Chapter 2
Cartographic Representation of Soundscape: Proposals and Assessment

Saúl Gomez, Catherine Dominguès, Pierre Aumond, Catherine Lavandier, Gaëtan Palka, and Kamal Serrhini

Abstract Environmental noise is a major concern for city dwellers, however, actual noise maps are not adapted to them. The work described here is developed in the context of the CartASUR project which specifically addresses these deficiencies of noise maps. CartASUR collected perceptual data in several places of Paris using a survey and aiming to define new urban soundscape indicators to offer the possibility of several interpretations depending on the users' personal and cultural characteristics, and to show them on maps. In this chapter, the indicators *sound pleasantness* and *global loudness* are presented. Several cartographic proposals are made to portray indicators during one, two, or three periods (day, evening, night) on maps, and their characteristic features (symbol design, visual variables) are discussed. Cartographic proposals are assessed through a survey which addresses the understanding of cartographic symbols and global properties of maps. The survey concludes that map readers prefer to view complete (both sound pleasantness and global loudness) and precise (three measurement periods) information, even when the amount of information leads to complex maps, which are considered the most attractive and useful. Nevertheless, the survey shows that these complex maps are not well interpreted by a large part of map readers. Use of visual variables *color* and *quantity* is discussed and proposals are made to improve symbol understanding.

Keywords Soundscape • Sound pleasantness • Perceptive map • Semiology of graphics • Survey

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2.1 Introduction

Environmental noise is a major concern for city dwellers. A survey conducted in (2014) by IFOP, the French Institute of Public Opinion, found that 32–40% of the French population were rather troubled by noise. Such disturbance has a real negative impact on health. For example, Basner et al. (2013) described the effects of noise exposure on the sequence and duration of various stages of sleep. According to the World Health Organization (WHO 2011), environmental noise should not only be considered as a nuisance, but also as a public health problem because of "the relationship between environmental noise and specific health effects, including cardiovascular disease, cognitive impairment, sleep disturbance, and tinnitus".

In 2002, the European Parliament and the Council of the European Union adopted a directive (2002/49/EC) relating to the assessment and management of environmental noise. Consequently, cities are required to manage direct action on noise reduction (speed control, noise barriers, etc.) and to disseminate strategic noise maps. However, despite the positive aspects that current noise maps offered in several realms (mainly in physical aspects of sound as shown by Miedema and Oudshoorn (2001)), these noise maps have deficiencies regarding aspects of understanding and interpretation of noise (Schiewe and Weninger 2013). Usually, noise map data come from measurements directly taken from the city or from traffic noise and the calculations are made using mathematical models. The resulting maps are purely based on physical indicators. Particularly, noise is measured in decibels which follow a logarithmic scale that is difficult for most users to understand. Furthermore, the addition of noises depends on the volume of each individual noise and on the difference between them. Noise additions are shown in Fig. 2.1.

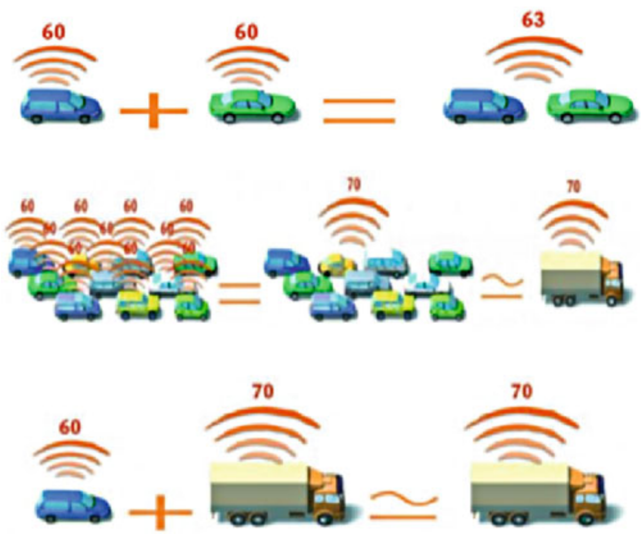

Fig. 2.1 Example of logarithmic addition of noise (Taken from Bruitparif, www.bruitparif.fr)

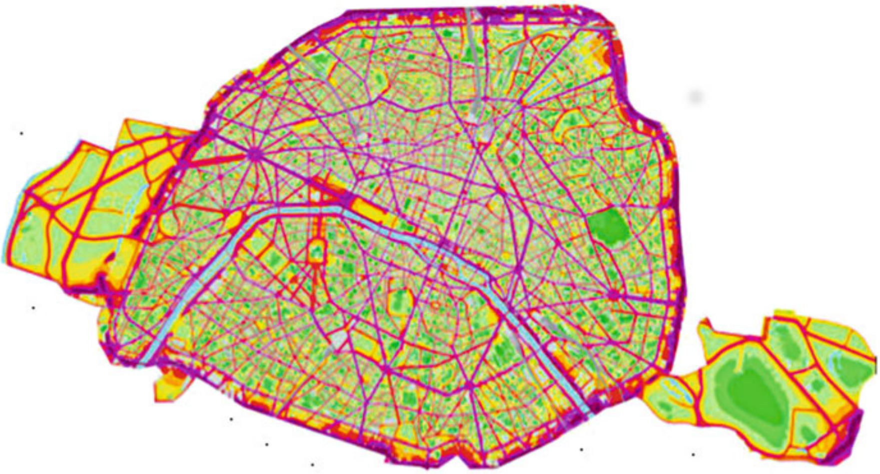

Fig. 2.2 Traffic noise map (L_{DEN} indicator) of Paris in 2007 (http://api-site-cdn.paris.fr/images/154512.pdf, pg. 24)

For example, if one car produces 60 decibels, two cars would produce 63 decibels. Or, if a 60-decibel car is behind a 70-decibel truck, since the noise difference is ten decibels or more, the higher noise conceals the weaker and the resulting loudness would be 70 decibels, as if there is just one truck. These examples seem to refute city dwellers' daily experience of sound (Schiewe and Weninger 2013).

Figure 2.2, the noise map of Paris in 2007, shows an example of an indicator recommended by the European Directive. It is the L_{DEN} indicator (a weighted average level for day, evening, and night sounds) which is also based on a logarithmic scale and which represents a weighted average sound level calculated over 24 h. It contradicts the natural human and physiological interpretations of sound and noise annoyance, because it is one single figure which is not able to describe the overall quality or nature of each sound that is heard by city dwellers at each location on the map (Haberle et al. 1984). Instead, over the last decade, soundscape researchers put forward soundscape descriptors that are closer to the perception of users (see (Aletta et al. 2016) for a review)). Guski et al. (1999) studied the personal and social aspects of the description of noise annoyance and showed that the same sound is interpreted differently depending on personal and social connotations. Morel (2012, pg. 3) concluded that "*it is necessary to improve the noise maps by the definition of complementary relevant indicators from the point of view of the individual to characterize the perceived noise annoyance*".

The CartASUR project (Cartographic representation of urban sound quality) specifically addresses these deficiencies of noise maps. This project, involving several universities, research laboratories, and public organizations, focuses on urban dwellers' feelings. It aims to define new urban soundscape indicators to offer the possibility of several interpretations depending on the users' personal and cultural characteristics, and to show them on maps. Section 2.2 explains the definition of these perceptual indicators by the CartASUR project. Section 2.3 introduces the cartographical proposals made to show indicators on maps. These maps have been assessed by a survey detailed in Sect. 2.4. Section 2.5 displays the results of the survey and comments on them. Conclusions and perspectives are laid out in Sect. 2.6.

2.2 Definition of Soundscape Indicators in the CartAsur Project

Guastavino (2007) showed that sound and noise are two different cognitive objects. Sound is an isolated phenomenon, independent of the source, which can be described in terms of physical properties. By contrast, noise is a sensitive phenomenon, inseparable from the source and interpreted according to the environment in which it is heard. In seeking a common approach to explaining soundscape (Aletta et al. 2016), soundscape researchers defined it as the "*acoustic environment as perceived or experienced and/or understood by a person or people in context*" (ISO 2014). Lavandier et al. (2013) proposed indicators of sound quality which depend not only on perceived loudness, but also on the presence of sound sources, such as traffic, birds, or voices (Guastavino 2007). Ricciardi et al. (2015) developed a survey in Paris regarding the global sound environment characterization, the perceived loudness of some emergent sources, and the perceived presence (in duration) of identified source that do not emerge from the background. Thus, they proposed indicators of urban sound quality based on linear regressions with perceptive variables. The authors showed that soundscape assessment depends on different perceptual data, such as sound pleasantness, global loudness, presence of birds, voices, etc. Based on these studies, CartASUR aimed to show that subjective indicators could complement a physical description of sound, and assist in creating their cartographic representations. In this study, the sound quality addresses the overall perception of the acoustic environment, measuring whether a soundscape is pleasant or unpleasant.

CartASUR aimed to define the soundscape in several places of Paris using a survey. Data were collected by city dwellers to record various perceptual and acoustic data in 29 locations across two districts of Paris (see Fig. 2.3). The locations had been selected to represent the diversity of places in Paris (Ricciardi et al. 2015) such as thoroughfares, crossroads, small streets, schools, parks, gardens, etc. Different periods had been also chosen in order to respect the rhythm of the sound environment in a city (Brocolini et al. 2013). In each survey location, participants were asked to answer a questionnaire about the various sound sources making up the landscape and contributing to their soundscape appraisal. There were 18 items on the questionnaire, such as sound pleasantness, global loudness, presence of trucks or buses, cars, voices, footsteps, birds, water, and wind. This perceptual data was rated on a scale of 1 (*weak*) to 11 (*strong*). Finally, the locations were perceptively

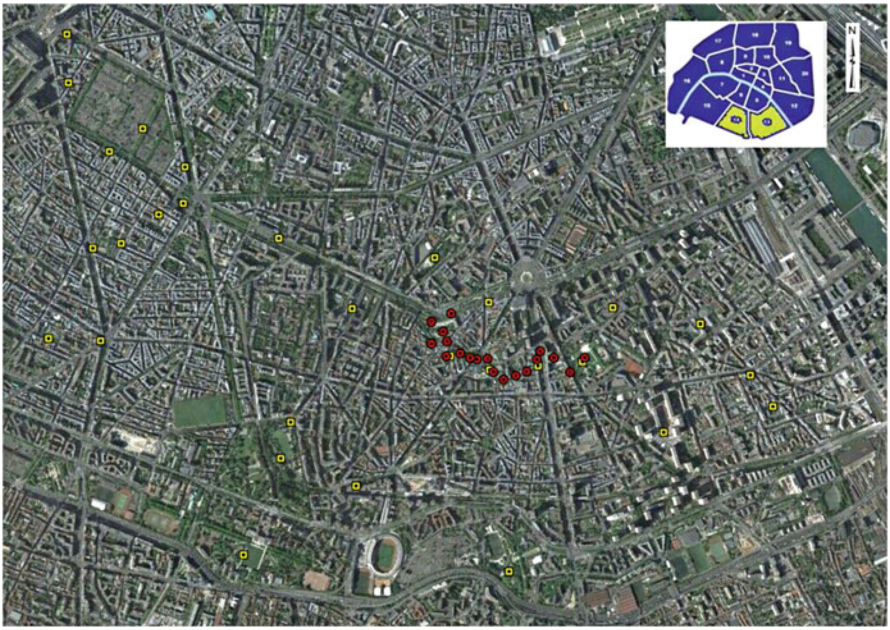

Fig. 2.3 Survey locations in the 13th and 14th districts of Paris. Fixed survey locations are portrayed by *yellow dots*; *red dots* show survey locations along an urban walking trip, during a field experiment (Aumond et al. 2016)

assessed between twice and five times a day, in summer and in winter. In total, 204 situations have been perceptively evaluated by at least 15 persons, being 3409 perceptive measurements.

The CartASUR approach is described in Fig. 2.4. Perceptual survey data (step 1 in Fig. 2.4) made it possible to understand how each noise source (cars, voices, birds, etc.) influences the overall opinion of sound pleasantness (Delaître et al. 2014). One of the purposes was to define formulas based on the survey to predict indicators across the entire city. A global sound quality indicator, modelled from the 3409 perceptive measurements was thus proposed on a scale from 1 (*unpleasant*) to 11 (*pleasant*) with a linear regression model, according to Lavandier et al. (2015):

$$Pleasantness = 8.11 - 0.38 * (Overall\ Loudness) + 0.20 * V + 0.15 * B - 0.14 * T, \quad (2.1)$$

where V is perceived presence of voices, B perceived presence of birds, and T perceived presence of traffic.

This model explains 34% of the individual variance of participant answers in this experimentation (correlation of 0.58 between the 3409 individual real sound pleasantness and the pleasantness predicted by the model). This correlation reaches a value of 0.89 if the average values of the sound pleasantness for each of the 204

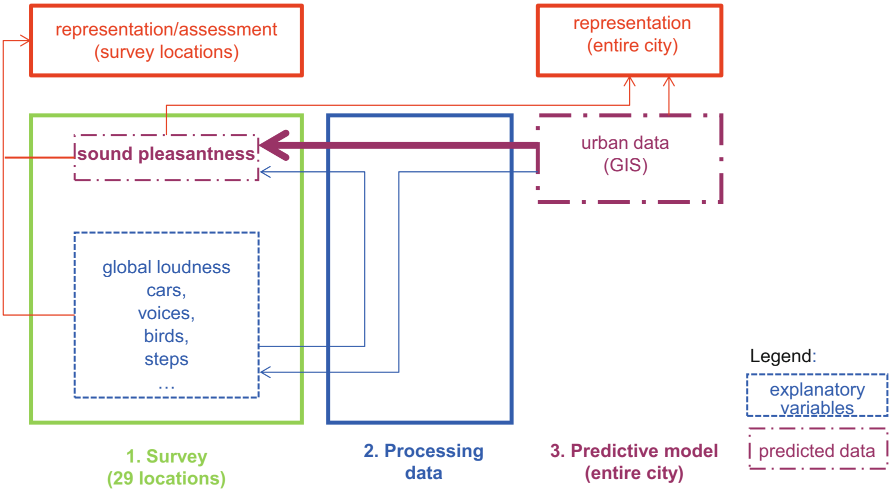

Fig. 2.4 CartASUR diagram

urban assessed situations are compared with the proposed model values, which are constructed from the averages of the independent perceptive variables (step 2 in Fig. 2.4). On the other hand, these variables can also be linked to urban data, which are contained in geographic and urban databases (step 3 in Fig. 2.4), which are part of the geographical information systems (GIS) of the city. It therefore becomes possible to predict perceptual data such as sound pleasantness, from the city GIS data (purple arrow in Fig. 2.4). This chapter presents several proposals for the representation of perceptual data collected in survey locations, including their assessment.

2.3 Soundscape Representation

The analysis of perceptual and acoustic survey data showed that sound pleasantness depends on the surrounding context. Consequently, one purpose of a representation is to provide map readers with the possibility of understanding and imagining the sound environment context (global loudness, presence of traffic, voices, and birds) and to interpret it according to personal criteria. Indeed, sound pleasantness and global loudness in a city are generally correlated, but not always. City dwellers have experimented with this situation. It may therefore be difficult for them to distinguish between both indicators. For example, it is not obvious for some people that a location may be loud and pleasant, or very quiet and very unpleasant. Consequently, maps have to show both indicators and the cartographic representation of the explanatory variables of soundscape. To simplify a comparison between both indicators, it would be useful that both are portrayed on the same symbol, the drawback being that the symbol becomes rather complicated. Thus, some cartographic representations are being suggested to portray sound pleasantness and global loudness in the survey locations, and to show urban features explaining the items which play a role in the formulas.

2.3.1 Features of the Cartographic Symbology

Cartographic symbols are designed to show two indicators, including sound pleasantness and global loudness. The symbols also need to allude to the explanatory variables, such as presence of traffic, voices, and birds. Indicators are portrayed by symbols and explanatory variables must be inferred from the map base.

Cartographic symbols need to portray sound pleasantness and global loudness, indicators that vary according to the time of the day. The temporal variable is something that does not need to be portrayed by a visual variable. Instead, it could be combined with the indicators, which would make it more difficult for the map to convey the message. Sound pleasantness is a perceptual ordinal variable. In this survey, it can vary between 1 (*unpleasant*) and 11 (*very pleasant*). In order to simplify the representation, these eleven values were reclassified into the following four categories: *unpleasant, rather unpleasant, rather pleasant, and pleasant*, thus eliminating the neutral assessment class. Global loudness is a perceptual ordinal variable too, which is rated on a scale of 1 (*weak*) to 11 (*strong*) in the survey. As for sound pleasantness, the eleven classes were reclassified into four categories, also: *quiet, rather quiet, loud,* and *very loud*. Mapping both sound pleasantness and global loudness is made possible by using a bivariate map. The difficult aspect is then to create the legend. In this case, it is a rectangular box with four categories a side, resulting into 16 (4 × 4) smaller boxes, with each box representing a unique relationship of the pleasantness and loudness variables. As Jeong and Gluck (2002) explained, "t*hose maps are extremely difficult to understand because the users need to refer to the arbitrary legend all the time"*. Leonowicz (2006) confirmed these findings by a survey and concluded that "*one-variable choropleth maps are more effective while reading the spatial distribution, and well designed two-variable choropleth maps are more effective in reading the spatial relationship"*. As there is no spatial relationship between sound pleasantness and global loudness, one of the aims of CartASUR was to distinguish between these variables. As a result, bivariate maps were abandoned.

Another cartographic solution was chosen to represent both indicators. It is based on the use of two different graphical variables (Bertin 1983) with the same symbol. In this case, color (i.e. variation of hue, lightness and saturation) was chosen to portray pleasantness and the number of colored bands to portray loudness, with the color of the band showing the level of pleasantness. Alberts and Rubio Alferez (2012) studied the use of colors according to the European Directive. Kornfeld et al. (2011) attempted a first recommendation base for noise mapping and Weninger (2013) concluded that "*to decide on a specific range of colours, the specific case of application has to be analysed with regard to the user group, the user tasks, and the map makers' aim*" and proposed a new scale of colors which is better adapted to noise representation. The cartographic proposals took this research into consideration. The point was to facilitate map users' lecture so that the number of levels was reduced and highly contrasted colors were chosen. In the ColorBrewer (Brewer et al. 2003), several diverging color schemes are offered and one example was chosen to design the symbols.

To show indicator variations according to the time of the day, symbols were divided depending on periods that they show. The number and duration of periods are specified by the L_{DEN} indicator. At most, symbols were divided into three parts for the three periods shown, including the day (from 8am to 6pm), evening (from 6pm to 9pm), and night (from 9pm to 8am). The size of each part of the symbol may or may not be proportionate to the corresponding period duration.

The map base was compiled using urban data from the GIS of the city. Different cartographic proposals were put forward to portray data connected to the explanatory variables (for example, vegetation to suggest the presence of birds) and to translate them into point symbols in order to facilitate the data interpretation of survey locations. These proposals of the explanatory variables were assessed but the results are too long to be discussed in this chapter, which focuses on the representation of indicators.

2.3.2 *Symbology Proposals*

Four proposals of cartographic symbology were made (Figs. 2.5, 2.6, 2.9, and 2.10) to portray indicators for sound pleasantness and global loudness. Proposals differ according to the information the symbols display (sound pleasantness and/or global loudness) and by their design. Symbols that correspond to legends are portrayed in Figs. 2.7, 2.8, 2.11, and 2.12. They all have the same size (the visual variable *size* is not charged with a meaning to portray the indicators).

Legends 1 and 2 (Figs. 2.5 and 2.6) just provide information on sound pleasantness. Only one visual variable is used to portray pleasantness levels, namely variations in color hue (with variations in color saturation and lightness). Compared

Fig. 2.5 Legend 1

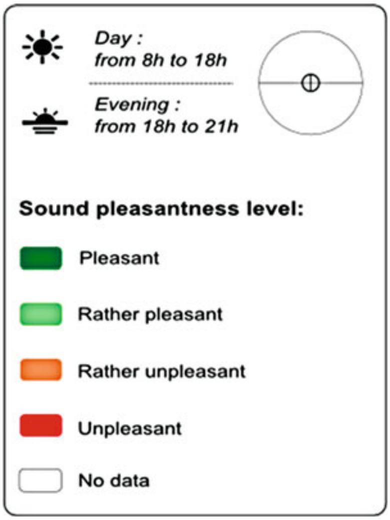

Fig. 2.6 Legend 2

Fig. 2.7 Symbol example of Legend 1

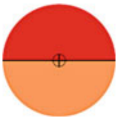

Fig. 2.8 Symbol example of Legend 2

to symbol 1, symbol 2 distinguishes between two periods, namely day and evening. For the latter, the legend specifies that the upper part of the symbol refers to day, and the lower part of the symbol refers to evening (with this symbol, the period size is not proportional to period duration). The symbol in Fig. 2.7 shows that the soundscape is *unpleasant*, whereas in Fig. 2.8, the soundscape is *unpleasant* during the day and *rather unpleasant* at night.

Proposals 3 (Fig. 2.9) and 4 (Fig. 2.10) are more complex. They show both sound pleasantness and global loudness. They are a combination of two graphical variables, including color hue (with variations in color saturation and lightness) to show pleasantness, and the number of bands to show loudness. They also distinguish between several periods. Proposal 3 shows two periods (day and evening) and can be interpreted similar to proposal 2 (upper half of symbol for day, and lower half for evening). Proposal 4 shows three periods (day, evening, and night). In this case, the symbol is divided into three parts (the size of each part matches the number of hours). In the example of Legend 3 (Fig. 2.11), the symbol shows that it is *unpleasant & loud* during the day, and *rather unpleasant & rather quiet* in the evening. The example of Legend 4 (Fig. 2.12) shows a symbol indicating that it

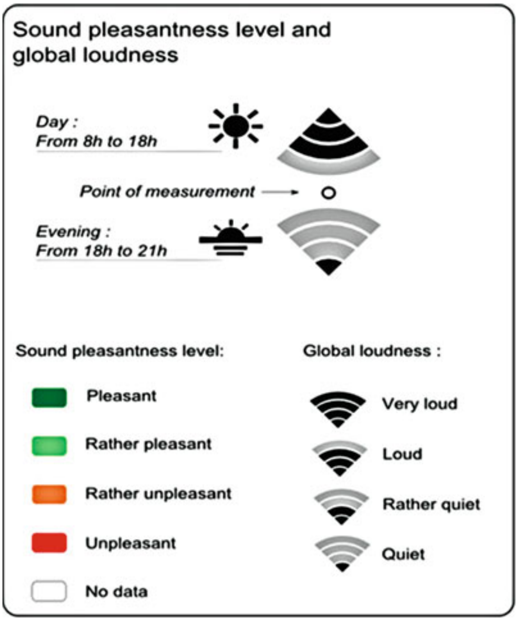

Fig. 2.9 Legend 3

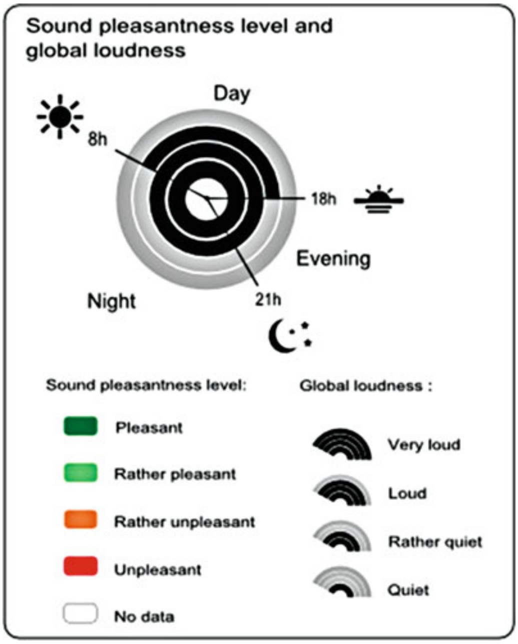

Fig. 2.10 Legend 4

Fig. 2.11 Symbol example of proposal 3

Fig. 2.12 Symbol example of proposal 4

is *unpleasant* & *loud* during the day, *rather unpleasant* & *rather quiet* during the evening, and *rather pleasant* & *rather quiet* at night.

2.4 Assessment Survey of Cartographic Proposals

Four cartographic proposals were made. The purpose was to select the best symbology to help city dwellers distinguish between the two indicators and to imagine soundscape from urban features (in the same way as formulas compute the two indicators through urban features). Consequently, an evaluation survey of the cartographic proposals was developed. Its purpose was to test the interpretation and understanding of various map elements relating to the design of soundscape. The survey was quantitative and based on a close-ended questionnaire which was split into different sections. The aim of each section was to assess one cartographic proposal by identifying the understanding and users' preference of the indicator(s) portrayed.

2.4.1 Participants of the Assessment Survey

The final mapping was designed to be used by any city dweller, regardless of his/her experience, academic background, or training. Consequently, survey participants were not asked whether they possessed specific work-related, social, or cultural characteristics. In order to receive as many answers as possible, the questionnaire was launched on the Limesurvey[1] online platform. This enabled a speedy and easy distribution and facilitated the storage of answers. Calls were made in professional sites and mailing lists; the questionnaire was provided in two languages (French and Spanish) to include responses from remote geographic locations and it was available from March 2015 to July 2015.

[1] www.limesurvey.org

In total, 174 individuals, mainly between 19 and 39 years of age, responded to the questionnaire. In Table 2.1, a column *Survey* shows the percentage share of participants by age, whereas a column *Paris* shows the share of Paris population for the same age ranges. Both groups vary from each other; this can be explained by the method of data collection, namely the advertising in specialized electronic reviews or blogs and direct solicitation of researchers or doctoral students. The under-18 category is under-represented because this category is difficult to reach through calls in professional sites or mailing lists. Similarly, the over-60 age group is under-represented because very few people were interested in the survey whereas there are numerous in this category in Paris.

Most participants have a university education (compare Table 2.2) and often use maps (compare Table 2.3) and even use noise maps (compare Table 2.4).

In order to analyze what participants initially thought of the information displayed, the questionnaire did not allow them to return to modify any of their original answers. The average response duration observed to complete the entire questionnaire was between 20 and 25 min.

2.4.2 The Medium of the Assessment Survey

The page layout was the same for every proposal (see Fig. 2.13). It was divided into several parts. Every map showed the same area with the same five points of measurement (from *Point 1* to *Point 5*). The proposal name was on the top left corner, the legend in the rectangle on the bottom left corner. Questions, which aimed to verify whether the information was understood by map readers, depended on the cartographic proposal and were placed into the top right corner. Participants had to check the box(es) reflecting their choice. It should be noted that it was mentioned that more than one answer was possible to check.

Table 2.1 Age ranges of participants

Age ranges	Survey	Paris
From 0 to 18	1%	24,6%
From 19 to 29	39%	11,6%
From 30 to 39	29%	12,4%
From 40 to 49	9%	13,4%
From 50 to 59	7%	13,1%
From 60 to 90	1%	24,9%
Average age	29	41

Table 2.2 Socio-economic rankings of participants

Socio-economic rankings	
Artisan, shopkeeper or businessman	1%
Employee with a university education	67%
Employee without a university education	6%
Student	22%
Unemployed	3%
Other	1%

Table 2.3 Map use frequency of participants

Maps use frequency	
Never	1%
Rarely	6%
Once a year	10%
Once a month	16%
Once a week	17%
Several times a week	50%

Table 2.4 Noise map use of participants

Noise map use frequency	
Never	33%
At least one time	67%

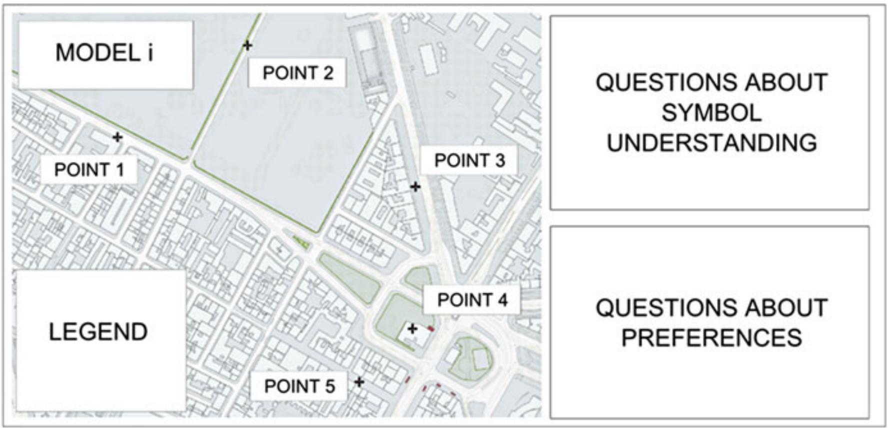

Fig. 2.13 Pattern of the page layout

2.4.3 Questions of the Assessment Survey

The questionnaire was quantitative and close-ended. It included a total of 72 questions that were divided into eight sections. It aimed to assess the participants' understanding of cartographic symbols and their preferences.

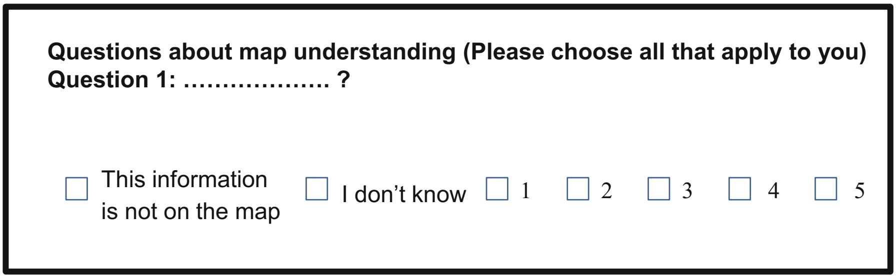

Fig. 2.14 Type of questions for each proposal (*Top right* corner of page layout)

2.4.3.1 Questions About Understanding of Cartographic Symbols

CartASUR maps aim to help city dwellers build an image of soundscape and distinguish sound pleasantness from global loudness. Part of the survey was therefore intended to assess the mapping proposals by finding out whether the message delivered was understood by the map reader. The message is based on both sound pleasantness and global loudness, so the questions aimed to check that readers distinguished between both notions and that they did not answer about loudness, when the symbol showed information about pleasantness. Questions *Q.2* for proposals 1 and 2 were formulated to assess this and may be seen as being tricky (see below). Four maps were made (one for each cartographic proposal) and readers were asked to interpret symbols and to compare them.

Figure 2.14 shows the type of questions about the map understanding. There were two questions in proposals 1 and 2, and four questions in proposals 3 and 4 with this type of questions. Figure 2.15 shows the complete example of proposal 3.

Questions 1 and 2 aimed to check whether readers understood that the symbol was about sound pleasantness and that they could distinguish it from loudness. The formulation of both questions was very similar for the four proposals. For proposals 1 and 2 which only show sound pleasantness, Question 1 verified that map readers could understand information shown with the symbol and Question 2 aimed to distinguish between sound pleasantness and global loudness. Since symbols do not show global loudness, the right answer was: "*The information is not on the map*".

For proposals 3 and 4, two questions (Questions 3 and 4) were added to assess periods and measurement understanding. Both questions were supposed to verify that readers understood representations of periods with the chosen symbols. Proposal 3 only gives information for the day and the evening. So, the right answer for Question 4 was: "*The information is not on the map*". For Question 3 and Question 4, there was only one right answer. Questions (in italics) of each proposal are listed below.

Proposal 1:

– *Q. 1: What is the most pleasant point according to noise (pleasantness)?*
– *Q. 2: What is the loudest point according to noise (loudness)?*

a

b

1. Questions about understanding (please choose all that apply to you)

Q. 1: During the evening, what is the most unpleasant point according to noise (pleasantness)?

☐ This information is not on the map ☐ I don't know ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Q. 2: During the evening, what is the loudest point according to noise (loudness)?

☐ This information is not on the map ☐ I don't know ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Q. 3: In what point the noise has not been measured in the evening?

☐ This information is not on the map ☐ I don't know ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Q. 4: At 23h, what is the loudest point (loudness)?

☐ This information is not on the map ☐ I don't know ☐ 1 ☐ 2 ☐ 3 ☐ 4 ☐ 5

Fig. 2.15 Questionnaire about proposal 3, including the map (**a**), questions about understanding (**b**), and questions about global map properties (**c**)

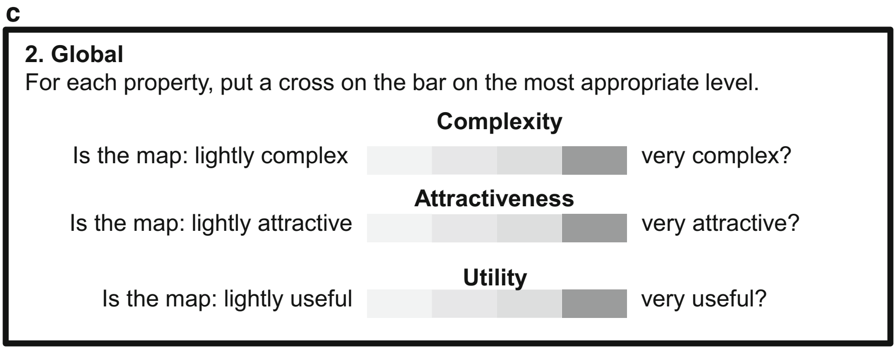

Fig. 2.15 (continued)

Proposal 2:

- *Q. 1: During the day, what is the most unpleasant point according to noise (pleasantness)?*
- *Q. 2: During the evening, what is the quietest point according to noise (loudness)?*

Proposal 3:

- *Q. 1: During the evening, what is the most unpleasant point according to noise (pleasantness)?*
- *Q. 2: During the evening, what is the loudest point according to noise (loudness)?*
- *Q. 3: In what point the noise has not been measured in the evening?*
- *Q. 4: At 23h, what is the loudest point (loudness)?*

Proposal 4:

- *Q. 1: During the day, what is the most unpleasant point according to noise (pleasantness)?*
- *Q. 2: During the day, what is the loudest point according to noise (loudness)?*
- *Q. 3: In what point is the loudness different during the day and during the evening (loudness)?*
- *Q. 4: In what point is the loudness the same during the day and during the evening (loudness)?*

2.4.3.2 Questions About Readers' Preferences

The survey aimed to assess readers' preferences about maps, in terms of their understanding, where appropriate. The aim was to examine the map readers' preferences about global map properties and the amount of information. Consequently, three questions were asked for each mapping proposal, using close-ended questions.

In your opinion, how many periods in the symbol do you prefer (only one answer)?

☐ one period (day) ☐ two periods (day and evening) ☐ three periods (day, evening, and night)

In your opinion, what is more relevant information about noise (only one answer)?

☐ sound pleasantness ☐ sound pleasantness and global loudness

Fig. 2.16 Questionnaire about amount of information

These questions were located in the rectangle at the bottom right corner in Fig. 2.15 shows the complete example of proposal 3.

Global Map Properties

Global map properties may be complexity, attractiveness, utility, range of colors, information density, etc. They may relate to the map base as they affect the whole map and not just one, singular point. This set of questions addressed the map's complexity, attractiveness, and utility. There were four levels for each property, for example: "*Is the map: lightly complex, moderately complex, complex, very complex?"*. Participants had to put a cross on the bar at the level which seemed to be the most appropriate (see Fig. 2.15). The same set of questions was repeated for each proposal.

Amount of Information

The last set of questions (Fig. 2.16) was not related to a specific cartographic proposal; it focused on the amount of information which can be portrayed on maps according to map readers' preferences. The information relates to the number of periods and indicators. Periods may be portrayed in three ways, including one period (day) as in proposal 1, two periods (day and evening) as in proposals 2 and 3, or three periods (day, evening, and night) as in proposal 4. With regards to indicators, sound pleasantness may be portrayed on its own as in proposals 1 and 2, or with global loudness as in proposals 3 and 4. It should be noted that the representation of global loudness was not studied on its own because the main indicator is sound pleasantness.

2.5 Results and Interpretation

The survey addressed the understanding of cartographic symbols and global properties of maps. The questionnaire answers were grouped into these two themes which are explored in the next sections.

Table 2.5 Distribution of answers for proposals 1, 2, 3, and 4 with boxes about sound pleasantness being highlighted in grey

Proposals:	1		2		3				4			
	Q.1	Q.2	Q.1	Q.2	Q.1	Q.2	Q.3	Q.4	Q.1	Q.2	Q.3	Q.4
Correct answers	93%	49%	89%	52%	89%	56%	94%	68%	95%	68%	56%	57%
Incorrect answers	6%	1%	9%	12%	11%	41%	4%	31%	4%	30%	42%	41%
"I don't know"	1%	3%	2%	2%	1%	3%	2%	1%	1%	2%	2%	2%
Wrong answers		47%		34%		(26%)						

2.5.1 *Symbol Understanding*

Questions 1 to 4 addressed the understanding of cartographic symbols, portraying sound pleasantness and global loudness. Table 2.5 shows the distribution of answers by questions. Answers are grouped into categories which distinguish between “incorrect answers” and “wrong answers” concerning Question 2; differences are explained in the section “Confusion between pleasantness and loudness” below.

2.5.1.1 Understanding of Pleasantness Symbol

The understanding of the pleasantness symbol is measured by *Q.1* questions and results are mostly correct. On average across all *Q.1* questions, over 91% participants understood the information about pleasantness, regardless of the number of periods shown in the symbol.

2.5.1.2 Understanding of Loudness Symbol

In terms of loudness, the symbol understanding is measured by *Q.2*, *Q.3* and *Q.4* questions. Participants got the majority of the answers correct. On average, there are 63% correct answers. There are slightly fewer correct answers for question *Q.3* of proposal 3, where participants were asked to identify what information was missing/excluded. On average, the proportion of correct answers declines to 58%. When the answers for *Q.2* in proposals 1 and 2 are examined, it is clear that participants did not realize that only pleasantness was portrayed. They answered the questions about loudness instead and consequently, the answers were wrong.

2.5.1.3 Confusion Between Pleasantness and Loudness

The comparison between *Q.1* and *Q.2* answers enables us to verify whether the two concepts, sound pleasantness and global loudness are understood and differentiated by participants. When interpreting *Q.2* answers, the distinction is made between "incorrect answers" and "wrong answers". When participants replied about loudness looking at maps that only portrayed sound pleasantness information (Q.2 in proposals 1 and 2), their answers showed that they confused the two concepts. The answers are recorded as "wrong answers". There are 47% "wrong answers" for proposal 1 and 34% for proposal 2. For *Q.2* in proposals 3 and 4, both pleasantness and loudness were portrayed, so the answers which are incorrect are recorded as "incorrect answers". This analysis can be examined further. Indeed, amongst the 41% participants who gave an incorrect answer in proposal 3, 26% selected the point which was the more unpleasant instead of the loudest. This seems to show ongoing confusion between the two indicators, even when both are portrayed. Lastly, for proposal 4, the point which was the loudest (*Q.2*) was also the more pleasant point. So, in this case, answers which do not indicate the right point are really incorrect and they are recorded as "incorrect answers". They represent 30% of the answers. This means the legend was simply not understood by the reader. The findings could be that symbols proposed do not help map readers to differentiate between concepts of sound pleasantness and global loudness, even when legends point out differences between such representations. Lastly, the number of correct answers on loudness interpretation (*Q.2* for all proposals) increases from the first proposal (49%) to the 4th proposal (68%), suggesting that map readers have learned to distinguish the two perceptual dimensions as the survey did progress.

2.5.1.4 Understanding of Representing Time Periods

Symbols in proposals 2, 3, and 4 were divided into several parts to show different time periods of the day or during a 24 h period. Proposals 2 and 3 divide the day into two periods (day and evening) and proposal 4 into three periods (day, evening, and night). The size of each part of the symbol may be proportionate to the corresponding period duration (as in proposal 4) or not (as in proposals 2 and 3). Survey participants mostly understood the suggested time period representation, when the question was simple, such as in Question *Q.3* of proposal 3, when no information of the time period was asked. When the question addressed something more specific, the number of correct answers decreased. This can be seen in *Q.4* of proposal 3, which asked about the time period representation of symbols (the representation of the time period may not depend on the indicator). In this case the number of correct answers is 68%. This shows that the time period information is not easy to read with the symbol in proposal 3. The symbol chosen in proposal 4, which portrays more time periods, would even be more difficult to comprehend.

2.5.1.5 Comparison Between Locations

Questions *Q.3* and *Q.4* in proposal 4 asked readers to make comparisons between locations. This task was the most complex of the questionnaire. In order to answer this question correctly, readers had to interpret symbols and summarize pieces of information about both loudness and time periods. Less than 58% of participants answered both questions correctly. However, one goal of reading maps is to compare locations according to the indicators represented (sound pleasantness and/or global loudness) and a comparison must be made possible. In this case, just over half of the readers (56 and 57%) were able to correctly make this comparison.

2.5.1.6 Use of Color Hue (and Color Lightness and Color Saturation)

Questions *Q.2* of proposals 3 and 4 about loudness (*What is the loudest point?*) were similar to question *Q.1* about pleasantness (*What is the most pleasant point?*). Nevertheless, the numbers of correct answers were very different. 62% of participants correctly identified the loudest point, but, interestingly 91% correctly identified the most pleasant point. An explanation may be found in the visual variables used for the various representations. It seems that color that was used to portray sound pleasantness maybe much easier to comprehend and to interpret than quantity variation in the form of several bands used to portray global loudness. The prevailing influence of color has been described by Bertin (1983) and our results provide an additional confirmation. A significant part of this misunderstanding may be due to the difficulties in interpreting the visual variable chosen (quantity variation in the form of bands) to visualize global loudness variations. In these symbols, color variations seem to conceal quantity variations.

2.5.1.7 "I Don't Know" Answers

Lastly, the results included a few "I don't know" answers (less than 2%). It seems that map readers did not hesitate to interpret symbols, but they often made a mistake when symbols were complex.

Some findings can be derived from this section regarding symbol understanding. Even though sound pleasantness and time period representations are well understood, loudness representation is less understood. This is true for simple tasks. When tasks are more complex and require a comparison between locations and an understanding is required about both indicators and time periods, just over half of all survey participants were able to interpret symbols correctly. Interestingly, participants did not check the "I don't know" answers. They did not realize that they might make a mistake and they proceeded with an answer that sometimes resulted in making mistakes. Two alternative hypotheses can be expressed: (i) A large part of map readers does not distinguish between the two concepts of sound pleasantness and global loudness, even when definitions about both concepts are available at the beginning of the questionnaire, including the theme of questions, or (ii) The use of quantity variations to show global loudness variations is so complicated to understand that it hampers all other understanding tasks. In addition, the visual variable *color* seems to capture map readers' attention.

2.5.2 Preferences

2.5.2.1 Global Properties

Legends and symbols are shown in Figs. 2.5, 2.6, 2.7, 2.8, 2.9, 2.10, 2.11, and 2.12. As can be seen, they gradually provide more information and become more complex. Table 2.6 shows participants' answers about map complexity. Not surprisingly, proposals 1 and 2 are considered to be lightly to moderately complex with both categories adding up to over 90% each for all answers. Assessments of proposals 3 and 4 are almost equally distributed between the categories *lightly* and *moderately complex* (47% and 43%) and *complex* and *very complex* (53% and 57%).

Table 2.7 shows the participants' answers about map attractiveness. An assessment of map complexity does not seem to influence the evaluation on attractiveness, quite the opposite. Attractiveness increases as complexity does and, paradoxically, the map with the most complex symbology (proposal 4) is considered to be the most attractive.

Likewise, Table 2.8 shows that utility, like attractiveness, increases as complexity does. The most useful maps are therefore the most complex ones. 78% and 77% of participants rated proposals 3 and 4 to be useful or very useful. However, "only" 63% rated proposals 1 and 2 with the two same categories.

To summarize the results about the symbols' overall properties, it can be concluded that the most attractive and the most useful symbols are also the

Table 2.6 Map complexity

COMPLEXITY	Proposals:			
	1	2	3	4
Lightly complex	79%	34%	7%	6%
Moderately complex	17%	57%	40%	37%
Complex	3%	7%	45%	41%
Very complex	1%	2%	8%	16%

Table 2.7 Map attractiveness

ATTRACTIVENESS	Proposals:			
	1	2	3	4
Lightly attractive	17%	15%	15%	9%
Moderately attractive	39%	44%	38%	35%
Attractive	43%	40%	46%	51%
Very attractive	1%	1%	1%	5%

Table 2.8 Map utility

UTILITY	Proposals:			
	1	2	3	4
Lightly useful	13%	7%	4%	5%
Moderately useful	24%	30%	18%	18%
Useful	55%	56%	65%	59%
Very useful	8%	7%	13%	18%

Table 2.9 Participants' preferred number of time periods

One period (day)	9%
Two periods (day and evening)	26%
Three periods (day, evening and night)	65%

Table 2.10 Participants' preferred number of indicators

One indicator (sound pleasantness)	10%
Two indicators (sound pleasantness and loudness)	90%

most complex ones. Participants are aware of the importance of both pieces of information (sound pleasantness and global loudness) offered in proposals 3 and 4 to understand soundscape. Nevertheless, by comparing these results with those on symbol understanding, complex maps are preferred even though map readers are not always able to make complex operations with them, such as comparing locations.

2.5.2.2 Amount of Information

Tables 2.9 and 2.10 show that map readers largely prefer to have a lot of information displayed with symbols. This preference is valid for both time periods (see Table 2.9) and indicators (see Table 2.10). Such results are consistent with findings on global map properties. The most attractive and useful proposal is proposal 4, which also includes the most complex map symbols with three time periods and two indicators portrayed.

This answer about preferred number of indicators does not depend on the noise map use of participants (Table 2.4).

As a conclusion, it can be said that map readers prefer to view complete (both sound pleasantness and loudness) and precise information (three time periods), even when the amount of information leads to complex maps, which are then considered to be the most attractive and useful by map readers.

2.6 Conclusions and Perspectives

The European Directive's definition of "noise mapping" takes into account the need for more information about noise pollution in cities. Strategic noise maps are based on the L_{DEN} indicator, which is not easy to interpret by the general population. "*A positive attitude towards maps [...] also produces a positive judgment about user-oriented cartography as a decision support tool*" (Reinermann-Matatko 2013). Noise representation is a complicated task due to concept complexity. A new approach is to directly map the sound pleasantness instead of the L_{DEN} exposure level. In previous studies, a sound pleasantness indicator based on loudness, presence of traffic, presence of voices, and presence of birds was put forward. However, the strong link between sound level and sound pleasantness still introduces some difficulties for the general population to understand both dimensions.

In addition, the specific and personal nature of map readers interferes with the interpretation of urban sounds and this is an element that can hardly be predicted. Therefore, the CartASUR project develops maps that can also be interpreted in a particular way by each user. CartASUR aims to portray the soundscape of Paris based on two indicators, including sound pleasantness and global loudness which are directly measured in 70 places and predicted across the entire city. To portray them, four symbology proposals have been designed and assessed. This chapter focuses on cartographic proposals and the assessment of symbol understanding and map readers' preferences which were measured in the survey. Other proposals about representation of traffic and presence of voices and birds are not discussed.

The findings are that map readers are aware of soundscape complexity and they express their preferences for maps which portray both indicators according to different periods. Even if these maps are complex, map readers consider them to be the most attractive and the most useful. Nevertheless, the survey showed that most map readers do not interpret these complex maps well and such maps do not provide a suitable medium to perform complex tasks. In this respect, this result agrees with the main conclusion of Hegarty et al. (2009) on the users' preference for complex information. Besides, survey participants were used to handling maps. In contrast, the results of map readers, who are more representative of the Parisian population is expected to be worse. To address this difficulty, a proposal could be to portray each indicator on a different map. Then, the main drawback would be that the comparison between sound pleasantness and global loudness would require to handle two maps at the same time.

An explanation for the wrong interpretation of indicator symbols may be the chosen visual variables. Pleasantness variations are associated with color (actually color hue, lightness and saturation vary in the same time) variations, whereas loudness variations are shown with a number of bands. The *color* (hue, lightness, and saturation) visual variable seems to capture map readers' attention best. So, color variations are easy to read and push variations of the other visual variable into the background, especially in this case where sound pleasantness seems to be closely tied to global loudness. To confirm this hypothesis, an additional test could have been done that may swap the visual variables used for pleasantness and loudness symbols, to verify whether a loudness symbol using color variations would be more correctly interpreted.

Another hypothesis is that map readers do not read legends carefully. Hegarty et al. (2009) pointed out how knowledge about represented data was important to interpret symbols and understand maps. The effect explained in Sect. 2.5.1.3.

"Confusion between pleasantness and loudness" shows that for an audience that includes not only specialists when doing sound research, training would be more significant than merely providing information required to distinguish between the two concepts, pleasantness and loudness. Besides, the authors are currently planning an additional test related to this research, based on an eye tracker. The objective is to study how readers look at different map indicators, especially at the duration and the number of times they return to the legend, and the order of reading operations. This analysis should indicate whether participants really try to understand legend information or, by contrast, answer quickly without much thought.

The findings in this book chapter show that the need for understanding noise maps is still of high interest to the general population. The prediction formulas of sound pleasantness have shown that this indicator depends on presence of traffic, birds, and voices. In order to help map readers to imagine sound pleasantness, it would be useful to portray these perceptual variables, i.e. to design cartographic objects which allude to traffic, birds, and voices and to assess them for map readers. The prediction formulas are able to determine sound pleasantness and global loudness in each location of the city. Thus, the representation of predicted indicators would be continuous across the entire city of Paris, whereas the survey representation in this chapter only shows indicators at specific survey locations.

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