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# A study on Lisbon waterfront urban public space soundscape

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**Abstract**

Waterfront areas can provide ample possibilities as restorative sites that contribute to improve people's quality of life. In this sense, their soundscape becomes an important perception factor to be considered in their analysis or urban space planning process. Nevertheless, how the waterfront sound environment is perceived by the users has been scarcely studied.
In order to understand the soundscape perceptive process related to waterfront public spaces, from the user's perspective, a study of 10 Tejo River waterfront urban public spaces in the city of Lisbon, Portugal, was carried out. Sound source identification started with a soundwalk programme which also helped the site selection. Sound environment data were recorded and a questionnaire was applied to 500 users. The sound recordings and the users' responses were analysed in the laboratory, where the predominance of each perceived sound source was identified and quantified.
Despite the fact that all studied public spaces featured a direct relationship with the river, and perhaps since local traffic sounds generally dominate the acoustic environment, only in some sites the waterfront characteristic sounds (water, boats, seagulls, pier) were those most frequently identified by the users. Here, the more perceived sound sources, mostly natural sounds and those related to the waterfront, produce a masking effect relative to other sounds that were detected as having a higher temporal predominance in the laboratory. The research results were correlated with other user's subjective evaluations, in order to better understand the waterfront public space soundscape appreciation process.

**Keywords:** technical paper, FIA, Sobrac, acoustics, vibration

**PACS**: 43.28. Hr

## 1. INTRODUCTION

Soundscape studies are attracting worldwide interest, and changing the historical view of "sounds", that focus on the human perception of acoustic environments, with an alternative approach on managing sound in the urban environments [1]. This is the reason-for which, the environment researchers and professionals, started to question how modern cities should "sound like", instead of just "look like" [2].

Cities or city areas at the water's edge are places that have their own identity, with uses, visual elements, and also sound particularities that are derived from the combination of the urban context with the water (urban and maritime culture). The sound environment of these areas carries important dynamic information from its reference sources, such as the sounds of water, winds, birds, or boats, which give meaning to their landscape, allowing an identity relationship with their users. However, the current and essentially urban use of such areas usually produce distinctive peculiarities to this characteristic sound environment, due to the presence of other sources, with its own features (such as human, traffic and operational sounds).

Nevertheless, especially in these waterfront areas, the soundscape approach is not usually considered, both on the analysis and planning, as one of objective determinants to the project concept to be considered by the urban planners in their design process.

Therefore, this research aims to carry out a soundscape semi-empirical study of a waterfront urban area from the urban designer's perspective.

The urban waterfront area of the Tejo River, on Lisbon city (Portugal), was explored, focusing on a detailed study regarding the most perceived sound sources, in order to contribute to the understanding of the perceptual process of its soundscape.

The work followed a case-study line of action with an empirical survey on different public spaces of the Tejo's waterfront, which included *in-situ* observations, data collection, laboratory tests, and a comprehensive cross analysis.

## 2. STUDY AREA

Ten sites from the Tejo River waterfront were selected for study. They are distributed over two large areas named as Area I and Area II, as shown in Figure 1.

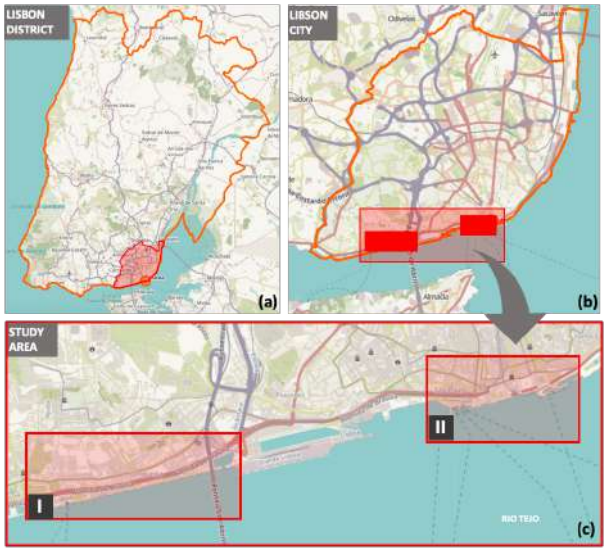



**Figure 1**: Waterfront area location: (a) Lisbon District, (b) Lisbon Municipality, (c) Tejo's River Waterfront with Area I and Area II location: *©OpenStreetMap contributors, author adapted.*

Area I is located between the Doca de Belém dock and the 25 de Abril Bridge, and comprises five selected public spaces, sites 1 to 5, as shown in Figure 2.

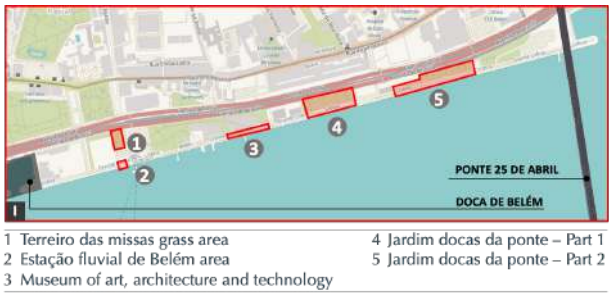



**Figure 2:** Area I with the location of sites 1 to 5. *Source: ©OpenStreetMap contributors – author adapted*

Area II, located between the Cais do Sodré train station and the Praça do Comércio square, comprises also five public spaces, sites 6 to 10, as shown in Figure 3.


6 Jardim de roque gameiro – bench area
7 Jardim de roque gameiro – river bank area
8 Ribeira das naus - tree area
9 Ribeira das naus - grass area
10 Ribeira das naus - center area

**Figure 3:** Area II with the location of sites 6 to 10.
*Source: ©OpenStreetMap contributors – author adapted*

## 3. METHODOLOGY

The data collection for the qualitative evaluation of the sites was carried out through two simultaneous procedures, one consisting on the application of questionnaires to the users of each site, and the other on sound recordings and measurements on the sites.

The application of the questionnaires made it possible to obtain information on the users' perception regarding the sound environment of the sites.

While the inquiries were applied, the local sound sources and the moment they were perceived were identified and registered, in a way to capture the existing temporal sound composition of the sound environment. Sound pressure measurements were also carried out.

The sound recordings together with all the information gathered were organized and analysed on a laboratory environment and later listened by a laboratory listening panel, in which the sound environments were assessed subjectively, according to the panel members' perception.

### 3.1 Inquiry

The inquiry was designed based on recognised research about soundscape and supporting information specified on the ISO soundscape standards [3].

The second part of the inquiry was built especially focusing on the data collection regarding the user perception about the different types of sounds and the overall sound environment of the sites, in which, firstly, the acoustic environment of the site is characterized by the sound sources heard and identified. Therefore, the user is requested to list those sounds that he/she perceived best, in a decreasing order, starting with the most dominant ones, as in Figure 4.

Please list the 4 SOUND SOURCES (eg traffic, birds, people talking, wind, water, machine noise, music, train, etc.) that you perceive best.

***Start with the most noticed source.***

1
2
3
4

**Figure 4:** Inquiry second part: sound perception.

The sound sources perceived by the site users were compared later with the answers obtained by the laboratory listening panel. In order to make the data obtained from both methods comparable, since the perceived sounds on the sites were listed by free-text answers, a classification of these responses considering the same categorization applied on the laboratory panel was necessary.

Therefore, a classification was established, following Table 1 criteria, mostly based on ISO 12913-2 [3] recommendations, but introducing the "waterfront sounds" category, in line with the research objectives.

**Table 1:** Classification of the sound sources.

| Waterfront Sound | Natural Sound | Human Sound | Traffic Sound | Other Sound |
|---|---|---|---|---|
| boat | birds | ball | airplane | alarm |
| boat whistle | cicada | palms | bus | ambulance |
| pier | dog barking | people | cars | bicycle |
| seagull | wind | sneeze | helicopter | construction |
| water | | whistle | motorcycle | drag objects |
| | | | train / tram | kiosk operation |
| | | | truck | music |
| | | | tuktuk | scooter |

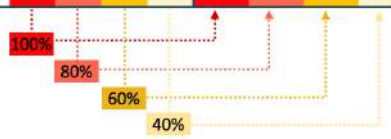
In addition to the categorization, it was also found necessary to attribute more importance to the established ranking order of the sound sources, putting more weight to those which were perceived best.

In this sense, a weighting criterion was set up which consisted of attributing different scores according to the perception order, where the highest score (100%) was assigned to the first most perceived sound source, a medium score (80% and 60%) to the second and third ones, and the lowest score (40%) to the fourth.

A practical example of the weighting procedure is shown in Table 2, where the values from the second up to the fifth column, group (i), represent the number of listeners who ranked the specific sound source respectively as the first, second, third, or fourth most perceived.

**Table 2:** Tutorial to weighting the sound sources ranking established by listeners.

| | Public Space 7 | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Sound Source Perceived | | | | Ranking Order Weighted (i) | | | | Total | % |
| | 1st | 2nd | 3rd | 4th | 1st | 2nd | 3rd | 4th | (ii) | (iii) |
| Waterfront Sound | 9 | 2 | 1 | 4 | 9,0 | 1,6 | 0,6 | 1,6 | 12,8 | 18% |
| Natural Sound | 0 | 0 | 1 | 1 | 0,0 | 0,0 | 0,6 | 0,4 | 1 | 1% |
| Human Sound | 0 | 16 | 7 | 3 | 0,0 | 12,8 | 4,2 | 1,2 | 18 | 26% |
| Traffic Sound | 9 | 4 | 7 | 4 | 9,0 | 3,2 | 4,2 | 1,6 | 18 | 26% |
| Other Sound | 8 | 4 | 9 | 7 | 8,0 | 3,2 | 5,4 | 2,8 | 19 | 28% |




The values from the sixth to the nineth column, group (ii), represent the applied weighting, in which the numbers of listeners were multiplied by the factors 100%, 80%, 60% and 40% respectively according to the perceived order. Then, the tenth column (iii) shows a sum of the values weighted for each sound source category. Lastly, the eleventh column (iv) presents the percentages obtained which means the contribution of every sound source category on the acoustic environment, according to the user's perception.

### 3.2 Laboratory listening panel

The listening panel was set up so as to obtain a subjective assessment of the sound environment of the waterfront sites, in a laboratory environment. Essentially, it was asked to the panel members which sound sources they perceived best by watching and listening to ten videos that represented each one of the Tejo waterfront sites, composed of an audio sample of its sound environment and of illustrative photographs of the place.

The listening panel was composed by non-acoustical experts and not necessarily familiar with the waterfront sites, with different socio-demographical characteristics, such as gender, age, occupation, and education. The participants were sent an e-mail with the video, the link for the online form access and a tutorial which explained how to autonomously perform the assessment.

As participants were supposed to have a good hearing, since auditory accuracy was required, the listener's hearing ability was entrusted to a self-declaration at the moment when he/she agreed to participate in the panel.

The set up of the listening panel was adapted to the covid-19 pandemic situation by creating a safe environment for the participants. In this sense, (i) the sound environment of each site was characterized and presented in a virtual way, and (ii) an on-line form was structured and built, for an individual and autonomous assessment by the panel members.

For the panel implementation, the various sound recordings needed to be summarized in a single audio sample for each site, that could represent its sound environment according to its temporal sound composition.

Firstly, at the IST Acoustics laboratory environment, each sound recording was analysed using the computer program "*Audacity*", in order to characterize the sound environment of each site, by recording the sound sources categories perceived and the time period they remained being noted. By using that software, as shown in Figure 5, (i) the changes on the sound time history of each recording could be observed through the visual information of its sound wave, and then (ii) each sound source perceived were identified, aided by the annotations carried out *in-situ*, from the exact instant when it started to be noted until when no longer could be perceived.

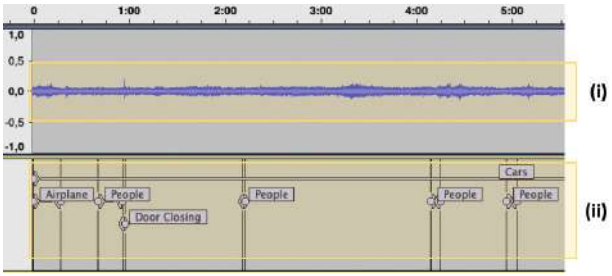



**Figure 5:** Sound recorded, and sounds labelled by Audacity Software.

Hence, considering the sound source categories and the time period that each one was perceived on the recording, as shown on the example of site 9 in Table 3, (i) the percentage of the recording time of every category was calculated, (ii) to then calculate an average of the percentages of the categories and to obtain the temporal sound composition of the sound environment for each site.

**Table 3**: Sound environment characterization. Example of the mean calculation of each sound source perceived from the recordings

| Site 9 | | | | | | |
|---|---|---|---|---|---|---|
| Recordings | Waterfront Sound | Natural Sound | Human Sound | Traffic Sound | Other Sound | |
| 1 | 100,0% | 0,0% | 100,0% | 100,0% | 0,0% | (i) |
| 2 | 3,3% | 0,0% | 17,4% | 100,0% | 5,8% | |
| 3 | 100,0% | 0,4% | 21,8% | 100,0% | 1,1% | |
| 4 | 2,9% | 0,5% | 41,1% | 100,0% | 0,0% | |
| 5 | 100,0% | 1,6% | 3,5% | 100,0% | 8,0% | |
| 7 | 15,7% | 0,3% | 12,5% | 100,0% | 10,3% | |
| Mean | 53,6% | 0,5% | 32,7% | 100,0% | 4,2% | (ii) |

By taking into account the resulting temporal sound composition for every sound environment, an audio sample was composed for each site by combining parts of the sound recordings, in a way to contemplate, as much as possible, the same percentages of the different sound source categories.

For the on-line form application, short videos were composed for each site, with an approximate duration of 1 minute and 45 seconds each, by combining the audio sample and a sequence of six representative photographs of the place. The images aimed to provide visual information on the site, such as its characteristics, its surrounding environment, and, mainly, its relationship with the water.

The videos were complemented by an online form to be filled in by the listener sequentially following the presentation of each site. The form asks for the four sound source categories which the respondent perceived best by watching the video with the sound environment recording composed, starting with the most relevant ones as shown in Figure 6.

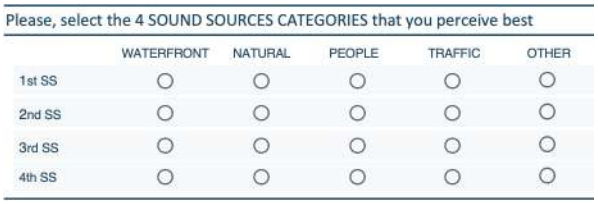



**Figure 6:** Laboratory panel form question regarding the sound sources perceived on the video of each site of the electronic form about.

For an appropriate sound source categorization, the listener was previously introduced by a tutorial regarding its classification, as shown in Figure 7, in line with the criteria established in Table 1.

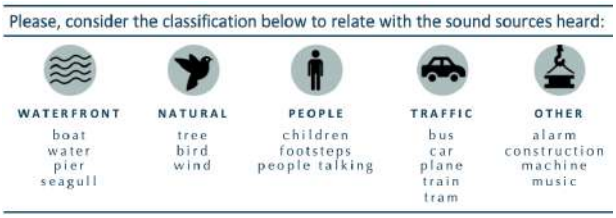



**Figure 7**: Orientation for the sound source classification to answer the electronic form.

Similarly to the inquiry results processing, the panel's best perceived sound source categories, for each site, were weighted in the same way, from the first to the fourth category, using the method illustrated in Table 2.

Through the weighting procedure, a higher importance was attributed to those sound source categories best perceived making the results from the listening panel comparable to the inquiry responses.

## 4. RESULTS

The inquiry was applied to 642 users, aged between 15 to 71 years, with 411 being women and 231 being men (M age = 28,5 years).

The application of the questionnaires covered different days of the week, different periods of the day and different seasons of the year.

The laboratory listening panel comprised a group of 26 listeners that voluntarily participated on the laboratory experiment, with 16 being women and 10 being men (M age = 42,5 years).

The results obtained from the site' users (I) and from the panel listeners (L) were correlated, in order to compare the sound sources best perceived obtained from the two approaches, i.e., from the site users *in-situ*, assessed through the inquiry (I), and, at a laboratory environment, assessed through the online form (L) by the laboratory panel members.

Figure 8 represents the general percentages regarding the sound sources most perceived by the sites' users (I) and by the panel listeners (L), considering the assessments for all the waterfront area places.

The general perception demonstrated that, despite the sites being in a waterfront environment, in which their characteristic sounds could have been the most perceived, the "traffic sounds" were still the best perceived, perhaps due to the urban characteristics of the waterfront.

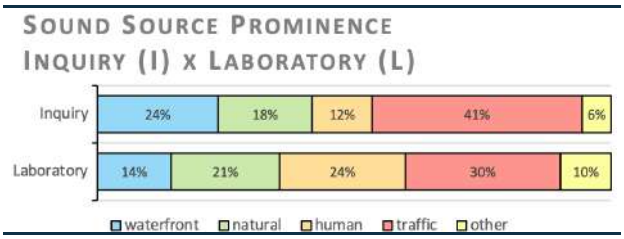



**Figure 8**: Average perception percentage of each sound source on the Tejo's waterfront public spaces [%] obtained on the inquiry (I) and on the laboratory (L).

Comparatively, the "traffic noise" category was more perceived by the users of the sites (41%) than by the panel listeners (30%). Likewise, "waterfront sound" was also more perceived by the users (24%) than by the listeners (14%), even with a temporal sound composition which includes the "waterfront sound", and also with the visual support of the photographs which illustrate the relationships of the sites with the water.

In contrast, the "natural sound" and the "human sound" categories were more perceived by the panel listeners (natural: 21% / human: 24%) than by the users of the sites (natural: 18% / human: 12%). It is important to highlight that while the "human sound" was the second sound source category more perceived by the listeners, it was only the fourth perceived by the users.

The comparation between the perceived sound sources obtained from both assessment approaches was also carried out site by site, as shown in Figure 9.

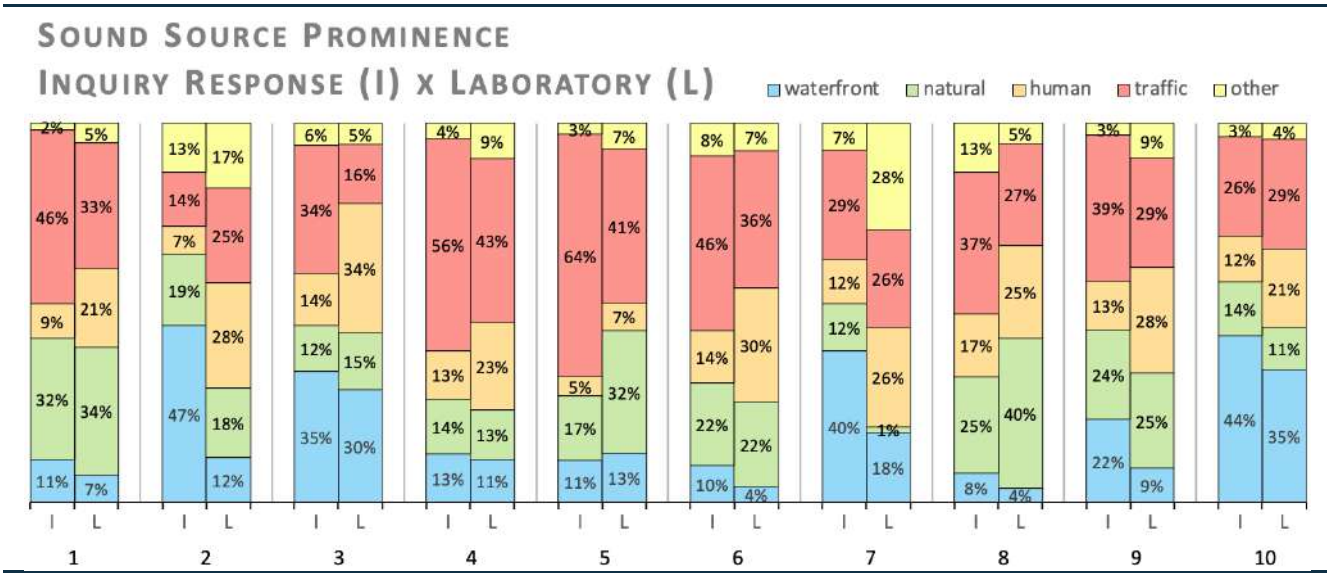



**Figure 9:** Average perception percentual of each sound source on each site [%] obtained on the inquiry response (I) and on the laboratory response (L).

When comparing both assessment environments, one can note that the most perceived sound sources were significantly distinct on sites 2, 3, 5 and 7.

It stands out that the sound sources categories much more perceived by the users than by the listeners are the "waterfront sound" on the sites 2 (47% by users, 12% by listeners) and 7 (40% by users, 18% by listeners), and as the "traffic noise" on the sites 3 (34% by users, 16% by listeners) and 5 (64% by users, 41% by listeners). On the other hand, the "human sound" was perceived much more by the listeners than by the users on the sites 2 (23% by listeners, 7% by users) and 3 (34% by listeners, 14% by users).

On sites 1, 4, 8 and 10 the percentage differences between both assessment methods were lower, meaning that the perceptions were very similar, especially on site 10.

Table **4** shows the sound sources categories most perceived from both assessment environments, on a ranking order, from the most prominent to the least.

From the table, two analyses can be performed from the two method results, namely, (i) the established ranking order and (ii) the sound sources that dominate the sound environment.

The ranking orders from both assessment methods presented most differences on the sites 2 and 7, while presented an equal order only on site 5.

In general, one can note that both the "waterfront sound" and the "traffic noise " categories were more prominent by the users of the sites, except in site 2, while the "human sound" was more prominent for the panel listeners.

Concerning the "natural sound" and the "other sound", the results obtained from both methods were similar, as far as, on some sites they were more perceived by the listeners and better noticed by the users.

Regarding the sound sources that dominate the acoustic environment, it was possible to observe that the "traffic noise" category dominated the sound environment at both assessment environments on sites 4, 5, 6 and 9. However, on sites 1 and 8, while the "traffic noise" was also the most perceived category by the users of the sites, for the panel listeners, it was the "natural sound" category.

On site 10, the "waterfront sound" category dominated the sound environment of both assessment environments. However, on sites 2, 3 and 7, while the "waterfront sound" was also the most perceived category by the sites' users,

for the panel listeners it was the “human sound” on sites 2 and 3, and the “other sound” on site 7.

**Table 4:** Comparative sound source predominance on each site – Inquiry Response (I) x Laboratory Panel Response (L): from the first to the fifth sound source more perceived.

| | 1 | | 2 | | 3 | | 4 | | 5 | | 6 | | 7 | | 8 | | 9 | | 10 | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | I | L | I | L | I | L | I | L | I | L | I | L | I | L | I | L | I | L | I | L |
| 1st | 46% | 34% | 47% | 28% | 35% | 34% | 56% | 43% | 64% | 41% | 46% | 36% | 40% | 28% | 37% | 40% | 39% | 29% | 44% | 35% |
| 2nd | 32% | 33% | 19% | 25% | 34% | 30% | 14% | 23% | 17% | 32% | 22% | 30% | 29% | 26% | 25% | 27% | 24% | 28% | 26% | 29% |
| 3rd | 11% | 21% | 14% | 18% | 14% | 16% | 13% | 13% | 11% | 13% | 14% | 22% | 12% | 26% | 17% | 25% | 22% | 25% | 14% | 21% |
| 4th | 9% | 7% | 13% | 17% | 12% | 15% | 13% | 11% | 5% | 7% | 10% | 7% | 12% | 18% | 13% | 5% | 13% | 9% | 12% | 11% |
| 5th | 2% | 5% | 7% | 12% | 6% | 5% | 4% | 9% | 3% | 7% | 8% | 4% | 7% | 1% | 8% | 4% | 3% | 9% | 3% | 4% |

Lastly, in Figure 10 andFigure **11**, the best perceived sound sources at each site, respectively by the sites’ users (I) and by the panel listeners (L), were introduced on the waterfront area maps. The different scales of the symbols of each sound source category represent the proportion that each one was perceived on the different sites, i.e. the larger symbols represent the most predominant categories, whereas the smaller symbols represent the least perceived.

For the site users (I), one can note that the “waterfront sounds” category dominates the sound environment of those sites that are really in front of the water, except for sites 4 and 5. Specifically at these sites, the "traffic sounds" was the sound source category perceived as predominant on the sound environment, which leads to conclude that this dominance might be masking the “waterfront sounds”, which it was noticed as common in the areas with this water relation. The masking effect seems to be quite relevant here.

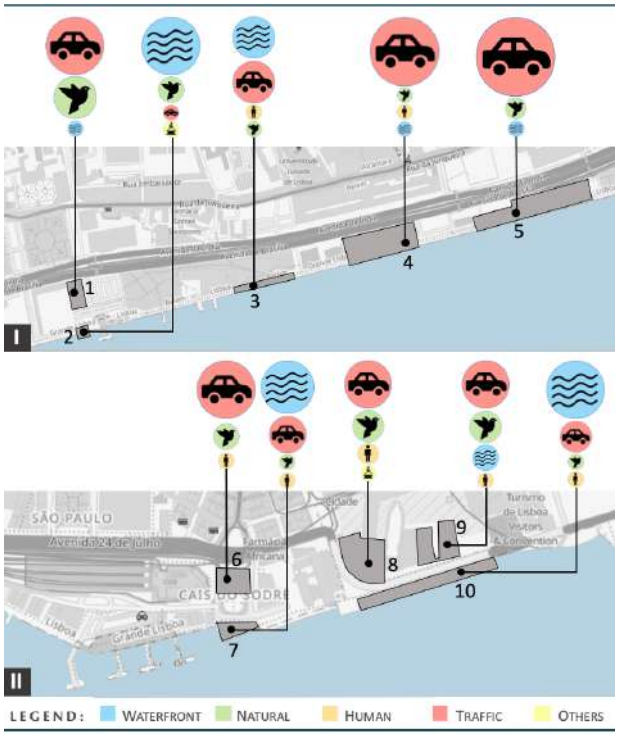



**Figure 10**: Tejo waterfront – Areas I and II - sound source categories most perceived on each site by their users (I) -larger symbol imply higher perception of the category. *Sources: ©OpenStreetMap contributors, author adapted.*

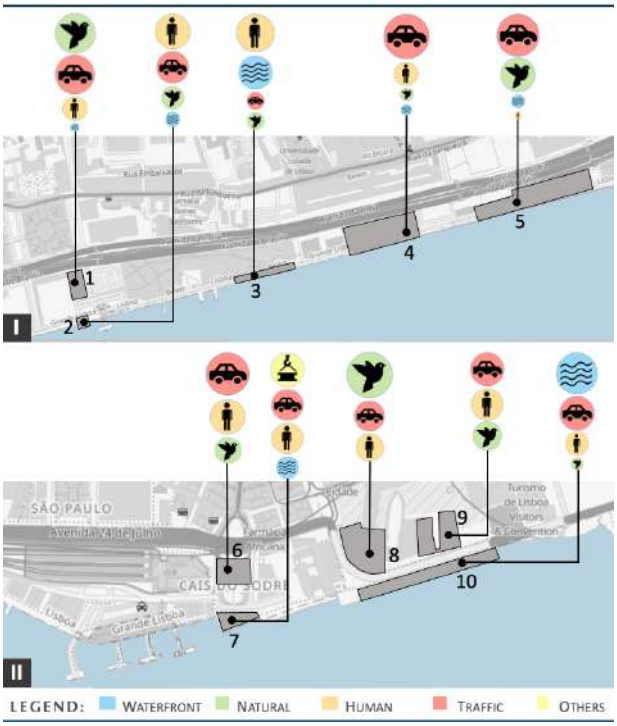



**Figure 11:** Tejo waterfront – Areas I and II - sound source categories most perceived on each site by the listening panel (L) -larger symbol imply higher perception of the category. *Sources: ©OpenStreetMap contributors, author adapted.*

For the panel listeners (L), the "waterfront sound" category was also best perceived on the sites that are closest to the Tejo River, but only on sites 3 and 10. However, regarding the other perceived sound source categories, no relations with the position of the sites on the waterfront were found.

## 5. DISCUSSION AND CONCLUSIONS

By comparing the two assessment environments, large differences can be assigned to both the context information and the existing stimuli to their participants, which could influence directly and considerably their perception process.

The listening panel member essentially had sound and visual stimuli, through the sound recordings and illustrative photos of the sites, for their assessment, whereas the user, *in situ*, had all the information about the site itself, she/he was familiar with it and was stimulated by all the other senses, in addition to the auditory and visual ones.

Considering this, it is possible to deduce that the differences found between the sound sources most perceived on sites 2, 3 and 7, may have been mostly influenced by the existing differences between both assessment environments. While the similarities found on sites 1, 4, 5, 6, 8, 9 and 10, seem to have been essentially influenced by the common aspects existing on both assessment environments, thus, mostly the auditory and visual stimuli.

The sites that presented the most different sound source perceptions between the assessments carried out *in situ* and at the laboratory, were the same ones where the "waterfront sound" was the best perceived sound source category by the waterfront users, except at site 10. And, as showed in Figure 10, these sites are located exactly in front of the Tejo waterline, which may mean that their proximity to the water can stimulate other senses of the users, not only the auditory one, which influenced them to perceive mostly the water-related sounds.

Despite this relation found between water proximity and "waterfront sound" perception, on sites 4 and 5, the "traffic noise" was the most perceived instead of the "waterfront sound".

Figure 12 shows that unlike users of the other sites at the waterline, that have a direct access to the water, the users of sites 4 and 5 usually remain in places with some physical restriction to the water, highlighted on the maps and on the photographs in Figure 13.

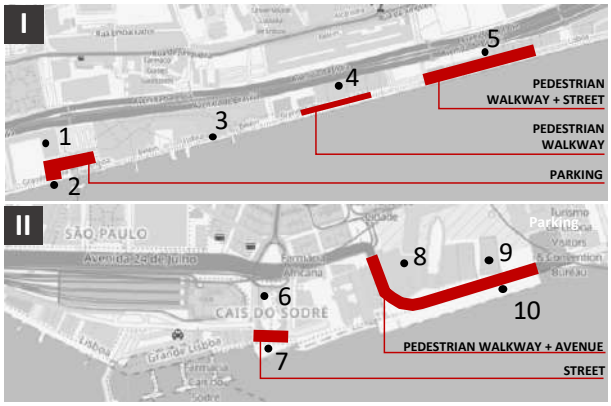



Figure 12: Tejo waterfront – Areas I and II – sites and barriers identification. Sources: ©OpenStreetMap contributors, author adapted.


**Figure 13**: Tejo's waterfront sites with their physical barriers highlighted on red areas, except on sites 2, 3, 7 and 10, without barrier; *by Nardi, 2020.*

It seems that these physical elements placed between the user and the water, which nevertheless allow the crossing of people, bicycles, scooters and even cars, influences the perception of the sounds on sites 4 and 5. They somehow interrupt a closer relationship with the water, and makes people notice more the "traffic noise" that is reported as the sound source category actually more present in the sound environment.

On sites 1, 6, 8 and 9, these characteristics might be even more determinant to the traffic noise perception, since besides being further away from the water, these places are also more restricted to it by physical barriers even more representatives, such as avenues and parking.

Overall, it seems that an association between the most perceived sound source categories and the relationship that the users establish with the water exists, since, despite the entire waterfront area being characterized by the presence of the traffic noise, a closer contact with the water might have influenced the perception of sounds that are more water-related.

Contrary to this, any type of barrier between the user and the water seems to emphasize the perception of the traffic noise, which is usually the sound source category most prominent in the waterfront of the Tejo River.

Therefore, since different restrictions to the water can impact on the overall perception of the sound environment and on the composing sound sources, they should be considered an objective criterion for the analysis and planning of the soundscape of a waterfront area.

The design of the soundscape of an urban waterfront area must be supported by the careful planning of the sound sources that will be perceived, which in turn, must be supported by the planning of the possible relationships between the user and the water.

## ACKNOWLEDGEMENTS

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