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NOISE MAPPING OF MOTOR RACES EVENTS WITH INNOVATIVE INDICATORS

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ABSTRACT

The sound of sports cars is usually considered by spectators an important feature of the motor races since it provides a complete and immersive experience in the event. Anyway, such an event can be extremely annoying for those living nearby the circuits due to high sound pressure levels and the timing of cars' pass-byes. Not a minor concern is the psychological and psychoacoustic aspect, deriving from the perception of an intrusive presence of the circuit activity, responsible for the violation of the home comfort. First, specific noise indicators (i.e., Race Equivalent Level - REL and Lap Equivalent Level - LEL) are assessed for different races. Therefore, REL values are used to tune the sound power levels of an equivalent point-like source describing the event. Such information is given as input to a noise map modelling tool. Finally, noise map results are validated by comparing them with recorded ground truth values. The results are promising, since the final mean absolute error is 2.4 dBA. The proposed approach has the advantage of possibly considering other sources, for instance, road traffic.

Keywords: *noise mapping, motor race noise, circuit noise, NoiseModelling.*

1. INTRODUCTION

In the last decades noise pollution has become a major concern in modern society, particularly in large cities which, on the one hand, are the hub of economic and social activities and, on the other, have a high population density. This inevitably leads to having a huge amount of people exposed to high noise levels and indeed to constant dangers. As a matter of fact, demographic and economic growth inevitably goes hand in hand with an increase in noise pollution, resulting from industries and private and public transport [1] The consequences of exposure to the deriving high noise levels, however, cannot be underestimated. In fact, it might affect sleep quality and cause short-term (tiredness and lack of concentration) and/or long-term consequences (chronic hypertension, increased stress level, high night-time diastolic pressure) [2]-[13].

There is, however, another very peculiar sound pressure source that cannot be overlooked, as it mostly affects urban areas in addition to the already countless sound sources present in them: motor race events. In this type of event, the main sound source is due to sports cars, which generally do not have built-in mufflers and, in any case, do not comply with the noise emission limits of passenger cars. Taking the Italian territory as an example, the presence of 18 racetracks, 17 kart tracks, and 10 mini tracks, totalling to 45 homologated tracks, indicates that a significant number of

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individuals are surely exposed to the noise levels coming from this type of activities [14]. The 2019 Formula 1 and MotoGP events, for instance, counted nearly 7 million spectators [15], [16]. However, exposed subjects not only include spectators of the events but also citizens residing in the nearby areas. Nonetheless, literature has not many works on this specific aspect and this gives motivations for deeper investigations. For instance, Tranter and Lowes' research [17] on the impact of motor race events in Australia briefly touches upon noise pollution but takes a broad approach that does not specifically address the issue of noise emissions. In a different study pursued by Dolder et al. [18], noise levels were measured during the 2013 Formula 1 Grand Prix of Canada, and the recorded levels exceeded the value considered as a safe threshold, indicating the need for wearing protective measures. Such investigations focus on the impact of the noise emitted by the specific circuit but considering that city environments include different sound sources, the possibility of discriminating their contribution in a possible general noise map seems significantly important.
This type of map, that are required by the EU for member states, can provide meaningful information, especially when interwoven with other information such as areas vulnerable to noise pollution. Moreover, noise mapping also plays a crucial role in developing urban planning policies and raising public awareness about the harmful effects of noise pollution deriving from different sources, encouraging individuals to adopt measures to reduce their exposure to excessive noise levels.
In this work, the main focus will be to further investigate the phenomenon of motorsport race events, evaluating how their noise emissions interact with the surrounding areas and the other existing sources, through the development of noise maps. In particular, this paper will take up some key concepts deepened in [19] in which the characterization of noise emissions during motorsport events was studied. This was pursued with the introduction and implementation of two novel acoustic indicators useful for this purpose: the Lap Equivalent Level (LEL) and the Race Equivalent Level (REL), which allows predicting the total noise emission at a given receiver of a motor race by knowing the number and type of cars involved. These indicators will be used to tune a point-like source, in charge of mimicking the circuit source during the time of each race or event. This point source will be implemented in a noise mapping framework to produce maps of the motor race events.

2. MATERIALS AND METHODS

Starting from the equivalent continuous A-weighted sound pressure level (L_{Aeq}), Pascale et al. [19] defined two innovative indicators that were adopted to better describe the noise emitted during a motorsport race event: LEL and REL.
LEL has been defined as the equivalent continuous sound level immitted at a certain receiver by a single vehicle in one lap of the track, as shown in equation 1.

$$LEL = 10\left(\frac{1}{t_{lap}}\int_0^{t_{lap}} 10^{\frac{L_p(t)}{10}} dt\right) \tag{1}$$

where t_{lap} is the single-lap time in seconds and $L_p(t)$ is the fluctuating sound pressure level in dBA.
On the other hand, REL is the equivalent continuous sound level immitted at a certain receiver during a race by all the vehicles running on the track, as shown in equation 2.

$$REL = 10\left(\frac{1}{t_{race}}\int_0^{t_{race}} 10^{\frac{L_p(t)}{10}} dt\right) \tag{2}$$

where t_{race} is the race time expressed in seconds.
The main difference between LEL and REL approach and the classic one, based on L_{Aeq}, is that they are computed over a variable time interval - respectively lap and race time - rather than a fixed one. With these indicators, it is feasible to evaluate the noise produced by a single car while running a lap on the track (LEL) and the noise generated by all cars during a race (REL). As a result, LEL and REL serve as metrics that focus on evaluating the noise immitted at the receivers rather than defining the exposure. In short, such parameters could be used to characterise motorsport race events and properly approximate the emissions produced by different transits, and on the whole competition itself. In particular, REL has been used in this work in order to define an equivalent point-like source representative of the noise emissions of the whole race events. The approximation of considering the latter as a point-like source is strong but adequate for the purposes of the investigation, as the authors are interested in studying how race noise emissions affect the surrounding area.
A point source is characterized by spherical propagation, which is described by Equation 3 in a fully absorbing scenario.

$$L_P = L_W - 20\log_{10} r - 11 \tag{3}$$

where L_w and *r* are the sound power level and the source-receiver distance, respectively.

Thus, it is necessary to estimate the sound power level of the equivalent point-like source from the measured REL to provide inputs for the employed noise map tool, as shown in Equation 4:

$$L_W \cong REL + 20\log_{10} r + 11 \quad (4)$$

where r is the distance between the REL measurement location and the centroid of the circuit, in which the point-like source is positioned.

Once the point-like source power level is set in octave frequency bands, according to the REL measured during the race, the noise maps can be produced by using any mapping software. It is worth underlining that this choice leads to the production of maps on the race time basis since REL is calculated on this time span. Thus, since the standard noise mapping procedures work with time spans defined by Environmental Noise Directive [20], a proper calibration of the sources must be performed to include the circuit source within a general mapping environment.

In this application, the authors used the NoiseModelling software, developed by the DECIDE team (Lab-STICC - CNRS UMR 6285) and the UMRAE Laboratory (Université Gustave Eiffel - formerly Ifsttar), France [21]. NoiseModelling is a free and open-source software that can be used to draw outdoor noise maps on any area, by characterizing the sources, such as roads and railways, buildings, and the ground.

Usually, the NoiseModelling software offers the possibility to import the latter information from free databases, such as the OpenStreetMap (OSM) database. However, sometimes crowdsourcing datasets are not robust [22], thus some adjustments have to be made. In this case study, the major issue was related to missing buildings in the OSM of the considered area. Adding these buildings was a fundamental step to properly model the site and the noise propagation.

In addition, NoiseModelling allows considering custom sources that can be defined in any GIS environment and inserted in the simulation. The point source that mimics the circuit in this application is created in QGIS as a point layer. Its position is a centroid that represents all the sources within the circuit (cars, loudspeakers, spectators, pit activities among others) and must be selected to respect the spherical propagation assumption.

The source power levels by frequency band are set in the layer as attributes, together with the georeferenced position. The file corresponding to the source is exported in geojson format, to be imported into NoiseModelling.

At this stage, the NoiseModelling software creates a grid by using the Delaunay triangulation, considering the position of the source and buildings, to create the receivers, that correspond to the vertexes of the grid triangles. Receivers number, in fact, is increased in proximity to buildings, to also assess the wave effects. The authors decided to fix the maximum propagation distance at 1000 m and the height at which the grid, the receivers, and then the whole map refers to 1.5 m. These values have been chosen to validate the results of the mapping procedure with the field measurements taken during the case study presented in the following sections. However, they can be adjusted according to [23] to be compliant with the CNOSSOS-EU propagation model.

Both vertical and horizontal diffractions have been included in the calculation, together with the absorbing characteristics of the ground and the building facades.

Once any map is created, it can be compared with field measurements, to validate the source representation and the mapping procedure.

3. CASE STUDY DESCRIPTION

The circuit used as a case study is the “Circuito del Sele”, located in the city of Battipaglia (Italy). In subsection 3.1 the circuit is shortly described, while the data collection is reported in subsection 3.2.

3.1 Track description

The track is 1.69 km long and it is one of the largest circuits in Southern Italy. The track’s location within the Campania region and its layout are shown in Figure 1.

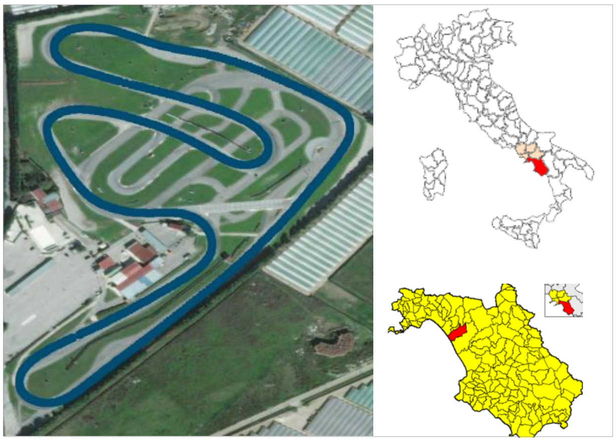

Figure 1. “Circuito del Sele” geographical position retrieved from [19].

Furthermore, it should be emphasized that the circuit is mostly flat with only some sections having a slope of about

1-2%. Even more relevant for acoustic applications, as the one presented in this paper, is the fact that the road surface is made of 6 cm-thick circuit-draining asphalt which is highly porous and draining to meet the requirements of sport federations regulations.
Table 1 reports the circuit's technical details.

Table 1. Circuito del Sele's mini-car tracks technical details (retrieved from [19]).

Length	1800 m
Max. width	13 m
Min. width	9 m
Pit straight length	~400 m
Direction of travel	Clockwise
Slope	2-3 %
Roadway width	10 m

3.2 Measurements description

Noise measurements were collected during the "*13th Superchallenge*" a competition event that took place on the 2nd of April 2023. The racing sessions were divided accordingly to the vehicle category, as reported on the official webpage of the federation [24].
The measurement interval covered eight races of the morning session, with different numbers and categories of cars competing. The categories included the so-called "minicars", that are Fiat 500 and 126, modified for racing purposes, as well as other kind of vehicles participating to the competition. Also single seater cars were present. All the cars were lightened, removing all the unnecessary parts, and provided with safety equipment. The engine and the exhaust system were modified with the aim of increasing performances, but still fulfilling the championship technical specifications and thresholds.
The measurement campaign was designed with a twofold aim: i) to measure REL values for different race events (in each octave frequency band from 63 to 8000 Hz) in order to estimate the sound power level of the corresponding equivalent point-like sources through equation 4 and to provide this information to the NoiseModelling tool; ii) to assess L_{Aeq} related to such events in different spots inside and outside the circuit area and use them as ground truth values when compared with the map results in their validation process. The first goal was achieved by placing a Class 1 sound level meter (Panasonic Soundbook MK2) in point 1 (see Figure 2), recording the linear sound pressure level (L_p) for each third-octave band from 20 to 20000 Hz with a time-frequency of 120 ms. It is worth mentioning that the instrument was permanently left in this position during the entire data collection. At this stage, the spectral history time related to the eight race events was extracted from the instrument's records. The L_p values were adjusted with the related A-weight in each frequency. From the latter, the REL values were computed in each third-octave band from 50 to 10000 Hz. Subsequentially, the REL values related to the corresponding octave bands were obtained by logarithmically summing the contribution of the central and the two lateral frequencies.
The second target was accomplished by directly measuring the L_{Aeq} on the race time basis, through another Class 1 sound level meter (Fusion 01dB). The latter instrument was set in seven different spots inside and outside the track (the reader can refer to Figure 2) during the selected race events.
It must be stressed that the two instruments were calibrated before the data collection with a reference signal of 94 dB at 1000 Hz, and their clocks were synchronized. A total of about three hours of noise data was collected.
Table 2 summarizes the obtained REL values at the first receiver (point 1) during the selected eight races.

Table 2. Measurements results at the first receiver for the selected eight races.

REL at the first receiver [dBA]								
63 Hz	125 Hz	250 Hz	500 Hz	1 kHz	2 kHz	4 kHz	8 kHz	Tot
46.4	75.9	83.0	82.2	87.7	86.6	82.1	71.4	92.1
50.5	74.9	81.1	80.4	84.8	86.5	81.4	71.9	90.7
49.7	76.5	84.5	85.0	89.0	87.8	83.4	73.0	93.6
46.9	70.4	78.9	83.6	84.5	84.1	79.7	69.3	89.8
45.9	68.2	79.4	85.7	82.6	80.1	74.1	62.1	88.9
48.7	69.3	78.2	84.0	84.9	82.3	77.5	68.6	89.4
45.6	63.1	84.0	87.7	88.1	88.0	84.1	75.7	93.8
38.2	63.3	73.2	81.8	80.2	75.2	69.1	58.6	85.1

The additional measurement points used for validation have been chosen randomly, with increasing distances from point 1, trying to avoid the presence of additional sources and with limited reflective surfaces. Anyway, the background sound levels, in some cases, were not negligible and have been considered in the results section. The positions of the selected points are reported in Figure 2 and their distances from the selected centroid of the circuit are resumed in Table 3.

Figure 2. Measurement points position.

Table 3. Distance of the measurement points from the centroid of the circuit.

Measurement points (2nd receiver positions)	Distance from the point source [m]
1	24
2	104
3	170
4	263
5	665
6	1170
7	1700

4. RESULTS AND DISCUSSION

The results of the above-described procedure are reported in this section, reporting the noise maps produced and the quantitative validation process.

4.1 Mapping results and qualitative validation

The mapping procedure described in section 2 has been repeated for the 8 selected races, by changing the source power level of the point source, according to the corresponding REL values measured in point 1 and reported in Table 2.

An example of the resulting map is provided in Figure 3 considering the first race as noise source.

It must be stressed that the map is drawn considering only the circuit equivalent source and it is built on the same time basis of the race, thus cannot be compared directly with noise maps, produced according to national and international standards.

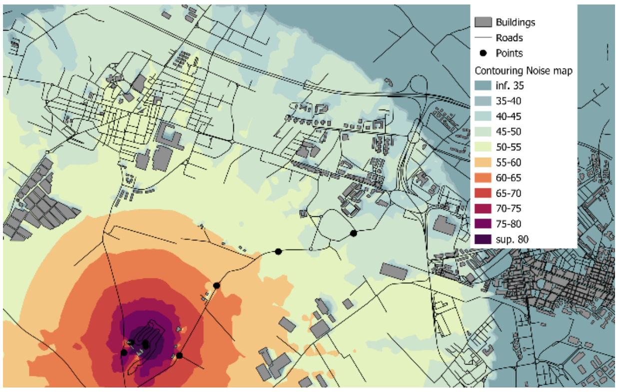

Figure 3. Simulated noise map of the first race.

It is easy to notice how the spherical propagation of the noise produced by the equivalent source is affected by the presence of buildings and other obstacles, due to reflections and diffractions. The designed pattern shows immediately the hotspot areas in which the highest levels are present and, similarly, hints which is the radius of influence of the source on the surrounding acoustic environment. The contour map areas characterized by levels similar to background noise ones, in fact, allow delimiting the circuit source influence region.

A first qualitative validation of the mapping procedure is provided in Table 4 in which the measured and the simulated L_{Aeq} intervals are compared. It can be noticed that in all the measurement points the simulated isolevel surfaces are equal or very close to those corresponding to the measured levels.

Table 4. Measured and simulated L_{Aeq} intervals at the second receiver for the considered eight races.

Race num.	2nd receiver position	Measured L_{Aeq} interval [dBA]	Simulated L_{Aeq} interval [dBA]
1	1	> 80	>80
2	2	> 80	75 – 80
3	3	75 – 80	75 – 80
4	4	60 – 65	65 – 70
5	5	55 – 60	55 – 60
6	6	55 – 60	50 – 55
7	7	50 – 55	45 – 50
8	7	45 – 50	40 – 45

In particular, looking at points 6 and 7, located further from the circuit, an underestimation is observed, probably due to the fact that the measurements in these points are affected by the background levels. For this reason, in the quantitative comparison presented in the next subsection, the measured L_{90} will be used to adjust the simulations when compared with field data.
The obtained results can be considered robust considering the complexity of the problem under study (geometry of the circuit, presence of buildings, reflections, diffractions, ground absorption, etc.).

4.2 Maps quantitative validation

The encouraging results of the previous subsection can be quantitatively confirmed by comparing the field measurements with the simulated sound levels in the selected points. To extract the simulated levels, an interpolation of the values obtained in the vertexes of the grid triangle that includes the measurement point has been done. This interpolation has been performed using a logarithmic function of the squared distance (coherently with the point-like source assumption) between the vertexes and the point as a weight. Point 1 has been excluded since one of the vertexes of its triangle coincides with the point source, thus producing a wrong interpolation output.
The results of the interpolation are reported in Table 5, together with the measured levels and the corresponding errors, calculated as the difference between measurements and simulated levels.

Table 5. Measured and simulated L_{Aeq} values at the second receiver.

2nd receiver position	Measured L_{Aeq} [dBA]	Simulated L_{Aeq} [dBA]	Error [dBA]
2	80.9	79.9	1.0
3	72.1	74.4	-2.3
4	63.3	65.0	-1.7
5	57.1	57.1	0.0
6	58.7	51.0	7.7
7	51.4	49.7	1.7
7	48.0	42.3	5.7

The mean error is 1.7 dBA, while the mean absolute error is 2.9 dBA. It is worth noting that points 6 and 7 present the highest underestimation. This is mainly due to the absence of background noise levels in the simulations, that consider only the circuit equivalent source. A possible improvement of the proposed model is to adjust the simulations by adding the L_{90} measured in each point, as an indicator of the background level. Such adjustment is basically negligible for points from 2 to 5, since they are close to the source and the circuit noise is predominant. On the other hand, points 6 and 7 observe an increase in the simulated level when adding the L_{90}, as shown in Table 6, lowering the mean error to 1.1 dBA and the mean absolute error to 2.4 dBA.
It is worth noting that the CNOSSOS propagation model [23] is designed to work on a propagation distance lower than 800 m, thus the results in points 6 and 7, whose distances are greater than this threshold, may be underestimated also because of this aspect.

Table 6. Measured and adjusted simulated L_{Aeq} values at the second receiver.

2nd receiver position	Measured L_{Aeq} [dBA]	Adjusted simulated L_{Aeq} [dBA]	Error [dBA]
2	80.9	79.9	1.0
3	72.1	74.4	-2.3
4	63.3	65.1	-1.8
5	57.1	57.4	-0.3
6	58.7	51.8	6.9
7	51.4	50.6	0.8
7	48.0	44.4	3.6

5. CONCLUSIONS

In this paper, an innovative way of mapping noise from motor race events has been proposed. The case study circuit was depicted as an equivalent point-like source whose power level was set by measuring the Race Equivalent Level (REL) defined by the authors in previous studies.
Once the source was properly tuned, simulations have been run in the NoiseModelling software, to produce noise maps of the area under study, using the CNOSSOS-EU propagation model. This model is designed to work under 800 m maximum propagation distance, thus the simulated noise levels at higher source-receiver distances should be addressed in further investigations.
The validation of the procedure has been performed using field measurements at seven points inside and outside the circuit area.
A qualitative validation of the noise level intervals has shown that the proposed approach produced robust maps, that

furnished indications about the noise hotspots and the circuit influence radius on the surrounding acoustic environment.
The comparison between field measurements and simulated levels confirmed the goodness of the procedure, resulting in a mean absolute error of less than 3 dBA. When adjusting the simulation with the background noise information, this error is lowered to 2.4 dBA, showing a good range of applicability of this procedure.
Future work will try to include the wind direction information and the merging of the circuit noise map with those resulting from other sources in the selected area.

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7. REFERENCES

[1] European Environment Agency, *Environmental noise in Europe - 2020*, no. 22/2019. 2020.

[2] D. Singh, N. Kumari, and P. Sharma, "A Review of Adverse Effects of Road Traffic Noise on Human Health," *Fluct. Noise Lett.*, vol. 17, no. 1, pp. 1–12, 2018, doi: 10.1142/S021947751830001X.

[3] C. Blume *et al.*, "Association of transportation noise with sleep during the first year of life: A longitudinal study," *Environ. Res.*, vol. 203, no. May 2021, 2022, doi: 10.1016/j.envres.2021.111776.

[4] L. Rossi, A. Prato, L. Lesina, and A. Schiavi, "Effects of low-frequency noise on human cognitive performances in laboratory," *Build. Acoust.*, vol. 25, no. 1, pp. 17–33, 2018, doi: 10.1177/1351010X18756800.

[5] D. Petri, G. Licitra, M. A. Vigotti, and L. Fredianelli, "Effects of exposure to road, railway, airport and recreational noise on blood pressure and hypertension," *Int. J. Environ. Res. Public Health*, vol. 18, no. 17, 2021, doi: 10.3390/ijerph18179145.

[6] D. Banerjee, "Road traffic noise exposure and annoyance: A cross-sectional study among adult Indian population," *Noise Heal.*, vol. 15, no. 66, pp. 342–346, 2013, doi: 10.4103/1463-1741.116583.

[7] J. I. Halonen *et al.*, "Associations of night-time road traffic noise with carotid intima-media thickness and blood pressure: The Whitehall II and SABRE study cohorts," *Environ. Int.*, vol. 98, pp. 54–61, 2017, doi: 10.1016/j.envint.2016.09.023.

[8] W. Babisch, "Updated exposure-response relationship between road traffic noise and coronary heart diseases: A meta-analysis," *Noise Heal.*, vol. 16, no. 68, pp. 1–9, 2014, doi: 10.4103/1463-1741.127847.

[9] A. Seidler *et al.*, "Aircraft, road and railway traffic noise as risk factors for heart failure and hypertensive heart disease—A case-control study based on secondary data," *Int. J. Hyg. Environ. Health*, vol. 219, no. 8, pp. 749–758, 2016, doi: 10.1016/j.ijheh.2016.09.012.

[10] M. L. Cantuaria *et al.*, "Residential exposure to transportation noise in Denmark and incidence of dementia: national cohort study," *Bmj*, p. n1954, 2021, doi: 10.1136/bmj.n1954.

[11] F. F. Zacarías, R. H. Molina, J. L. C. Ancela, S. L. López, and A. A. Ojembarrena, "Noise exposure in preterm infants treated with respiratory support using neonatal helmets," *Acta Acust. united with Acust.*, vol. 99, no. 4, pp. 590–597, 2013, doi: 10.3813/AAA.918638.

[12] A. Muzet, "Environmental noise, sleep and health," *Sleep Med. Rev.*, vol. 11, no. 2, pp. 135–142, 2007, doi: 10.1016/j.smrv.2006.09.001.

[13] F. Minichilli *et al.*, "Annoyance judgment and measurements of environmental noise: A focus on italian secondary schools," *Int. J. Environ. Res. Public Health*, vol. 15, no. 2, pp. 1–17, 2018, doi: 10.3390/ijerph15020208.

[14] "Automobile Club d'Italia." https://www.aci.it/, last accessed on May 11, 2023.

[15] "Formula1." https://www.formula1.com/en/latest/article.grand-prix-attendance-surpasses-4-million-in-2019.61fEHE3wb7Wl8tHfP8cBTd.html, last accessed on May 11, 2023.

[16] "MotoGP." https://www.motogp.com/en/news/2019/12/04/buriram-tops-2019-spectator-billing/321351, last accessed on May 11, 2023.

[17] P. J. Tranter and M. D. Lowes, "The place of

motorsport in public health: An Australian perspective," *Heal. Place*, vol. 11, no. 4, pp. 379–391, 2005, doi: 10.1016/j.healthplace.2004.07.004.

[18] C. N. Dolder, J. I. Suits, and P. S. Wilson, "Noise exposure in the general audience of a Formula 1 race," in *Proceedings of Meetings on Acoustics*, 2014, vol. 20, no. 1, doi: 10.1121/1.4865925.

[19] A. Pascale, S. Mancini, M. C. Coelho, and C. Guarnaccia, "Acoustic Indicators for Motor Race Noise: Definition, Validation, and Tests in Simulated and Real Races," *Appl. Acoust.*, vol. 200, p. 109071, 2022, doi: 10.1016/j.apacoust.2022.109071.

[20] European Parliament and Council of the European Union, "Assessment and management of environmental noise (EU Directive)," *Off. J. Eur. Communities*, no. L189, pp. 12–25, 2002, [Online]. Available: http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32002L0049&from=EN%5Cnhttp://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:32002L0049, last accessed on May 11, 2023.

[21] https://noise-planet.org/noisemodelling.html, last accessed on May 11, 2023.

[22] F. Biljecki, Y. S. Chow, and K. Lee, "Quality of crowdsourced geospatial building information: A global assessment of OpenStreetMap attributes," *Build. Environ.*, vol. 237, no. October 2022, p. 110295, 2023, doi: 10.1016/j.buildenv.2023.110295.

[23] S. Kephalopoulos, M. Paviotti, and F. Anfosso-Lédée, *Common Noise Assessment Methods in Europe (CNOSSOS-EU)*. 2012.

[24] Program and results of the races, available at https://risultati.ficr.it/#/VAR/listpdf/13° SUPERCHALLENGE ASSOMINICAR PISTA E LIGHT 2023/2023/89/3.