A) during the day and levels from 50 dB(A) to >70 dB(A) during the night. The latter is extendable with the value band 45 dB(A) to 49 dB(A). To accommodate both day and night sound pressure levels, we create a sequential color scheme consisting of seven classes. The colors feature perceptual steps of saturation and match the logarithmic nature of sound pressure levels. This map tackles the problem of contrasting colors on regular noise maps by applying effective and attractive color schemes approved by established color or map design techniques. Furthermore, the color-coding of sound sources prepares for the simultaneous presentation of multiple sound sources which is barely explored within noise mapping (Fig. 11 gives an idea of an exemplary implementation).

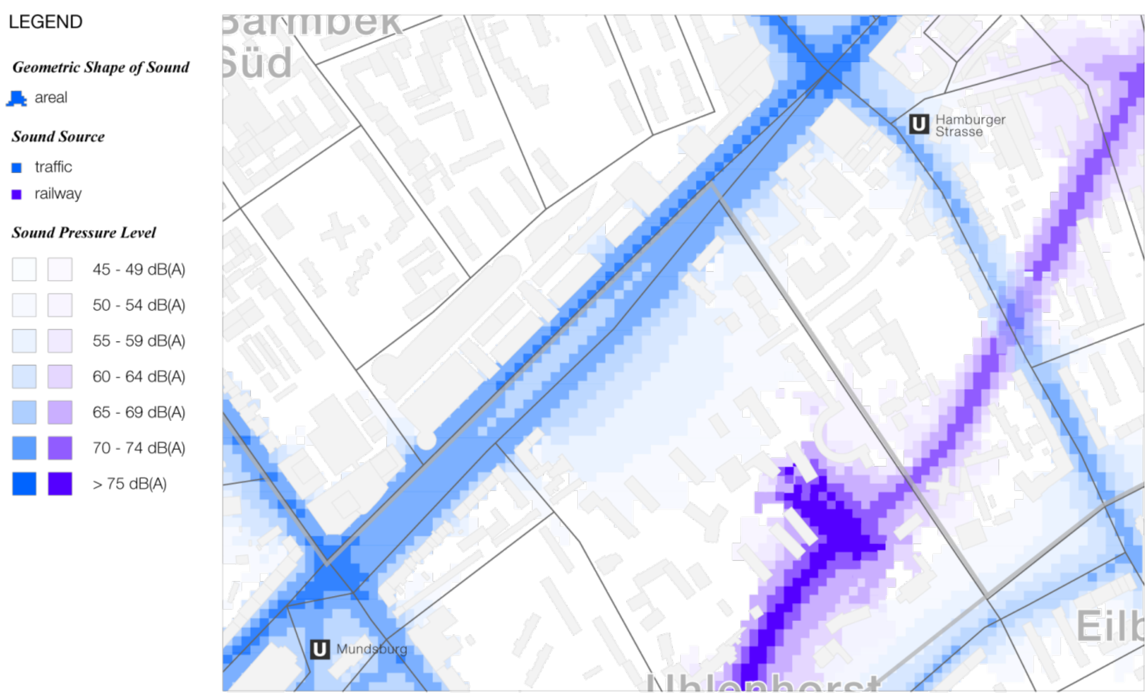

Fig. 11. Map features sound pressure levels of sound sources analog to encoding guideline.

6.2 Simulation of Sound Propagation

The map presented in Fig. 12 traces back to an ongoing research project dedicated to the simulation of sound propagation in cities. The algorithm is based on ray tracing methods and models the emission of independent sound sources within a small section of the above mentioned research area. This application focuses on a high-level simulation of the spatial distribution of rays and presets default emission input values, such as number of rays, and position or power of the sound source. The visualization of accurate data is not required in this context. We derive geometric shape of sound, sound source, and linear sound energy as relevant acoustic parameters. Consulting the guideline, we consider basic graphic elements varied in shape, color hue, and saturation to visualize them. We utilize line segments to describe the distribution of sound. We vary line segments and use dashed lines instead to illustrate the scattering at building façades. As this application implements sound source placeholders we apply the color hue of traffic emitters to map the sources analog to our previous example. We consider a perceptually-linear variation of saturation that emanates from absolute values, i.e., a range from 100 % to 0 % saturation. It is possible to adjust the variation range when concrete input and output data are valuable. Additional determining factors are accessible concerning the absorption and roughness properties of the building façades responsible for reflection, absorption, and scattering of sound. We visually integrate this information by changing the contours of the buildings. We decrease transparencies of the color-coded rays to match the resulting energy value of the reflected sound due to absorption. Transparency allows for graphical superpositioning of emitted sound energies to detect sound intensities at specific receiver locations. Beyond that, the change of opacity of the color hue meets the absorption coefficient of the reflecting material.

Together, we yield exemplary cartographic presentations of sound describing aspects of the sonic environment. They cover common applications and utilizations in practice or science and rely on concrete data or algorithms. Further hypothetical examples of visualization are conceivable, such as spatial reach or soundmarks within soundscape research or the depiction of noise limit values in combination with demographic and socio-economic data relevant in urban and architectural planning. Not least, they constitute mapping examples of an applied audio cartography.

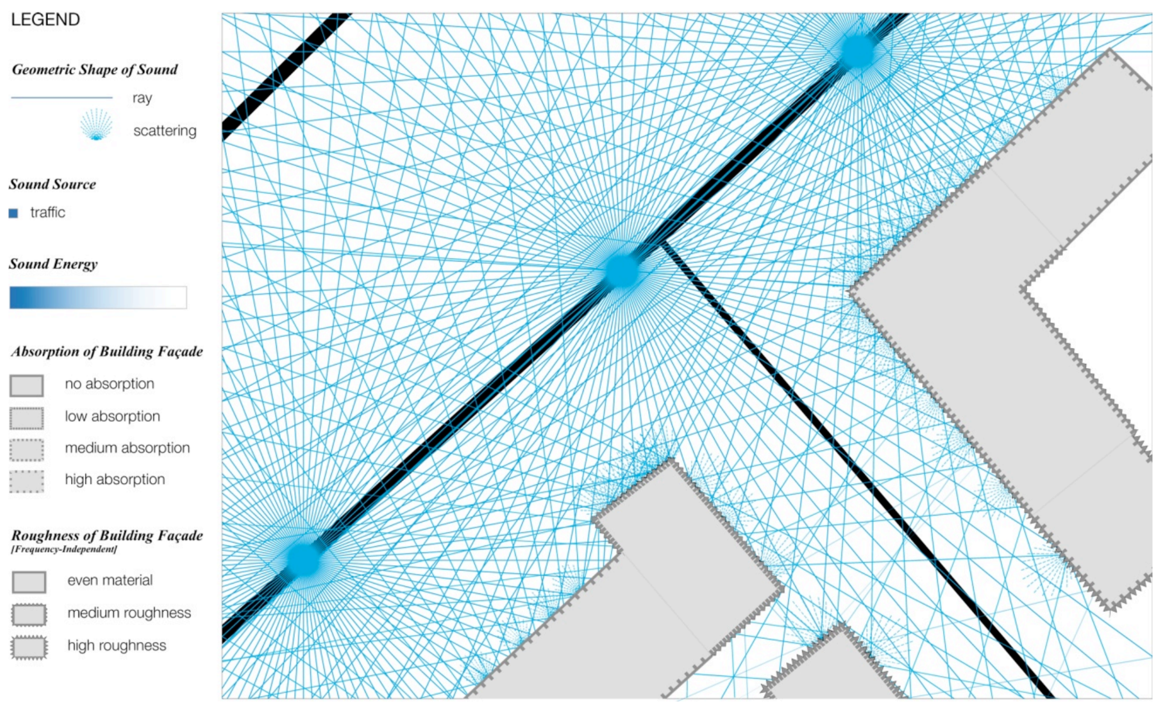

Fig. 12. Map depicts distribution of rays and varies color hue according to their sound energy.

7 Conclusion

This contribution addressed the shortage of appropriate tools supporting an interdisciplinary discourse about the sonic environment by providing a visual communication framework for its systematic description. We created fundamental building blocks for the spatial visualization of sound and offer guidelines for an audio cartography.

The guidelines address essential design challenges as they provide the means to envision and map sound in large-scale environments. We were able to transfer auditory stimuli systematically to visual metaphors by accomplishing a general and consistent visual encoding of acoustic parameters. The codification came up with plausible design solutions for the visualization of sound that can be flexibly arranged according to specific tasks. A multifunctional and –disciplinary usage of the design is expected by facilitating a systematic and modular usage while fostering the continuation or modification of the expandable guidelines. In subsequent work, we applied our encodings in practice and mapped them onto large-scale cartographic presentations in the context of EU noise mapping and sound propagation modeling. We showed that our suggestions support an integrated map design and graphical intersection with other topographical objects. The resulting maps highlight audio cartography as a beneficial visual communication framework to connect knowledge about the sonic environment.

We aspire an automation of our guidelines based on certain use cases to advise concrete visualizations according to a certain aspect of sound that is being mapped for a particular reason. This approach assembles the compilation of design patterns and patterns library which would immensely enrich the functionality and utilizability of audio cartography. It would be of great value to get empirical feedback via crowdsourcing as a possible means of information evaluation and validation.

Acknowledgments

The noise mapping data are provided by Lärmkontor GmbH, Hamburg. The authors wish to thank REAP Research Group at HafenCity University for the useful simulation algorithms and valuable feedback.

References

[1] C. Hurtley, “Night Noise Guidelines for Europe,” World Health Organization, Copenhagen, 2009.

[2] European Parliament and Council of the European Union, “Directive 2002/49/EC of 25 June 2002 relating to the assessment and management of environmental noise,” 2002.

[3] J. Kang, *Urban Sound Environment.* Oxford: Taylor & Francis, 2007.

[4] P. Lercher, “Medizinisch-hygienische Grundlagen d. Lärmbeurteilung,” *Taschenbuch der Angewandten Psychoakustik,* M. T. Kalivoda and J. W. Steiner, eds., Wien: Springer Verlag, pp. 42-102, 1998.

[5] soundscape-cost.org, “About Soundscape of European Cities and Landscapes,” http://www.soundscape-cost.org. 2010.

[6] International Organization of Standardization, “Technical Committees,” http://www.iso.org/iso/iso_technical_committee?commid=48474. 2010.

[7] A. Arteaga and T. Kusitzky, “Klangumwelten – Auditive Architektur als Artistic Research,” *Sound Studies: Traditionen - Methoden - Desiderate,* H. Schulze, ed., : Bielefeld: Transcript, pp. 247-265, 2008.

[8] Deutsche Gesellschaft für Akustik e.V., “Tag gegen Lärm,” http://www.tag-gegen-laerm.de. n.d.

[9] R. Scaife and Y. Rogers, “External Cognition: How Do Graphical Representations Work?,” *J. International Journal of Human-Computer Studies,* vol. 45, no. 2, pp. 185-213, 1996.

[10] S. K. Card, J. D. Mackinlay, and B. Shneiderman, *Readings in Information Visualization: Using Vision to Think.* San Francisco: Morgan Kaufmann, 1999.

[11]C. Ware, Information Visualization: Perception of Design. San Francisco: Morgan Kaufmann, 2004.
[12]M. Bugajska, “Spatial Visualization of Abstract Information – A Classification Model for Visual Spatial Design Guidelines in the Digital Domain,” PhD dissertation, Swiss Federal Institute of Technology Zurich, 2003.
[13]M. Woolman, *Sonic Graphics: Seeing Sound.* London: Thames & Hudson Ltd., 2000.
[14]S. Baron-Cohen and J. E. Harrison, *Synaesthesia – Classic and Contemporary Readings.* Oxford: Blackwell Publishers, 1997.
[15]C. Nicolai, C. Doswald, K. Ottmann, and B. Schröder, *Static Fades.* Zurich: JRP, 2008.
[16]A. M. MacEachren, How Maps Work: Representation, Visualization, and Design. New York: Guilford Press, 1995.
[17]M. Dodge, M. McDerby, and M. Turner, “The Power of Geographical Visualizations,” *Geographic Visualization: Concepts, Tools, and Applications,* M. Dodge, ed., Hoboken: Wiley, pp. 1-11, 2008.
[18]H. Scharlach, “Lärmkarten – Kartographische Grundlagen und audiovisuelle Realisierung,” PhD dissertation, Ruhr University Bochum, 2002.
[19]M. Southworth, "The Sonic Environment of Cities," *J. Environment and Behavior*, vol. 1, pp. 49-70, 1969.
[20]S. Servigné, R. Laurini, and M. A. Kang, “A Prototype of a System for Urban Soundscape,” *Proc. 21st Urban Data Symposium*, 1999.
[21]F. Michel, “Simulation and Visualization of In- and Outdoor Sounds,” PhD dissertation, Fachbereich Informatik der Technischen Universität Kaiserslautern, 2008.
[22]A.-L. Kornfeld, “Die kartographische Visualisierung des akustischen Raums”, *J. Kartographische Nachrichten*, vol. 6, pp. 294-301, 2008.
[23]R. M. Schafer, The Soundscape – Our Sonic Environment and the Tuning of the World. Rochester: Destiny Books, 1977.
[24]J. Bertin, Graphische Semiologie. Diagramme, Netze, Karten. Berlin: Walter de Gruyter, 1974.
[25]W. S. Cleveland and R. McGill, “Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods,“ *J. Journal of the American Statistical Association*, vol. 79, no. 387, pp. 531-554, Sep. 1984.
[26]J. Mackinlay, “Automating the Design of Graphical Presentations of Relational Information,” *J. ACM Transactions on Graphics*, vol. 5, no. 2, pp. 110-141, Apr. 1986.
[27]J. K. Wright, “The Terminology of Certain Map Symbols,” *J. Geographical Review*, vol. 34, pp. 653-654, 1944.
[28]J. Wood, A. Slingsby, and J. Dykes, “Layout and Colour Transformations for Visualising OAC Data,” *Proc. GIS Research UK*, 2010.
[29]M. Wijffelaars, R. Vliegen, and J. van Wijk, “Generating Color Palettes using Intuitive Parameters,” *J. Computer Graphics Forum*, vol. 27, no. 3, pp. 743-750, 2008.
[30]A. H. Robinson, R. D. Sale, J. L. Morrison, and P. C. Muehrcke, *Elements of Cartography.* New York: Wiley, 1984.
[31]J. L. Morrison, “A Theoretical Framework for Cartographic Generalization with the Emphasis on the Process of Symbolization,” *International Yearbook of Cartography*, vol. 14, pp. 115-127, 1974.
[32]Working Group on the Assessment of Exposure to Noise, “Presenting Noise Mapping Information to the Public,” European Environment Agency, Copenhagen, 2008.
[33]C. A. Brewer, "Colour Use Guidelines for Mapping and Visualisation," *Visualization in Modern Cartography,* A. M. MacEachren and D. R. F. Taylor, eds., Oxford: Pergamon Press, pp. 123-147, 1994

[34]M. A. Harrower and C. A. Brewer, “ColorBrewer.org: An Online Tool for Selecting Color Schemes for Maps,” *J. The Cartographic Journal*, vol. 40, no. 1, pp. 27-37, 2003.
[35]J. L. Caivano, “Visual Texture as a Semiotic System,” *J. Semiotica*, vol. 80, no. 3/4, pp. 239-252, 1990.
[36]A. M. MacEachren, “Visualizing Uncertain Information,” *J. Cartographic Perspectives*, vol. 13, pp. 10-19, 1992.
[37]R. Kosara, “Semantic Depth of Field – Using Blur for Focus+Context Visualization,” PhD dissertation, Vienna University of Technology, 2001.