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Design of urban furniture to enhance the soundscape: A case study

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ABSTRACT

In modern urban scenarios all the aspects of the historical heritage, including public open spaces and ancient buildings, have to meet the high increase of density of infrastructures and constructions, with the consequent change of visual and sound environments. This in turn affects people's quality of life. Because of the growing interest on this problem, this study investigates the relationship between soundscape and design solutions for urban furniture, considering technical and environmental feasibility of the designing process, from the materials characteristics, to the acoustic and psychoacoustic impact of the tool on the user. The process includes the acoustic suitability of 3D printing materials, the suitability of acoustic design using software simulation, the experimental assessment of the performance of the 3D printed prototype, and the statistical evaluation of the chosen studying parameters and conditions. This paper describes all the stages of the designing process, with a focus on the study of shapes and volumes of the prototype and on its impact on the user's perception. FEM simulations and experimental tests performed in a semi-anechoic chamber allowed to validate the design process. These analyses proved that the designed prototype of urban furniture can not only positively influence the physical environment but also the psychoacoustic perception of it.

Keywords: soundscape; psychoacoustics; urban furniture; additive manufacturing; Finite Elements Method.

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1. INTRODUCTION

Nowadays there are several different ways to manage the environmental acoustics in open public spaces [1]. Many of them are related to obstructing sound propagation paths between the source and the receiver, commonly using sound absorbing barriers made of materials such as concrete, wood, metal, or green strategy through trees implantation [2]. Designing correctly such a tool is then a fundamental part of the soundscape management of a certain public area. The design of the urban furniture is of primary importance and becomes a social experiment due to the fact that it is addressed to people, who are a social factor.

As stated from the EU Directive on Environmental Noise [3] it is of primary importance to gain certain levels of noise during the day and night time. This can guarantee to the people a limit of exposure to sounds in public spaces, which increasingly grew during the last fifty years due to the wild urbanization worldwide. According to Fritschi et al. 30% of the EU population is exposed to noise levels exceeding 55 dB(A) during night time [4].

However, since the definition of Shafer [5] of the soundscape concept, the modern acoustics has led to a new methodology which is more focused on people's psychoacoustic perception of open spaces, going beyond the standard descriptors, as the A-weighted Sound Pressure Level (SPL), and meeting the idea of Shafer and its new discipline.

The use of the acoustics subjective sphere is also encouraged by the International Organization for Standardization which defines the concept of soundscape as "the acoustic environment as perceived or experienced and/or understood by a person or people, in context" [6]. So it is clear how this new acoustic approach put more effort on the enhancement of the more pleasant sounds rather than the mere reduction of the noise level [7]. However, to describe this new approach clearly are required new type of descriptors [8-10] focused on people perception in specific soundscape environments: psychoacoustic parameters.

Starting from the outcomes of previous analyses, the present research aimed to investigate the potential of designing elements in terms of soundscape and psychoacoustics. The case study for this research was identified in the regeneration project of the green area of Valley Gardens in Brighton & Hove [11,12,13], shown in Figure 1, which highlights how the proximity of the park to a street affects negatively the park soundscape quality and the use of itself. This in turn puts a restriction on the social activities and the potential appreciation from the community of such a crucial place, for the city of Brighton [14,15,16].

Figure 1. Street view of Valley Gardens.

The study tried to solve this problem using specifically designed street furniture that should enhance the user's perception of the soundscape of the park, without affecting its visual perception, by the application on already existing street furniture such as benches. Firstly, to demonstrate the feasibility of the design process, a material analysis and selection has been processed in terms of acoustic and physic characteristics. Then the design development and optimisation have been carried out from a FEM physic simulation stage. This led to a modular designed screen, built through 3D printing, which could allow not only a localised noise control coming from a certain direction, but also change sound characteristics in terms of psychoacoustic parameters and soundscape parameters. These parameters have been selected with the aim of studying the capability of the prototype to facilitate the perception of desirable sounds coming from the park, which can be considered as one of the most important features influencing the global assessment of public open spaces quality [17]. The selected parameters have been used in the evaluation of the recorded data from the anechoic chamber tests through a descriptive analysis of the effectiveness of the screen on the user and through a statistical analysis on head position effect, source position effect, and head-source position interaction.

2. METHODOLOGY

2.1 Development of a specific design to enhance the soundscape

To conduct the study, it has been fundamental to investigate the acoustic properties of ceramic powder, polylactic acid (PLA) based filaments and acrylonitrile butadiene styrene (ABS) based filament, which are different 3D printing materials. At a first stage this was conducted using the data sheet from the manufacturers reporting physic data of each material. Then, it was necessary to use the impedance tube (tested samples showed in Figure 2), to measure the normal incidence sound absorption coefficient.

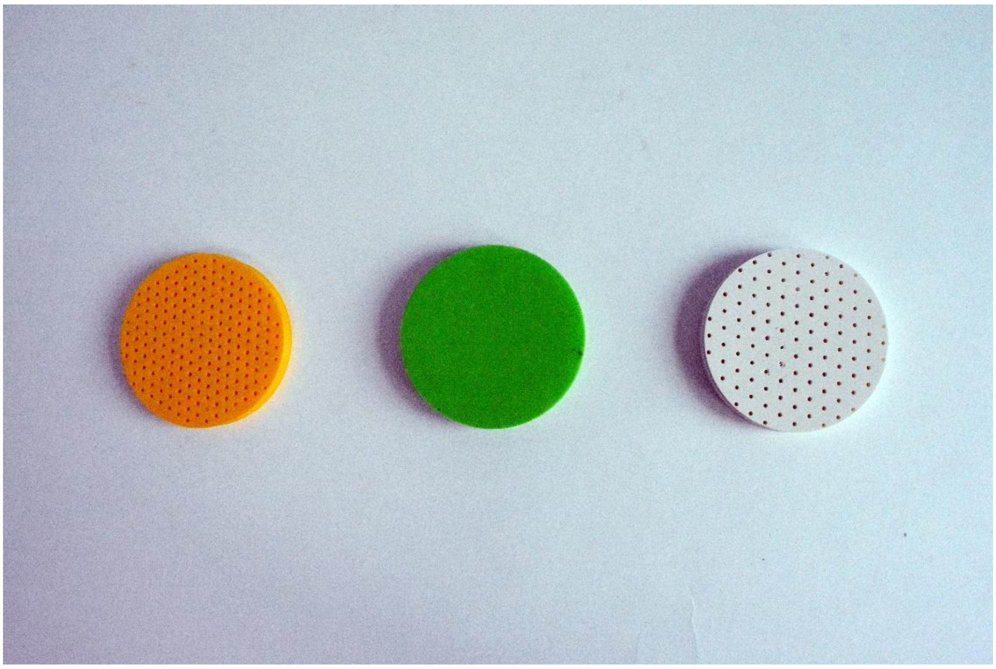

Figure 2. Picture of the three samples for the impedance tube test.

In this following stage the study was carried out just on the two typology of PLA, ColorFabb Signal Yellow and Fenner Drives NinjaFlex [18]. ABS wasn't chosen as it comes from petroleum processing and it is non-recyclable, whether in terms of ecological aspect polylactic acids (PLA) are less affecting, while they are created from processing any number of plant products including corn, potatoes or sugar-beets. Ceramic powder was excluded from the test because of its less suitability for the project in terms of appealing on the user in urban open space dynamic context.

Between the samples studied, two (made of basic PLA ColorFabb signal yellow) were designed with a perforation percentage of 25% and 50%. The third one was produced using the Fenner Drives NinjaFlex material using a mere extrusion with 35% of fill density.

The results highlighted that the most suitable material to continue the study was PLA NinjaFlex, since it was more malleable in terms of being shaped and flexible, even if the sound absorption characteristics were similar to the simple PLA [19]. These values were then compared with most common materials used as acoustic and street furniture devices, such as smooth and coarse concrete, plywood and wood panels [20]. The comparison is shown in Figure 3. Sound absorption coefficients used as references are evaluated in diffuse sound field conditions. It is seen that the selected 3D printing material is more suitable than other conventional materials, not just because it can be processed through design and printing stage easier, but also because it is superior to all the other materials in terms of absorption coefficient.

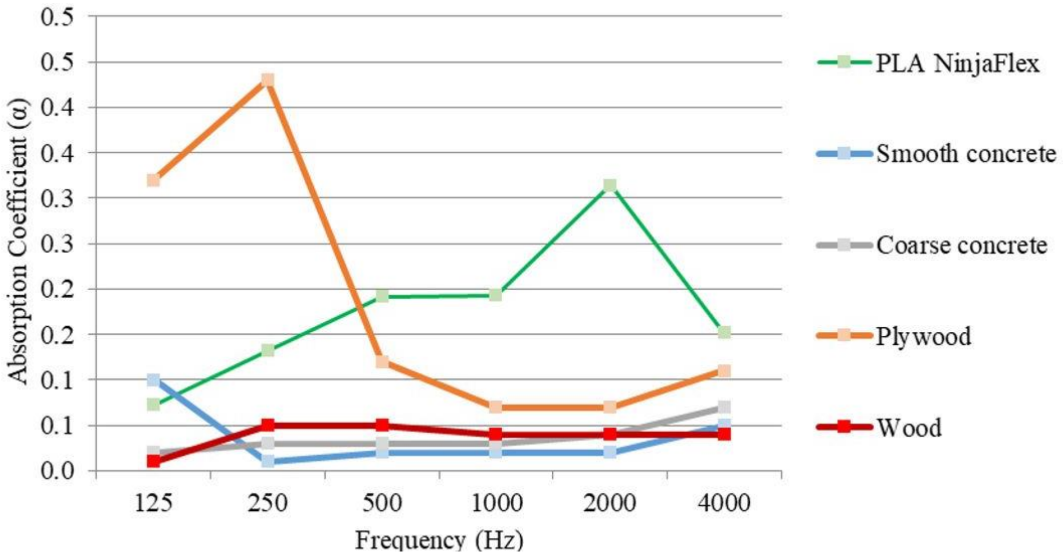

Figure 3. Comparison with absorption coefficient of other materials used for urban furniture.

In the same time, a design concept has been proceeded, considering the already existing models of sound screens and other devices for sonic environment management, such as loud-speakers placed inside parabolic screens or outside street screens. The designed prototype has aimed to allow a significant reduction in terms of noise level produced by the traffic at the specific receiver's position, and in the same time to be integrated in the current landscape without affecting the visual. The receiver position was assumed with the head of the user horizontally central to the screen and with ears height placed at 1.1 m from the ground which is representative of the average real condition of the position of the ears. In fact, this measure took into account the following assumptions: seat height at 0.5 m from the ground, relative ears position for a child or a short person at 0.8 m of height while relative ears position for an adult or a tall person is at 1.4 m of height. Moreover, as the main aim was to build a prototype which was not visually invasive and that could be integrated in the already existent street furniture, the design process was focused on a middle dimension model.

After the choice of the design strategy, it was necessary to realise a numerical model, using a finite element analysis and to simulate a set of boundary conditions for the frequency domain that could be replicable in a real test. At the beginning a 3D model of boundary box measuring 4 × 4 × 2.2 m was built. To recreate the average conditions of the general vehicles engines which use to cross the street close to the case study park of Brighton [21], the source was set as a 0.25 x 3 m rectangular surface, with a height assumed at 0.8 m. Then, within the boundary box, an emission of white noise was set in order to come out from the source surface directed to the inside of the box. The sound power level was assumed as 80 dB. Moreover, a study line was set with a parallel direction to the y axis and a height of 1.1 m (for the reasons explained above). This was done so as to evaluate the sound propagation (250 Hz) considering different distances from the source. During the whole design optimisation process, to recreate the conditions of the screen over a bench, the 3D model of the screen was placed at the centre of the box, at 0.7 m of height, and 2 m away from the source. PLA NinjaFlex's acoustic properties measured using the impedance tube have been assigned to the 3D model in order to perform a design optimisation process.

The shape of the model was studied through a FEM physical simulation software package, COMSOL Multiphysics, with the aim of including also the diffraction of the acoustic wave coming from the surface source, succeeding in to achieve a quiet point where people can perceive mostly pleasant sounds from the front direction. The FEM method in particular, allowed to study the behaviours of the acoustic sound wave in all the points of the space.

This stage was fundamental in the discussed process, because a detailed physical simulation helped to improve the design stage in detail finding the best solution in terms of costs and benefits. In particular, five design options were investigated. Different criteria were used to shape the prototype. For example, the first case was a simple flat screen designed as parallelepiped with the dimensions of 1.8 x 1 x 0.06 m (Figure 4), whether in the second one the shape has started to be more defined in order to experiment and observe the consequent changes in the physic simulation results. Its geometry was a flat extruded trapeze with shorter base 1.4 m long, longer base 1.8 m long, with a height of 1 m and a thickness of 0.06 m. The reason for this choice was the facility to change the outline and analyse the results in terms of physic simulation. Differently, in Case 3 the evolution concerned the observation of the physic simulation changes adding an extension of the screen in a plane perpendicular to the one of the main body. In this case one of the corners of the trapeze has been bent down so the part that originally was a wall then is a canopy. The geometry was an extruded trapeze with shorter base long 1.4 m long, longer base 1.8 m long, a thickness of 0.06 m, the upper corner has a height of 1 m while the shorter has a height of 0.55 m. Continuing the evolution of the shape in Case 4 was experimented a new form of the canopy, the criterion followed here it was forging the top part of the screen with curves to examine if the diffraction changed with it. Shorter base was again 1.4 m long, longer base 1.8 m long, a thickness of 0.06 m, the upper corner has a height of 1 m while the shorter had a height of 0.55 m, and the curve of the canopy creates 3 concave curves (two directed down and one directed up). Finally, Case 5 design was made following the considerations acquired through the previous physics simulations plus the criterion of suitability of the model to be printed by the 3D printers. So, to better concentrate and direct the diffracted rays, two wings were applied laterally. The canopy became horizontal but the shape remained curve in the main wall of the screen. The base was 0.6 m long while the upper part was 0.4 m long. The whole screen thickness was 0.2 m.

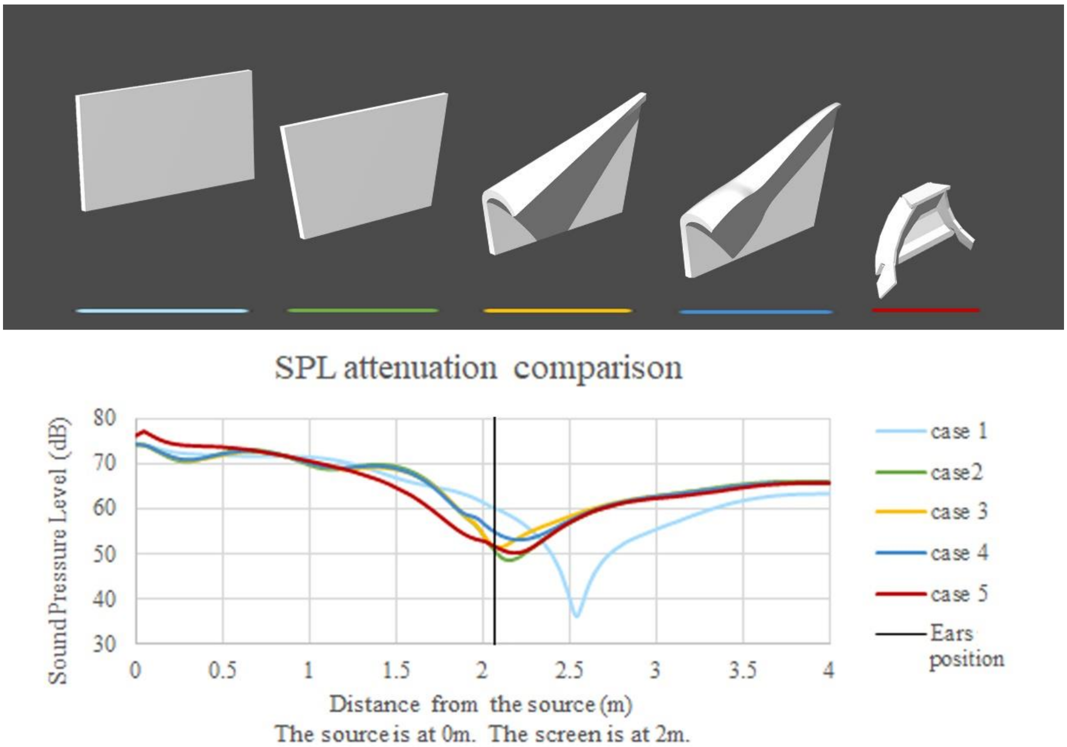

Figure 4. Render of the 5 designed cases studied within the physic simulation and graph of the SPL attenuation through the design optimization process referred to 250 Hz.

2.2 Experiments to test the effectiveness of the screen

After the design process (results in Figure 2 and 4), a test in a semi-anechoic chamber at the University of Sheffield was performed in order to evaluate the perception impact of the designed prototype on the user.

For the setting of the boundary conditions, the model was placed on a wooden panel to simulate the real conditions of application on a street furniture (such as a bench), as shown in Figure 5b. The semi-anechoic chamber also simulates the real screen context (as in public open spaces the ground is semi-rigid as the ground of the chamber). The net volume of the chamber was of 31.1 m^3 (3.6 m x 3.6 m, height 2.4 m): the chamber respected the requirements of Annex A of the ISO 3745:2012 [22]. While for the test, it was not possible to replicate exactly the conditions as those set in the physical simulation stage, a loudspeaker (model: HS7 powered studio monitor Yamaha) was used alternatively to those conditions. The speaker was placed two meters away from the screen and it was moved through a linear direction in five different positions respectively to the screen (Figure 5a). This was set in order to have a wider evaluation on the possible configurations of the real context where the prototype should have been used (so assuming the sound coming not only from the back of the user but also from a more lateral direction). For each measurement, a continuous broadband white noise signal of 10 seconds was produced.

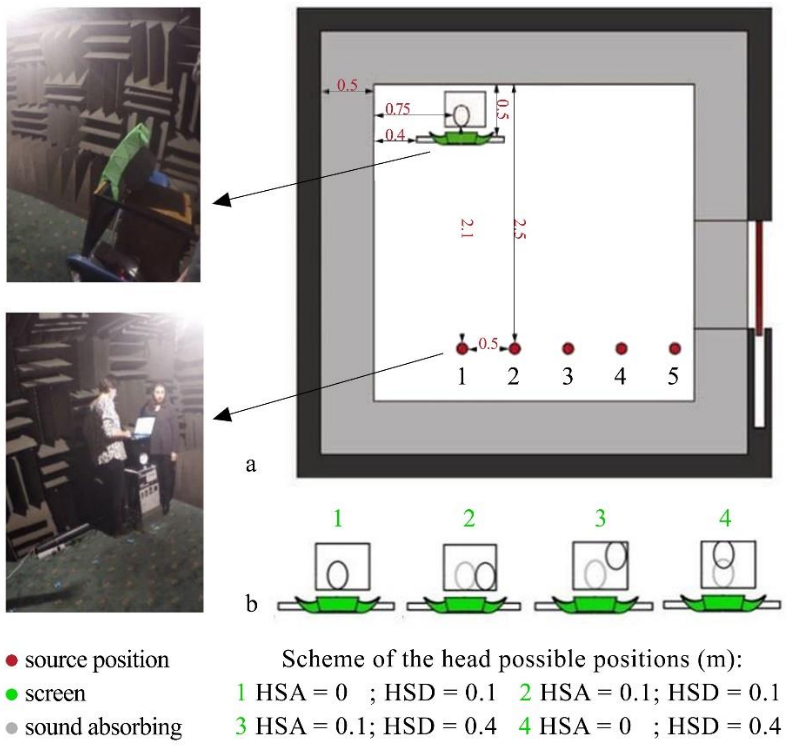

Figure 5. Scheme of the anechoic chamber configuration (a) and of the binaural dummy head positions (b).

A dummy head (model: Neumann KU 100 Binaural Dummy Head Microphone System) was placed 0.1 m away from the screen in the opposite direction of the sound source. The head itself was relocated for each position of the source in 4 different places: moving it perpendicularly to the screen (Head-Screen Distance = HSD) with distance of 0.1 and 0.4 (Figure 5b) and in a parallel way respect to the screen (Head-Screen Angle = HSA), with the head at the centre of the screen first and moved then of the right of 0.1 m. The analysis was carried out with two different configurations, with and without the screen, to evaluate the possibility of an enhancement in the soundscape performance of the design element. Forty measurements were performed in total.

2.3 Data Analysis through Acoustic and Psychoacoustic Evaluation

The methodology of this study includes an analysis of the data collected in the semi-anechoic chamber performed through the HEAD Artemis 11.0 software. In order to evaluate the effect of the design screen in the experimental soundscape environment, the present research has been developed through the study of a physic parameter, such as SPL, and psychoacoustic parameters such as Loudness (N), Roughness (R), Sharpness (S) and Fluctuation Strength (FS).

Perception of sounds involves a complex chain of events to interpret the information contained in sound signals emitted from sound sources [23]. For the purpose of obtaining a complete evaluation of the design potential in soundscape management, it is necessary to consider two different spheres of study: an objective one consisting in physical parameters, and a psychoacoustic one made up of psychoacoustic components. While sound parameters (such as SPL and Insertion Loss, i.e. difference in SPL measured with and without the screen) can help in the study of the physical tolerance of the human organ of auditory perception, psychoacoustics is the science of sound perception, investigating the statistical relationship between acoustic stimuli and hearing sensations.

The following section examines the variations of the analysed parameters expressed as arithmetic averages over all the values. The obtained values are expressed with respect to the two different configurations (with and without the screen), the five different sound source positions, and the four positions of the head/binaural receiver (40 averages). By means of SPL and psychoacoustic parameters analysis, 200 averages have been obtained. This process is summarized in Figure 6.

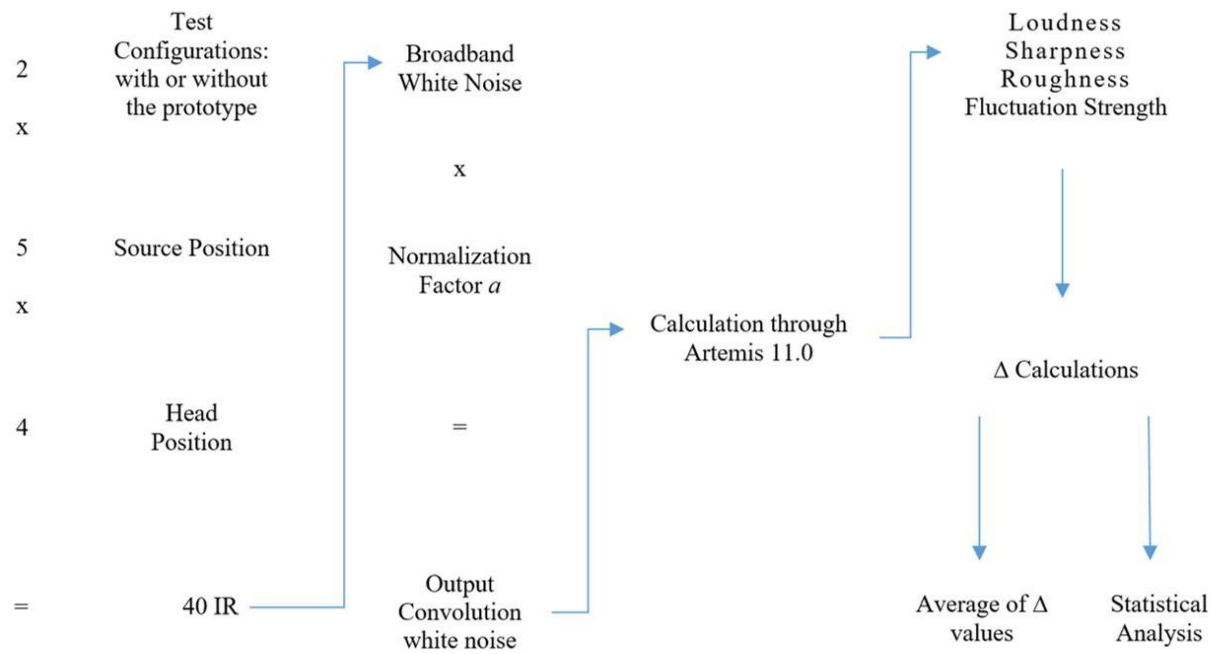

Figure 6. Scheme of the process bringing data from the recording to the final analysis.

3. RESULTS

3.1 Design process results

The design process, through the modulation of the prototype shape, generated an interesting result on the internal central part of the screen, which is the most important area for this study. Therefore, the research achieved the purpose of defining step by step a 3D model which has a focused reduction of SPL in the specific point where is supposed to be the head position. This is reached in the case study number 2 and 5, as it is clear from the SPL attenuation comparison graph (see Figure 4) where the most effective and high IL is reached in the closest position to the screen. However, Case 5 has been chosen as design base of the prototype, because compared to Case 2 it is less visually invasive and its insertion in a pleasant environment won't change substantially the visual perception of it. Moreover, a model with this dimensions is more suitable for being printed through the 3D printing technologies available.

Following the design optimization process, it has been necessary to prepare the original 3D model in the physical scale. To keep the design simple, the structure has been divided in 59 modular pieces printed across four 3D printers (model Ultimaker2 Extended) at the University of Sheffield laboratories. This has been occurred by creating a specially designed jigsaw shape in the pieces, which allows connections without the use of glue. The design process included the adaptability of the prototype to different scenarios. For example, it is adaptable to different kind of bench backrests, and, due to its modularity, it can be used both for a single or a double station.

3.2 Descriptive results on the effectiveness of the screen

In order to verify the efficiency of the design element in improving the user acoustic comfort conditions, it is necessary to detect the minimum differences in these metrics which are subjectively perceived: just noticeable differences [24], ΔMIN, for each parameter used for the analysis: 3 dB(A) for SPL, 32 phon for Loudness, 17% asper for Roughness, 0.04 acum for Sharpness, and 17% vacil for Fluctuation Strength.

Moreover, for the sake of simplicity, the source position horizontal axis is labelled with numbers from 1 to 5 as the progression of the source position in terms of distance from the point where the source is perpendicular to the screen (Figure 5b), defined as 0 cm distance, to 2 m of distance from that point (1 = 0 m, 2 = 0.50 m, 3 = 1 m, 4 = 1.5 m, 1 = 2 m). The head position horizontal axis is labeled by numbers from 1 to 4, as the progressive nomenclature of the 4 head positions.

For each psychoacoustic parameter, the value ΔX represents the difference of the parameter X have been evaluated with and without the screen interposed between the source and the dummy head. To analyse ΔX of each parameter X for a depending factor (head position or source position), an average of the values of the other factor has been used. For instance, when the content of the graph depends on the source position, it means that those values are the results of the average of the values measured in each source position with the head in the 4 positions.

The analysis demonstrates that Loudness, Roughness and Fluctuation strength are not significantly affected by the presence of the screen. In fact, according to what was previously discussed, Loudness has a maximum Δ at position 1 (both of head and source) of 2.5 phon, Roughness, which is also barely affected in general by white noise signal, is not relevant, with the average between the two configurations (with and without) exceeding 10% (1.01 – 1.10 asper), while Fluctuation Strength presents an average between the two configurations (with and without) exceeding ±10 % (0.91 – 1.015 asper). On the contrary, as far as the average of SPL and Sharpness differences are concerned, there are perceivable results according to noticeable differences listed before. For the first one, the calculated Insertion Loss (IL) reached a maximum level of 4.4 dB(A), when the source was at position 1 according to Figure 5a. On the other hand, at a distance of 2 m from the source, the IL drops to 1.5 dB(A) and in the mean distances between 0.5 m and 1.5 m it varies from 4.3 to 2.8 dB(A).

According to Figure 7a, it is proved that the closer to 1 source position the higher the IL. Moreover, it is clear from the results that, to feel the screen effect, the user has to be in its immediate proximity, as shown in Figure 7b.

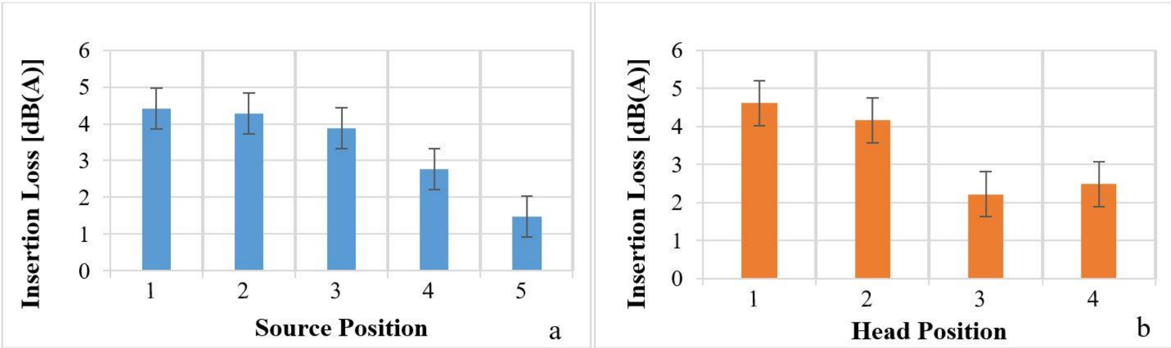

Figure 7. IL graph depending on the source position (a) and on relative head position (b).

Regarding Sharpness, the design element behaves well in its reduction over the person sitting on the street furniture where the design element is applied, with a decrease of up to around 1.2 acum. The most effective configuration of the screen to reduce sharpness is the one with the sound source in position 1 (less 1.28 acum, Figure 5a) and the head in position 2 (less 1.15 acum, Figure 5b). Even the smallest reductions are still over the minimum perceivable difference value (0.04 acum): 0.45 acum for the further source position (position 5, Figure 8a) and 0.65 acum with the head in position 3 (Figure 8b).

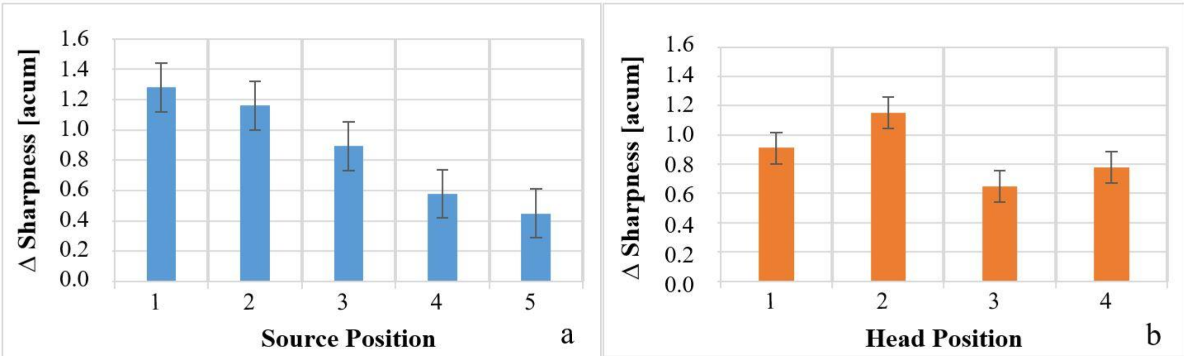

Figure 8. Sharpness difference variations depending on the source position (a) and on relative head position (b).

3.3 Statistical effectiveness of the screen

The calculated difference values of SPL, loudness, roughness, sharpness and fluctuation strength have been analysed statistically [25]. Three different variance tests have been conducted: one T-Test, two One Way ANOVA test and one Two Way Factorial ANOVA Test. Since this study aims to understand the potential of the soundscape element design, it has also been fundamental to involve psychoacoustic parameters. To better understand how people will perceive the difference between with and without the screen in the soundscape, it has been determined useful to conduct a statistical analysis of the collected data for each parameter. The results of this part of the study will be evaluated both for source position dependence and head position dependence. Once that the statistical significance has been determined, the tendency of each parameter will be discussed.

The independent-samples t-test (or independent t-test) has been used to consider the effectiveness of the screen in terms of soundscape enhancement. This means to study how statistically significant the user perceives the prototype effect in terms of quality of the soundscape, depending on the objective and subjective parameters. The input of the t-test analysis were the 20 possible combinations of head and source positions and the presence of the screen (with or without), respectively as test variables and grouping variables.

A p-value under 0.05 has been considered as significant [26]. Data regarding each parameter have been analysed both separately for left and right receiver of the binaural dummy head and considering their average (in Table 1: L = left, R = right, A = average). The t-test between the two configuration groups (with and without the screen) shows that there are significant differences between every single parameter, apart from the values of fluctuation strength relative to the right receiver.

T-Test grouping variables		SPL	Loudness	Roughness	Sharpness	Fluctuation Strength
with or without screen	L	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$
	R	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p = 0.466$
	A	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$	$p < 0.05$

Table 1. p-values calculated from the analysis of the variance for each data set of calculated Δx.

3.4 Head position effect

The ANOVA tests are necessary to verify that the variations between the various studied situations are statistically significant, and do not occur due to casual factors. Moreover, it is useful to apply a Tukey's test after the ANOVA statistical analysis. This is one of the possible POST HOC tests and it helps to understand where a significant variation of the studied groups tendency is exactly positioned. In particular, Tukey's test is a single step multiple comparison procedure based on a studentised range distribution (q). A p-value under 0.05 has been considered as significant [26]. The test has been conducted over the calculated difference values of SPL, loudness, roughness, sharpness and fluctuation strength (in terms of configurations with and without the screen). The averages have been used then as dependant variable of the ANOVA analysis and the sound source position and the head position have been the fixed factors.

From the Tukey's POST HOC test it has been highlighted that there is only a statistical significant configuration of the head and it concerns just SPL, as shown in Table 2. This means that the design element, statistically, does not influence the user's head position for psychoacoustic parameters. The SPL present a statistical variance with the head between position a and c (see Figure 5b) that are the most extreme situations in terms of common position of the user's head.

Anova Fixed Factors			SPL	Loudness	Roughness	Sharpness	Fluctuation Strength
with or without screen	1	2	0.947	0.963	0.987	0.799	0.882
		3	<u>0.048</u>	0.100	0.985	0.750	0.720
		4	0.087	0.161	0.919	0.958	0.383
	2	1	0.947	0.963	0.987	0.799	0.882
		3	0.131	0.226	0.904	0.261	0.988
		4	0.220	0.338	0.771	0.511	0.800
	3	1	<u>0.048</u>	0.100	0.985	0.750	0.720
		2	0.131	0.226	0.904	0.261	0.988
		4	0.989	0.993	0.991	0.957	0.934
	4	1	0.087	0.161	0.919	0.958	0.383
		2	0.220	0.338	0.771	0.511	0.800
		3	0.989	0.993	0.991	0.957	0.934

Table 2. p-values calculated from the analysis of the variance for each data set of calculated differences. Significant p-values are highlighted and underlined.

3.5 Source position effect

An analysis of variance test (ANOVA) has been conducted over the calculated difference values of SPL, loudness, roughness, sharpness and fluctuation strength (in terms of configurations with and without the screen) using as fixed factors the sound source positions. The ANOVA test has been necessary to verify that the variations between the various studied situations, depending on source position, are statistically significant, and do not occur due to incidental factors. A Tukey's POST HOC test was used also in this case, where a p-value under 0.05 has been considered as significant as well.

The main results, as shown in Table 3, show that there is a significant statistical difference passing from point 1 to point 5 and between 2 and 5 (see Figure 5b) for SPL, loudness and sharpness, while for roughness and sharpness it is significant in terms of the difference between point one and four (see Figure 5b). It is important to consider in this case the tendency of variation of each parameter.

Anova Fixed Factors			SPL	Loudness	Roughness	Sharpness	Fluctuation Strength
with or without screen	1	2	1.000	1.000	0.990	0.980	0.967
		3	0.976	0.965	0.884	0.426	0.051
		4	0.400	0.284	0.032	0.039	0.538
		5	0.036	0.035	0.106	0.013	0.895
	2	1	1.000	1.000	0.990	0.980	0.967
		3	0.991	0.971	0.990	0.741	0.158
		4	0.474	0.298	0.076	0.107	0.879
		5	0.047	0.038	0.227	0.036	0.999
	3	1	0.976	0.965	0.884	0.426	0.051
		2	0.991	0.971	0.990	0.741	0.158
		4	0.732	0.624	0.169	0.609	0.573
		5	0.105	0.115	0.434	0.296	0.238
	4	1	0.400	0.284	0.032	0.039	0.538
		2	0.474	0.298	0.076	0.107	0.879
		3	0.732	0.624	0.169	0.609	0.573
		5	0.611	0.748	0.965	0.974	0.959
	5	1	0.036	0.035	0.106	0.013	0.895
		2	0.047	0.038	0.227	0.036	0.999
		3	0.105	0.115	0.434	0.296	0.238
		4	0.611	0.748	0.965	0.974	0.959

Table 3. p-values calculated from the analysis of the variance for each data set of calculated differences. Significant p-values are highlighted and underlined.

Moreover, analysing the POST HOC test in its homogenous subsets part, it is possible to draw a graph to compare the means significantly different one from each other. Figure 9 shows tendency of parameters variation depending on the source position, and it can be seen that the overall variation of the mean variation decreases from point one to point five. For SPL it happens gradually in a semi-parabolic way, while for loudness and sharpness, the tendency is the same, apart from the unit interval that is shorter. Roughness shows a similarity as well, even if the interval where it decreases is even smaller, until observing the trend of Fluctuation Strength mean, which has a non-evident decrease. The SPL statistical results showed a higher difference in variation than the psychoacoustics one but, looking at the tendency, it is quite similar between SPL, loudness and sharpness, which means that, assuming a dependence from the source position, the element affects the variation of these parameters in the same way.

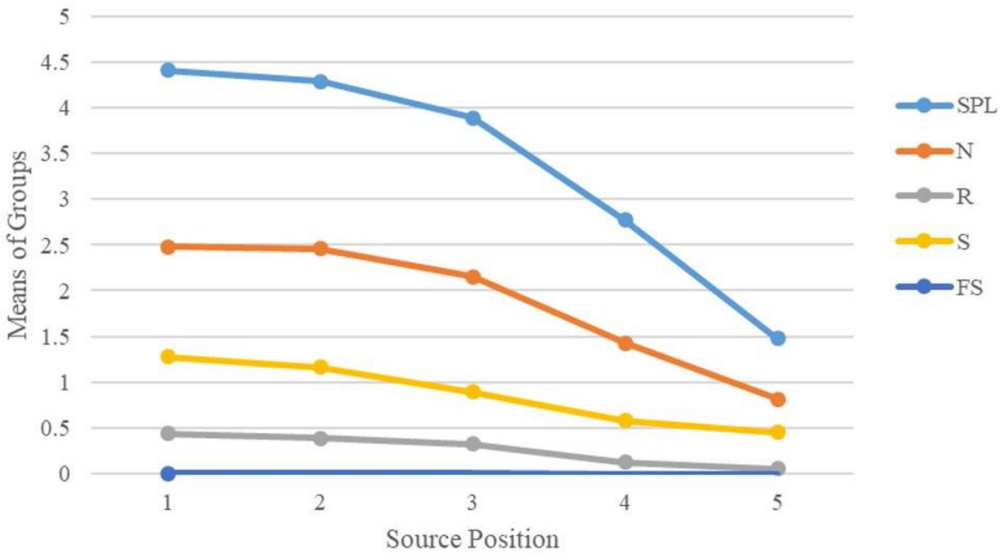

Figure 9. Tendency of parameters variation depending on the source position of: sound pressure level, loudness, roughness, sharpness, fluctuation strength.

3.6 Head and source position interaction

The statistical interaction between the head and the source as fixed factors has been analysed. The two-way ANOVA compares the mean differences between groups that have been split on two independent variables (called factors). The primary purpose of a two-way ANOVA is to understand if there is an interaction between the two independent variables on the dependent variable, in this case head and source position.

First of all, the available data had to be organised in a specific form to set the dependent variable measured at the continuous level (i.e., they are interval or ratio variables as the Δ of each evaluated parameters) and the two independent variables consisted of two or more categorical, independent groups (Source Position = SP, Head Position = HP). Moreover, checking the absence of significant outliers, it is necessary to obtain independence of observations, which means that there is no relationship between the observations in each group or between the groups themselves.

As in the previous cases, a p-value under 0.05 is considered significant [25]. The statistical significance does not tell the size of the effect, so for Two Way ANOVA test, it is necessary to introduce a new element, which is eta squared (η_p^2). The Effect Size (E.S.) is used to quantify the size of the difference between two groups (in this case ΔParameter statistically analysed depending on the HP or on the SP). This method is particularly valuable for quantifying the effectiveness of a particular intervention, relative to some comparison between two data groups. Using Cohen's guidelines [26] [27] E.S. can be interpreted as small if $\eta_p^2 = 0.2$, medium if $\eta_p^2 = 0.5$ and large if $\eta_p^2 = 0.8$. Cohen does acknowledge the danger of using terms as "small", "medium", and "large" out of context, so for his terminology he defines:

- "small" E.S. as one in which there is a real effect but detectable only through a careful study;
- "medium" E.S. as if it is large enough to be visible;
- "large" E.S as an effect which is grossly perceptible and which is big enough, and/or consistent enough, that can be seen evidently.

The results show that for all the parameters (psychoacoustic and not) the p-values are always over 0.05, meaning that there is not statistical significance between the interaction of the head and the source position. Besides, the η_p^2 value is over the minimum range on the most of the case, and in particular it is over the small significance for Δ SPL and ΔRoughness, and it is over a medium significance for ΔLoudness, as shown in Table 4. This means that there is no statistical relation between the behaviour of the acoustic receiving system depending on the head or the source position. Even if the E.S. of some of the parameters analysed is small or medium. In other words, there is a common tendency between each analysed group.

Two Way Factorial Anova		SPL	Loudness	Roughness	Sharpness	Fluctuation Strength
Head and source position interaction	p	0.570	0.009	0.357	1	0.993
	η_p^2	0.348	0.665	0.415	0.014	0.124

Table 4. p-values and η_p^2 values calculated from the analysis of the variance for each data set of calculated differences between the head and the source position. Significant η_p^2 are highlighted and underlined.

4. CONCLUSIONS

The study aims to evaluate a new experimental process which moves from the study and the design of the material to produce a prototype to manage the soundscape to the effectiveness that this produces in field.

The acoustic suitability of 3D printing materials, the use of an acoustic design using software simulation, the actual performance of the 3D printed prototype, the experimentally assessed in laboratory conditions, and the statistical evaluation of the chosen parameters and conditions, allow to establish a first attempt of understanding the whole design process and all the possible potential benefits of acoustic furniture construction for soundscape purposes.

It is proved that the proposed urban furniture plays an important role in the variations of SPL and sharpness, and has a relatively small effect on loudness and roughness, while it has practically no effect on fluctuation strength. It can reduce both SPL and sharpness, respectively, by up to 4.3 dB(A) and 1.28 acum. It is possible to ascribe this fact to the element shape and the sound absorbing properties of the screen material made by a specific 3D printed structure. The sharpness reduction given by the design element represents an important result, since sharpness is a subjective acoustic parameter, strongly related to human noise perception [8].

Further investigations will lead to a programmed and fast system of planning, which may allow the designer to realise the more integrated soundscape tool solutions, with less possible waste, and with the most dynamical adaptability on the psychophysical needs of the users. Moreover, deeper study will bring to a shape improvement characterized on psychoacoustic factors, and also considering the overall soundscape design process [28-29].

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