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► To cite this version:

Gwenaël Guillaume, Gwendall Petit, Cédric Foy, David Ecotiere, Judicaël Picaut, et al.. Use of a smartphone measurement application to teach basics in buildings and environmental acoustics in an educational setting. e-Forum Acusticum 2020, Dec 2020, LYON, France. pp. 2587-2594, 10.48465/fa.2020.1039 . hal-03231869

HAL Id: hal-03231869

<https://hal.science/hal-03231869>

Submitted on 26 May 2021

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USE OF A SMARTPHONE MEASUREMENT APPLICATION TO TEACH BASICS IN BUILDINGS AND ENVIRONMENTAL ACOUSTICS TO SCHOOLCHILDREN AND TEACHERS

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ABSTRACT

The teaching of acoustics notions with a young or heterogeneous audience in a school or public event context can be facilitated by acoustic measurement practices through entertaining activities. NoiseCapture is a smartphone application dedicated to the evaluation of environmental noise and to the realization of collaborative noise maps based on voluntary measurements sharing. This paper presents initial experiences of environmental noise information to the general public based on NoiseCapture Parties within scientific events context. NoiseCapture relies on the GPS location to allow for the measurements geolocation and thus map representation of the noise environments. The application has been diverted from its first purpose within an educational context by proposing training courses to secondary school teachers, middle school and university students concerning basic concepts in buildings acoustics, introducing noise measurements and noise mapping. The paper gives first feedbacks from these training initiatives.

1. INTRODUCTION

The education of scientific notions concerning acoustics with a young audience or the general public can be made easier by practical applications associated with new technologies. The use of a smartphone application make thus the teachings all the more playful. The NoiseCapture¹ application, initially devoted to environmental noise assessment, allows to capture geolocalized sound environment indicators along a track thanks to both the embedded microphone and GPS sensor. The application enables the user to share its measurements and thus to participate to the production of a collaborative noise map [1]. The application has been diverted from this latter starting objective for teaching purpose in diverse contexts and public.

After a brief description of the NoiseCapture ecosystem (section 2), the paper presents interventions performed in an educational context addressed to schoolchildren and students (section 3) and teachers (section 4). Finally, a few examples of NoiseCapture Parties are presented that aim at

training general public to acoustic measurement by raising awareness of its appropriate achievement with good practices.

2. THE NOISECAPTURE ECOSYSTEM

NoiseCapture is part of the Noise-Planet² research platform that provides scientific tools for environmental noise assessment. This platform was developed and is managed by the Noise-Planet team, made of people from the UMRAE (Gustave Eiffel University) and Lab-STICC CNRS laboratories³. All components of the NoiseCapture ecosystem presented below are hosted by the Noise-Planet platform.

2.1 The NoiseCapture application

NoiseCapture is a free and open source Android application which allows any user to measure and to share its sound environment [1]. The GPS track associated with each acoustic measurement enables to display the sound levels on an interactive map that can be consulted on the device (figure 1(f)) or online.⁴ Available on Google Play Store,⁵ the application is aimed both at general public and expert users with technical and scientific skills.

NoiseCapture allows to calibrate the microphone in three different ways (figure 1(a)):

1. a manual calibration process that consists in reporting the reference L_{Aeq} measured simultaneously by reference device (such as a sonometer) in the application;
2. a manual calibration process that uses an acoustic calibrator and an external microphone;
3. an automatic calibration process, which requires an already calibrated smartphone with which the smartphone under calibration communicates.

² <http://noise-planet.org/>

³ <http://noise-planet.org/members.html>

⁴ http://noise-planet.org/map_noisecapture/index.html

⁵ https://play.google.com/store/apps/details?id=org.noise_planet.noisecapture

¹ <http://noise-planet.org/noisecapture.html>

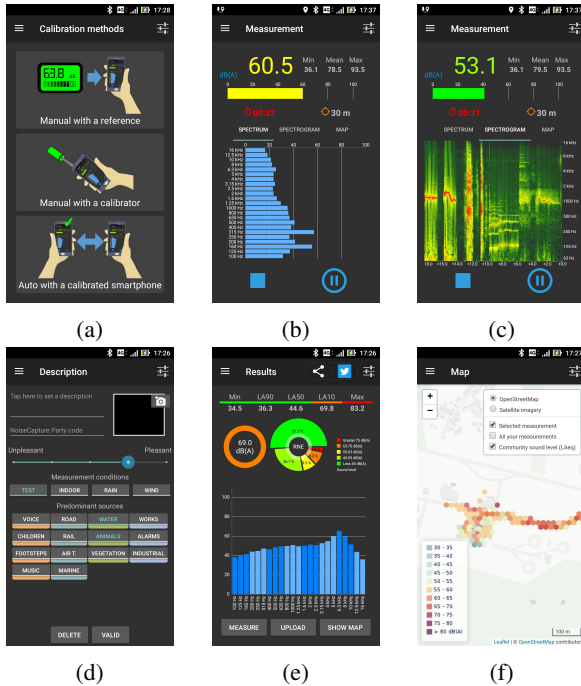


Figure 1: NoiseCapture app screenshots: (a) calibration window, (b)-(c) measurement window tabs with spectral and time-frequency representations, (d) description window, (e) results window and (f) community noise map.

A NoiseCapture measurement involves three main steps:

1. the measurement process itself, for which spectral (figure 1(b)), time-frequency (figure 1(c)) and cartographic representations are proposed as three different tabs;
2. the description of the sound environment (figure 1(d)), which appears when measurement is stopped;
3. the consultation of results that gives common environmental noise indicators (L_{Aeq} , L_{Amin} , L_{Amax} , L_{A90} , L_{A50} and L_{A10}), as well as the average spectrum and the time distribution of noise exposure in different noise classes (figure 1(e)), or else the noise map associated with the latter measurement or all measurements already achieved by the user and the whole community (figure 1(f)).

Unless users have disabled this option, measurements are automatically uploaded to the NoiseCapture servers. Once processed and corrected, the data are distributed to the public both through the world interactive web map and in the form of .geojson files, nightly updated, packaged by country (as .zip files) and provided as open data under the terms of the ODbL license [2].

2.2 The “NoiseCapture Party” concept

In order to promote the use of the application in a real context, the concept of NoiseCapture Party was created.⁶ A NoiseCapture Party is an event organized during a relatively short time (1 day, 1 week...) that covers a limited territory (a place, a neighborhood, a city...), which aims at bringing together a large number of contributors simultaneously in order to feed a participatory noise map, or to test new functionalities of the application. Such event is addressed to any audiences (citizens, associations, public bodies or companies...).

From a practical point of view, a party is organized as follows:

1. the organizers define both spatial and temporal extents, limiting the realization of the measurements;
2. a party code is chosen, which will be used in the application when describing the measurement, and will allow to link all the measurements achieved by all contributors of the party;
3. a map code is also chosen which will be used in order to instantiate a dedicated web map that will display all the measurements performed within the framework of this party, and that will remain permanently available at an address having this format: http://noise-planet.org/map_noisecapture/noisecapture_party.html#MAPCODE where MAPCODE corresponds to the chosen map code.

Once the NoiseCapture Party is created, the event can take place:

1. the organizers explain the objectives of the party and remind a few good practices to carry out measurements in good conditions (e.g. “do not hold the device in your pocket”...);
2. smartphones are calibrated using a reference sound level meter wherever possible, or otherwise thanks to an already calibrated smartphone;
3. the area to be covered is presented and the party code to be used in the application is given;
4. the participants are either spread out into teams, each to cover a sub-area by measurement, or free to roam the area as they please.

During the event, the measurements can be uploaded at any time to the NoiseCapture servers, which enriches the dedicated map in near real time.

2.3 The NoiseCapture Ambassadors

In order to increase the link with the territories, structure the activities and “professionalize” the actions undertaken,

⁶ http://noise-planet.org/noisecapture_party.html

a network of ambassadors was invested.⁷ An ambassador is someone having a minimum of knowledge in the field of environmental acoustics, who works either in a personal or professional capacity, who shares the NoiseCapture's values of open science and who wishes to contribute to the animation of the community, notably by organizing parties. Tending to expand, this network has currently 4 ambassadors (2 in France and 2 in Italy).

3. SCHOOL-BASED INTERVENTIONS

3.1 "Research Passport"

As part of the Regional Educational Pact of the Pays de la Loire Region, the "Research Passport in Pays de la Loire" operation invites young high school students each year to embark on a research and production process based on a scientific issue from the region's research laboratories. Through meetings with researchers, communication partners and a laboratory visit, the students develop new skills. Thus, the main objectives of this operation are to: (i) enable high school students to discover the research activity and its professions, (ii) to awaken their critical spirit on scientific and technical issues, and (iii) give them the opportunity to pass on their learning with the creation of a communication support. The operation is therefore above all a collaboration between students and scientists around a theme proposed by the researcher(s). The operation takes place throughout the school year with highlights that encourage exchanges, including a visit to the laboratory, the researcher's interventions in the school and a day of restitution in front of a large audience. In addition to these ways of promoting the work carried out between students, teachers and researchers, a short article was published on the school's website.

Thus the study proposed by UMRAE researchers in 2018 to the students and teachers of the high school of the City of Bouaye (44, France), focused on the problem of "calibrating sonometric applications for smartphones for the *in situ* measurement of sound environments". This societal issue - which is highly topical in view of the many smartphone applications available today [3] - has led to the emergence of many scientific questions (methodology, metrology, etc.) and echoed a number of concepts addressed by the teachers in their 1st programme of "Laboratory Science and Technology" (LST), for example on measurement uncertainties. In addition, it enabled rich exchanges with the whole classroom, both upstream of the measurements (collective development of an experimental protocol), during the campaign (each student was equipped with his or her smartphone for *in situ* measurements) and downstream (processing, analysis and discussion of the results, feedback groups and workshops).

Finally, a publication was written in order to communicate to the largest possible number of people both the approach of such a "research passport operation" and the scientific results of the study carried out within the frame-

⁷ http://noise-planet.org/noisecapture_ambassador.html

work of this operation.⁸ Thus, this publication, co-signed by all the students of the 1st LST of the College of Bouaye (44, France), presents the work carried out in partnership with UMRAE over the period October 2018 - May 2019 (approximately 8 months) at a rate of 2 hours per week, either within the College (in classroom and in workshops), or "outside the walls" (visiting UMRAE semi-anechoic room and during the acoustic measurement campaign).

3.2 "Immersion Science"

"Immersion Science" (shortly IMS) is an annual initiative, organized since 2011 by the region of Brittany (France), the academy of Rennes (the organization in charge of education in the region) and the French National Centre for Scientific Research (CNRS). Its objective is to immerse 60 high school students coming from 15 "rural" high schools into the universe of Sciences and thus encourage them to continue in Sciences studies.

The event takes place during a week in a nautical centre on the Tudy Island peninsula⁹ (France) (figure 2(A)), which increases the feeling of immersion. During this week, about twenty conferences and workshops are organized with researchers who come to present their work.

In this context, for the last two years, the NoiseCapture team has been intervening on the one hand to present its research on environmental noise assessment and on the other hand to organize a NoiseCapture party with the students and their teachers.

As the measurement workshop was only 2 hours long (the schedule was very tight), the area to be covered was divided into 5 sub-zones. These areas were then assigned to 1 or more pairs of students having an Android smartphone (and thus NoiseCapture). After an indoor calibration step, the students were able to take measurements for about 1 hour, taking care to go through the zones without following other groups, in order to optimize the spatial representativeness.

As a result, in 2018, 13 contributors made 45 measurements for a total duration of 4h38mn. This day was very windy and the resulting map shows that the measurements were heavily impacted (figure 2(B)). In 2019, 23 contributors made 192 measurements for a total duration of 4h48m. During this last event, the weather was milder and the results were much more realistic (figure 2(C)). In the end, with these successive measurement campaigns and tens of thousands of measurement points, we are beginning to have a very dense and representative map¹⁰ of noise levels on this small peninsula (figure 2(D)).

⁸ <https://www.bruit.fr/entreprises/mesure-environnementales-au-smartphone-travaux-de-recherche-des-lyceens-diriges-par-l-ifsttar>

⁹ <https://www.openstreetmap.org/relation/276009>

¹⁰ http://noise-planet.org/map_noisecapture/index.html#17/47.84239/-4.16735/

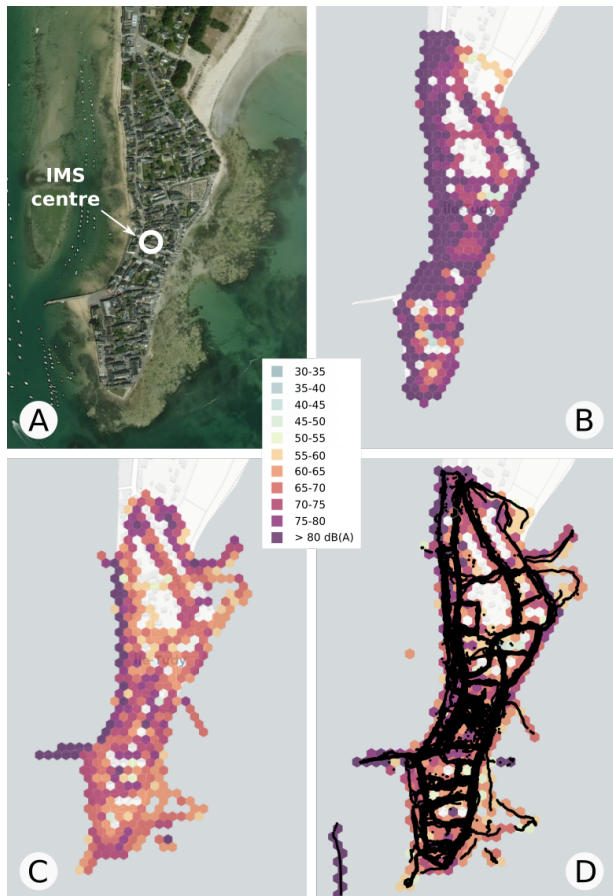


Figure 2: Satellite view (A), resulting maps in 2018 (B), 2019 (C) and map of cumulative measurements, with points (D), in Tudy Island peninsula (France).

3.3 “CGénial” competition

The french Ministry of National Education program “Sciences at School”¹¹ and the Foundation “CGénial”¹² pilot and organize the national scientific “CGénial” competition that is aimed at secondary-school and College students in order to promote Sciences. Students have to present a team-led scientific and innovative project by adopting a multidisciplinary approach (physics, chemistry, mathematics, life and earth sciences, technology, etc.). After a pre-selection phase based on report of work and actions realized within the framework of the project, all finalist teams are invited to present their project to a Scientific Committee in the National final.

The technical College Gutenberg (Illkirch France) carried out in 2018 a project that aimed at raising awareness among the students concerning the effects of noise on health and learning. The project involved the different pathways of the College - digital systems, multimedia visual communication, graphic and printed productions - and was organized in four axes:

- (i) collecting general information on noise;

¹¹ <https://eduscol.education.fr/pid23341-cid47459/-sciences-a-l-ecole.html>

¹² <https://eduscol.education.fr/pid23341-cid47459/-sciences-a-l-ecole.html>

- (ii) determining the origin of noise in the College;
- (iii) informing about the impact of noise on health and learning;
- (iv) making prevention and actions at College

One of the first actions carried out concerns the realization and analysis of an online questionnaire filled by the students and teachers. This step enables to get feedback about the feeling of the participants in terms of noise at College and in particular to determine the main “noise black-spots” in the College among which the workshop of printing facilities was emphasized.

Following this diagnosis, the UMRAE team takes part a first time in the project by presenting generalities about noise (physical mechanisms, health and learning effects, measurement...), in the form of a short lecture and concluding by a description of the practical work that will be the subject of the second intervention of UMRAE. These latter aimed at producing a noise map of the workshop of printing facilities based on measurements performed by the students with their own smartphones thanks to NoiseCapture app. The methodology has consisted in making markings on the floor in order to form a grid of one-meter spacing measurement points indexed with a letter symbolizing one of the cartesian directions and a number for the second direction (A11, B13, etc., Figure 3). This first step was realized by the students the week prior to our intervention (around one thousand marking points). Then, for the second step, all smartphones of the students were first calibrated by means of a reference measurement with a Class I sonometer. Afterwards, the students were organized into pairs so that one of the students measures the equivalent sound pressure level $L_{Aeq,10s}$ above a marking point and the other postpones the value into a table with the corresponding point index. Thus each pair of students moved in the workshop from one marking point to the other until all marking points were “captured” by the school class. A Python script was especially implemented, which generates the grid of measurement points and related indexes in order to prepare the floor marking step, and which concatenates the tables filled by the different students pairs after the measurements and interpolates the data in order to build the noise map. Two situations of printing machines use were assessed as shown at Figure 4: with all printing machines in operation (extreme scenario) and with only few machines in use (regular practical work scenario).

Other actions were carried out by the students such as the making of prevention films about noise as well as the design and conception of awareness campaign leaflets and posters. This project entitled “*Le bruit et nous*” (“Noise and us”) was selected to participate in the final of the “CGénial” competition that was held on 25 May 2018 at the “Cit  de l’Espace” in Toulouse and received the “CG nial” diploma.

3.4 “Educational kit”

Following the success of the first experiment carried out within the framework of the CG nial competition, an ed-

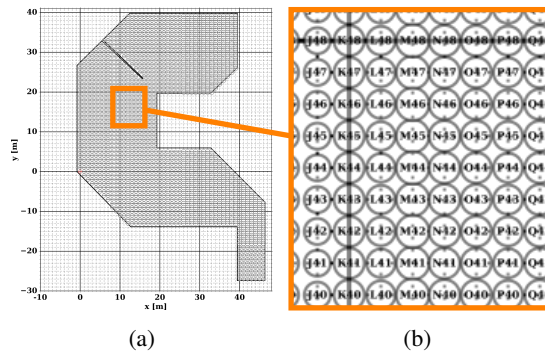


Figure 3: (a) Workshop of printing facilities and (b) grid of indexed measurement points.

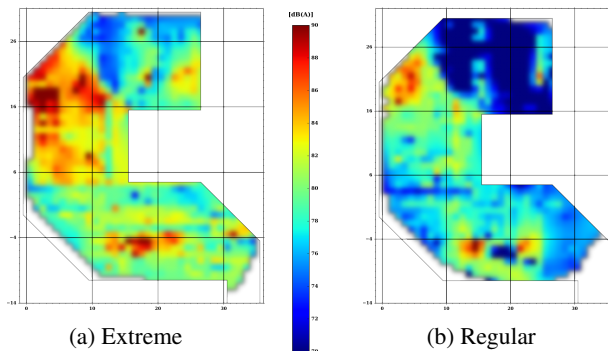


Figure 4: Noise maps of the printing workshop with (a) all printing machines and (b) for a regular practical work situation.



Figure 5: Participation of the students in the National final of the “CGénial” competition at the “Cité de l’Espace” in Toulouse (2018).

educational kit has been implemented. This latter is aimed at teachers who wish to raise awareness about noise and to organise a measurement campaign in their school and contains, among other, the following items:

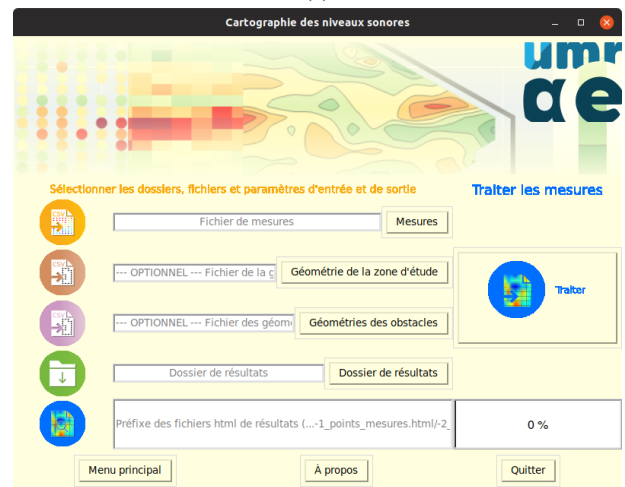
- resource documents (presentation slides or tutorials, provided as .pdf files), allowing the introduction of all the concepts inherent to environmental acoustics;
- a software allowing to drive, *via* a playful graphical interface, python scripts and that allow:
 - to generate the grid of points with user-

adjustable resolution (figure 6(a)) on the basis of a .csv file that contains the geometry of the room envelope;

- to produce 3 types of noise maps (measurement points, interpolation grid and isosurfaces) by optionally taking into account room geometry and the location of eventual obstacles (*e.g.* machines), before exporting them as interactive .html files that are displayable in any web browser (figure 6(b)).



(a)



(b)

Figure 6: User interfaces that enable to generate the grid (a) and to produce noise maps (b).

In order to test this educational kit, a collaboration with a school class of woodworking students from the Duguesclin Arts High School (“Lycée des métiers d’art Duguesclin”) of Auray (France) was initiated. At the instigation of the physics-chemistry teacher, it was undertaken to map the sound levels in the woodworking workshop (figure 7), which is equipped with nearly 15 woodworking machines and a ventilation system, and is 19×24 square metres in size.

The first step consisted in marking the measurement points on the ground of the workshop but, contrary to the



Figure 7: Partial view of the woodworking workshop (Duguesclin Arts High School of Auray, France).

experiment carried out at the Lycée Gutenberg for which square patterns on the ground made this marking step easier, these points were here materialized with the help of stretched ropes on which falling ropes were positioned every 1 m (the chosen grid size). Thus, with this spatial resolution, 437 points had to be marked over columns from A to S and rows from 1 to 23 (this task took about 4 hours).

Once done, the calibration process of student's smartphone was achieved. The values were compared to an already calibrated smartphone with an acoustic calibrator.

This was followed by the measurement campaign, which took place according to three scenarios ¹³ :

- Scenario 1: machines off;
- Scenario 2: machines turned on;
- Scenario 3: machines in action (wood has been cut).

Eight pairs of students were formed, each equipped with a calibrated smartphone and a paper sheet with the points indexes and coordinates on which the measurements had to be performed. Since noise sources were relatively stationary and the number of points relatively substantial, each measurement consisted in 5-second captures and the equivalent sound levels only were recorded (with one decimal place). Each pair of students was given one or two columns of the grid. Thus, around one hour and a half were necessary to carry out all the measurements, under the 3 conditions mentioned above.

All paper sheets were then digitally transcribed in a spreadsheet, which allows to produce a table by scenario. The three tables were finally treated by means of the educational kit software and gave the three noise maps given at figure 8.

3.5 “Week outside of the classroom”

As part of the pedagogical curriculum for first-year students in the Faculty of Geography at the University of Nantes, students are invited to spend a week “outside the classroom”. The objective of this week is to have a landscape reading on a field and an object of study, to gain autonomy and become familiar with the work of geographer.

¹³ For all scenarios, a ventilation system was in operation.

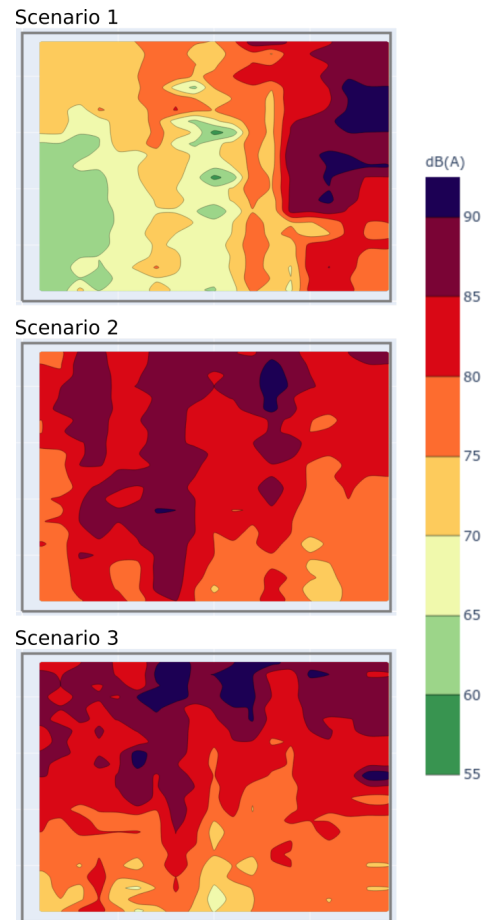


Figure 8: Resulting isosurfaces for the 3 scenarios in the woodworking workshop of the Duguesclin Arts High School of Auray (France).

In 2019 and 2020, the theme was the discovery of the soundscapes of Nantes. Each year, about 120 students went to their field in groups of 5 during 3 afternoons. The week was divided into half-day workshops, covering free listening in a predefined area, familiarization with the concepts of physical and perceptive acoustics through an intervention by UMRAE members, participatory measurements, collection of perceptual data, and work towards an oral restitution at the end of the week.

Tuesday afternoon was devoted to collecting physical and subjective data on 20 listening points per group, located on the pedestrian and road network. In total, 650 listening points were investigated over the two years. For each of these points, 3 minutes of measurements (L_{Aeq} and L_{A90} were calculated) were carried out using the Noise-Capture app. In addition, 1 to 5 students filled questionnaires on their perception of the sound environment (circumplex model of affect, time presence of sound sources, temporal structure of the sound environment...).

The physical data collected *via* the application allowed the students to confront the physics of noise in a ludic way, and to have a material to relate to: (i) the free reading of the soundscape they had been able to make, (ii) the perceptual data they had collected. At the same time, a geospatial analysis of segregated sound space data was presented the



Figure 9: Highlighting of the acoustic transmission through a wall based on a scale model of room.

last day. This was an opportunity to show them the collective interest of the data collected.

4. INTERVENTIONS FOR TEACHERS

The NoiseCapture application was also used for introducing basics in building acoustics to teachers. For practical reasons, models were used and the study frequency range was then adapted. The following well-known acoustic phenomena were then highlighted: stationary phenomena in rooms, acoustic absorption by walls and acoustic transmission through walls.

The natural modes of a room were highlighted using a scale model (figure 9). A sinusoidal sound source is emitted thanks to a smartphone sound generator positioned in an angle of the scale model and the sine wave frequency is adjusted to match its natural frequencies. The smartphone that records the sound level is then moved around the room in order to observe the room nodes and antinodes and thus to highlight the longitudinal and transverse modes.

The influence of the absorbent walls of a room was then illustrated in a simple way by measuring the sound level in the room with and without absorbent. This experiment allows to estimate the acoustic gain of a room with one, two, three or four absorbent walls.

Afterwards, the acoustic transmission between two rooms separated by a single wall was highlighted. First, two separating walls of different densities (plaster and balsa) were used to show that, for a given excitation frequency, the higher is the density, the lower is the acoustic transmission, which provides better acoustic insulation. In a second step, for a given separating wall, it was demonstrated that the more the excitation frequency increases, the lower is the acoustic transmission, which illustrates the mass frequency law. To carry out this exercise, a smartphone with a sound source generator application was placed in one of the two rooms (the emission room) and the sound level was measured thanks to NoiseCapture with a second smartphone in this emission room and in the reception room. The acoustic transmission was then estimated

by calculating the difference between the two sound levels.

Finally, the acoustic transmission between two rooms was illustrated and the effect of a double separating wall was demonstrated by comparison with a single separating wall case (figure 9). The objective here was to show that, for equivalent densities, a double wall operating on the principle of the mass-spring-mass system offers better sound insulation (lower sound transmission) than a simple partition wall. This experiment was carried in a similar way as the previous one.

5. GENERAL PUBLIC EVENTS

5.1 Bastia NoiseCapture Party

In order to set up actions to reduce noise pollution on its territory, the Bastia agglomeration (Corsica, France - 60,000 inhabitants) wanted to initiate the approach through a first step of public awareness. To this end, a Party was organised (October 5th, 2018) with the help of NoiseCapture members. This event, which was aimed on the one hand at high school students and on the other hand at the general public, took place in two parts:

- 1 afternoon, dedicated to two classes of students in ninth grade (high-school) (about 40 students - less than half of whom were equipped with an Android smartphone -, accompanied by 4 teachers)
- 1 meeting time, in the late afternoon, open to the public.

In both cases, the team members were able to present the approach, address the issues raised by noise pollution, calibrate the smartphones (figure 10) and finally accompany the participants in using the Noisecapture app and carrying out measurements for the party. Then, the party has been extended for two weeks during which anyone was free to take measurements and feed the map.¹⁴



Figure 10: Smartphones calibration step before starting the party

¹⁴ http://noise-planet.org/map_noisecapture/noisecapture_party.html#AGGLOBASTIA2018

As a result, during this 2 weeks, 19 contributors made 507 measures (more than 50,000 points) for a total duration of 16 hours and 37 minutes. The figure 11 illustrates this success.

The closing plenary gave rise to a restitution in front of the students, the teachers, elected representatives as well as journalists. It served as a basis for communication and awareness-raising among the inhabitants and resulted in numerous press articles.¹⁵

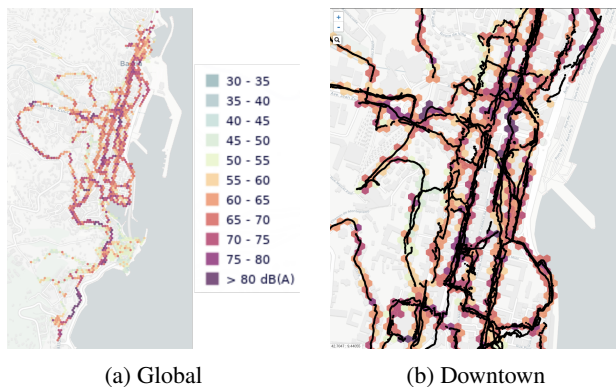


Figure 11: Resulting map, on Bastia city (a) and on the city centre (b) with measurement points (black points).

Finally, this experience also led to a complementary work with one of the two classes, which had the particularity of having classes in French and Corsican (a regional language still very active). Thus, with the help of one of the bilingual teachers, the students translated the NoiseCapture application in Corsica using the open platform Transifex¹⁶ used by the NoiseCapture team to translate the app.

5.2 Other NoiseCapture Parties

Many other parties have been held. Among the 26 parties co-organized by the team,¹⁷ 13 were dealing with education since 2017 in 4 countries (France, Spain, Italy, Ecuador).

Very encouragingly, some of these parties tend to be renewed every year. This is mainly due to the fact that the co-organizing teachers have integrated NoiseCapture in their pedagogical program (e.g. Universidade da Coruña, Immersion Science...) and because through the exchanges, a real relationship has been established with the NoiseCapture team. In this respect, it was following the organization of two parties at the University of Salerno that Claudio Guarnaccia, the organizing professor, became the first ambassador of NoiseCapture.

6. CONCLUSION

The NoiseCapture application, initially developed for the purpose of environmental noise assessment, has been em-

ployed in various educational contexts and with different types of audiences. The application constitutes an interesting interactive medium for both training in acoustic measurement and teaching acoustic basics. The paper presents thus several teaching interventions with secondary school teachers, middle school and university students, which met with a very positive reception from the participants. Other interventions addressed to the general public in the form of NoiseCapture parties are also presented that offer the opportunity both to train the participants to the acoustic measure in order to ensure optimal quality of measurement and to raise their awareness of the effects of noise especially on health. All the NoiseCapture team hopes that new ambassadors will join the community and will give rise to new applications of NoiseCapture in various contexts.

7. ACKNOWLEDGEMENTS AND FUNDINGS

The authors would like to thank all the people who allowed and still allow this ecosystem to live, in particular our 4 ambassadors, the organizers of the NoiseCapture parties and also the many contributors (more than 65,000 since the beginning of the project) who feed the world map *via* more than 100 daily measurements.

The NoiseCapture ecosystem was initiated and continues to be developed, in particular thanks to the funding obtained within the framework of the following projects: ENERGIC-OD,¹⁸ co-funded by the European Union and the GeoPAL platform¹⁹; CENSE,²⁰ funded by the French National Research Agency (ANR) (16-CE22-0012); "Plan Régional Santé Environnement-Grand Est" (PRSE Grand Est)²¹ (Regional Environmental Health Plan).

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¹⁵ <https://www.corsematin.com/articles/la-communaute-dagglo-de-bastia-a-lance-la-chasse-au-bruit-87361>

¹⁶ <https://www.transifex.com/LAE/noisecapture/>

¹⁷ http://noise-planet.org/noisecapture_party.html

¹⁸ <https://www.energic-od.eu/>

¹⁹ <https://www.geopal.org/accueil>

²⁰ <https://cense.ifsttar.fr/en/>

²¹ <http://www.grand-est.prse.fr/>