

# A Case Study of Road Traffic Noise Intrusion Simulation in an Italian Archaeological Site

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**Abstract** – This study investigates the impact of road traffic noise on the acoustic environment of a culturally significant archaeological site in Nocera Superiore, Italy. Using the open-source NoiseModelling tool, simulations were conducted to assess sound levels near key landmarks, including the Early Christian Baptistery of Santa Maria Maggiore and the urban archaeological park. Results show that current noise levels exceed regulatory thresholds for protected areas, despite partial compliance with limits for high-traffic zones. Two mitigation strategies—introducing one-way traffic and banning heavy vehicles—were simulated and shown to reduce noise by 3–4 dBA, though not sufficiently to meet Class I or II standards. The findings highlight the inadequacy of current acoustic zoning and underscore the need for integrated noise management strategies to preserve the soundscape and cultural value of archaeological sites embedded in urban contexts.

## I. INTRODUCTION

Environmental noise is a relevant problem for human health and wellbeing [1]. In 2011, the World Health Organization (WHO) published a report entitled “*Burden of Disease from Environmental Noise*”, which compiled data over ten years on environmental noise in Western Europe [2]. The research focused on noise generated by major urban sources, which are aircraft, trains, and motor vehicles, and investigated the relationship between these noise sources and their impact on human health. The findings revealed that, each year, at least one million healthy life years are lost across Europe due to noise pollution, excluding noise exposure in industrial workplaces. Furthermore, traffic noise was identified as the second most significant environmental threat to public health, following air pollution [1].

In this light, noise pollution emerges as an often-overlooked issue that affects individuals both physically and psychologically. This awareness has even influenced national tourism strategies. Approximately a decade ago, Paavo Virkkunen proposed an innovative Finnish tourism campaign based on the notion that silence—something increasingly rare in modern life—could become a powerful draw for visitors. Under the slogan “Silence, Please,” the campaign emphasized the country’s natural

quietness, leading to a significant increase in tourist numbers [3]. In a world frequently overwhelmed by noise and activity, silence is being reframed as a valuable asset—an “economic good.”

However, the concept of silence must not be mistaken for the complete absence of sound, but rather understood as the absence of artificial, urban, and human-made noise, which has become increasingly pervasive in everyday life. As composer John Cage famously remarked after visiting an anechoic chamber, “There is no such thing as silence. Something is always happening that makes a sound” [4]. Even in the absence of external stimuli, internal sounds such as one’s heartbeat or breathing remain perceptible.

This perspective highlights that the aim should not be to eliminate all sound, but rather to promote certain sound types—those that enhance, rather than degrade, our daily experiences. Sound, like any resource, can be beneficial or harmful depending on its nature and context. This is a central idea in the field of soundscape studies, which advocates for the management and enhancement of acoustic environments, rather than their eradication. Some real world soundscape experiences summarize this concept. In the Nauener Platz soundscape experience, as example, a small urban park in Germany has been redeveloped in 2009 to rebuild a space where people could relax and enjoy sound coming from audio island that could cover the traffic noise. The whole design and implementation has been developed in collaboration with local citizens [5]. In the city of Sheffield, a complex system of fountains and noise barrier has been implemented to mask noise traffic, creating an enjoyable space of walking and, at the same time, recalling a peculiarity of the city itself (the long experience in steel manufacturing). In this case, a seminal idea of cultural heritage also emerges, making the citizens passing by able to identify themselves with the whole idea [5]. This concept can be easily transferred to the need to preserve and enhance soundscapes, particularly in sites of historical and archaeological significance, where the intrusion of urban noise, especially from road and rail traffic, poses a serious threat to the quality of the acoustic environment.

Historical or archaeological sites represent the cultural and historical roots of a region. Therefore, any effort to enhance a territory should prioritise the valorisation of such areas, including the protection of their acoustic

identity. A comprehensive study regarding cultural preservation in Australia [6] clearly shows the importance of the valorisation of acoustic in heritage conservation, and the consequences of omitting it. It is evident that the presence of intrusive noise from nearby anthropogenic sources can hinder the enjoyment and appreciation of these sites. Several works can be found in the literature investigating the relationship between the fruition of archaeological sites and surrounding noise [7-9]. This issue is particularly pressing in Italy, especially in the Campania region, where many archaeological and historical landmarks, such as Pompeii and Paestum sites, have been absorbed into the expanding urban landscape. In such cases, it is increasingly difficult to preserve an appropriate soundscape that allows visitors to fully experience the cultural value of the site.

In this contribution, the authors will report how reducing excessive sound levels, particularly from vehicular and railway traffic, through mitigation measures, is not simply a matter of eliminating noise, but of fostering a positive and coherent soundscape that supports the cultural and experiential integrity of these important sites.

## II. MATERIALS AND METHODS

### A. Case study location

The case study examined in this work focuses on a historically significant area located in Nocera Superiore, in the province of Salerno, southern Italy. The modern municipality of Nocera Superiore stands on the site of ancient *Nuceria Alfaterna*, a city founded in the 6th century BCE and once considered one of the largest urban centers of ancient Campania. Historically, it was a crossroads for Etruscans, Samnites, and Romans and served as the capital of the *Lega Nucarina* (Nucerian League), which included other notable cities such as Pompeii, Herculaneum, Stabiae, and Sorrento.

The specific area analyzed includes three key historical locations: the Early Christian Baptistery of Santa Maria Maggiore (commonly known as *La Rotonda*), the Chapel of the Congregation of Saint Catherine of Alexandria, and the Urban Archaeological Park (formerly the cattle market, *Ex Foro Boario*). Fig. 1 provides an overview of the study area and highlights the principal landmarks.

The Baptistery of Santa Maria Maggiore (Fig. 2) dates back to the second half of the 6th century CE and was likely constructed adjacent to the now-lost cathedral of the ancient Diocese of Nocera. The structure, inspired by Byzantine architectural models, features a centrally planned, circular layout—which earned it the local nickname *La Rotonda*. It includes two concentric rows of columns, varying in both shape and height, that support a large central dome. At the heart of the building lies an imposing baptismal basin, the second-largest of its kind in Italy, with a diameter of over seven meters and a depth of 1.30 meters below a parapet that rises 70 cm from the floor.

The basin is octagonal on the exterior and circular inside and was used for the full-immersion baptism of catechumens. The building also contains noteworthy frescoes dating from the 14th and 15th centuries, preserved in two side chapels.

Today, the baptistery is open to the public and serves as a venue for various events, including baptisms and orchestral performances

The urban archaeological park of Nocera Superiore, Former Cattle Market (*ex Foro Boario*) is shown in Fig. 3 and covers approximately 12000 square meters. Archaeological excavations carried out between 2006 and 2007 in the area traditionally known as the *cattle market* unearthed important traces of ancient *Nuceria Alfaterna* (Fig. 3). These findings span a wide temporal arc—from the 6th–5th century BCE through to the medieval period and as late as the 19th century.

Among the earliest archaeological remains are wall segments likely dating to post-eruption construction following the 1631 eruption of Mount Vesuvius. These remains include two connected tanks and a well. Further excavations, down to a depth of approximately 7 meters below current street level, revealed the foundations of at least two Roman-era buildings. The oldest phase, tentatively dated between the 1st century BCE and 1st century CE, includes the remains of three columns built with bricks and covered with decorated plaster. Fig. 4 shows the remains from the former cattle market, which scholars now believe to be the ancient *forum*, the civic and economic heart of *Nuceria Alfaterna*. This interpretation is supported by the scale and richness of the structures uncovered and the artefacts discovered within a 200-square-meter area, including elements suggesting the presence of ancient thermal baths.

In 2018, a public notice marked the beginning of a coordinated development initiative for the site. The plan promotes a range of cultural activities that reflect and enhance the historical significance of the area, including theatrical and musical performances, art exhibitions, educational programs, concerts, and public gatherings



Fig. 1. Identification of historical sites of interest: 1) Early Christian Baptistery of Santa Maria Maggiore, 2) Chapel of the Congregation of Saint Catherine of Alexandria, 3) Urban Archaeological Park – Former Cattle Market (*Ex Foro Boario*)



Fig. 2. Early Christian Baptistery of Santa Maria Maggiore



Fig. 3. Section of the urban archaeological park



Fig. 4. Remains of the former cattle market (Ex Foro Boario)

### B. Main noise sources identification

As shown in Fig. 5, the study area is located near several significant noise sources, among which the main ones have been identified according to the proximity and the time persistence. They are the Naples–Pompeii–Salerno railway line, which features a level crossing and the Nocera Superiore train station nearby, and the local urban road Via Mercato. In addition to railways and roadways, a comprehensive acoustic characterization of the study area

requires the identification of other elements that contribute to elevated sound pressure levels. These elements may influence vehicular flow, lead to increased traffic, and result in greater footfall in the vicinity of the area under investigation. Among the most relevant are a railway level crossing, a small public square, a parking area, and the parish church of Santa Maria Maggiore.

### C. Acoustic zoning

Following a thorough urban analysis of the territory through the study of the Municipal Urban Plan and the related Technical Implementation Regulations (N.T.A.), an acoustic classification was carried out using the Acoustic Zoning Plan (P.Z.A.). The Acoustic Zoning is the division of territory into zones that are homogeneous from the acoustic point of view (with a similar average acoustic level) and their classification (from I to IV) according to the limitation imposed by law. Each city has to redact its own P.Z.A. [10]. From the documentation and the attachments provided in the acoustic zoning plan approved in 2017, referring to the “Nuceria 2020” master plan, it was possible to identify the acoustic classes of the study area, as shown in Fig. 6.



Fig. 5. Identification of principal noise sources

Although the municipal acoustic zoning plan of Nocera states that “historical and archaeological areas are included in class I” [11], Fig. 6 reveals that the area of interest is divided between class IV, due to its proximity to the railway line, and class II. It is clarified that class IV includes roads with high traffic (over 500 vehicles per hour), primary and arterial roads, highways, ring roads, major communication routes, and railways (with the extension of the area up to 60 meters from the centreline of the outermost railway track in the considered zone). This classification creates a clear division within the studied archaeological area, resulting in the separation of one portion of the area, located near the railway and the road, which corresponds to the acoustic class IV, and the other, located further south, which corresponds to an acoustic class of II. Consequently, the acoustic analysis of the area shows noise limits that do not align with the historical and cultural characteristics of the site.



Fig. 6. Identification of the acoustic zones assigned to the study areas [adapted from 12]

#### D. NoiseModelling tool

NoiseModelling software [13] was used to simulate the noise impact of the road infrastructure on the archeological site under study. This is an open-source software tool developed by the UMRAE research unit (a collaboration between Université Gustave Eiffel and Cerema) in Nantes, France [14]. It is designed for the simulation and generation of environmental noise maps, particularly focusing on urban areas and transportation-related noise sources like road and rail traffic. The software supports large-scale spatial analysis and implements the CNOSSOS-EU methodology for noise emission and propagation modeling [15-17]. It can be used either as a standalone Java application or integrated into workflows through its library functions. NoiseModelling is compatible with spatial databases such as H2GIS and PostGIS, allowing it to manage and process extensive geospatial datasets efficiently.

Initially developed for mapping traffic noise in the Nantes metropolitan region, the software has become a widely used platform in research, education, and public policy projects, including strategic noise mapping at the national level in France. It is distributed under the GNU GPL v3 license and is actively maintained by a team of acoustics and GIS experts.

#### E. Simulation input

In this application, the railway line was initially neglected. Even if it may represent an important source of noise, the experience of the site suggests that it is usually a short disturbance that does not occur so often during the opening time, because of small trains and reduced usage of this line. A more recent line, in fact, was built around 1970 and is nowadays used for high-speed trains and direct connections between Napoli and Salerno. The line crossing Nocera Superiore, then, is used only for local trains, which run at a low speed.

For the above reason, the noise levels have been simulated by using only road traffic as a source. The hourly vehicle flows have been set according to the average flows of the nearby roads, obtained by OpenStreetMap©. In this simulation, then, the flows have been set as follows:

- Daytime (06:00–18:00): 350 light and 17 heavy veh/h
- Evening (18:00–22:00): 100 light and 2 heavy veh/h

- Nighttime (22:00–06:00): 50 light and 0 heavy veh/h
- To enable comparison with Italian noise regulation limits, the data were adjusted to fit two standard time intervals: daytime (06:00–22:00) and nighttime (22:00–06:00), calculating  $L_{DAY}$  and  $L_{NIGHT}$  according to the usual formula of the equivalent level over the time range T:

$$L_{eq} = 10 \text{Log}_{10} \left( \frac{1}{T} \int_0^T \frac{p^2}{p_0^2} dt \right)$$

### III. RESULTS AND DISCUSSION

Measurement points used for data extraction are illustrated in Fig. 7. Points labelled "I" (I1 for the baptistery, I2 for the park) represent internal locations, near cultural landmarks, while external "E" points (E1, E2) are situated near the roadside. The results are reported in Table 1 for the internal points, that are evaluated against acoustic class thresholds in this section, with the aim of estimating the impact of external noise sources on the soundscape of the archaeological site. The external points results for  $L_{DAY}$  are 64.4 dBA and 64.2 dBA while  $L_{NIGHT}$  results are 55.3 dBA and 55.1 dBA, respectively for E1 and E2.

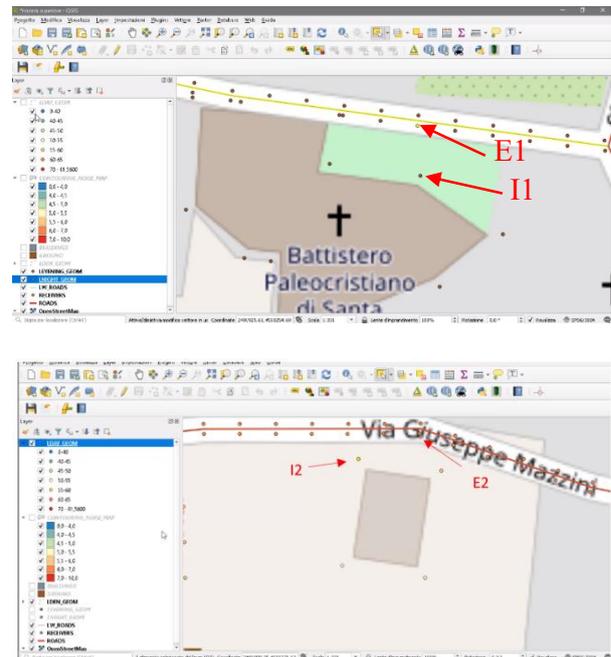


Fig. 7. Locations selected for simulations near the Baptistery (top) and the park (bottom).

The analysis of the results, based on data obtained using the NoiseModelling software, reveals interesting insights. First of all, the regulatory limits for daytime and night-time noise levels associated with Class II areas, which are 55

dB(A) and 45 dB(A), respectively, for day and night periods, are never respected in the internal points. Consequently, they are also not met for Class I areas, which should be the case for archaeological and cultural sites.

The regulatory limits for daytime and night-time noise levels associated with Class IV areas, which are respectively 65 dB(A) and 55 dB(A), are complied with, owing to noise levels being approximately 3–5 dB(A) below the maximum allowable values. Therefore, the noise levels are partially compatible with the identified Class IV designation but not with Class II or Class I.

Considering that the software employed relies solely on traffic flow data from Via Mercato and does not account for the additional noise generated by the nearby railway line or other sources, it is immediately evident that the actual noise levels at the analysed locations are higher than those reported.

This underscores the need for the municipal administration to conduct a thorough assessment of the acoustic criticalities, to develop an appropriate noise remediation plan, and to implement measures aimed at reducing noise levels, thereby mitigating their impact on the usability of the archaeological area.

Table 1. Simulated levels at the inner and outer positions, close to the baptistery and the archaeological park.

	I1 Baptistery [dBA]	I2 Park [dBA]
$L_{DAY}$	59.7	61.8
$L_{NIGHT}$	50.7	52.8

#### A. Possible interventions and simulation of related results

Two possible mitigation actions have been tested in this work, namely the reduction of traffic flow on the closest road (Via Mercato), by introducing a one-way rule, and the ban of heavy vehicles on the same road. A one-way traffic system is a traffic management strategy in which only one direction of travel is permitted on a given carriageway. When the two directions are balanced, this generally results in an approximate halving of vehicular traffic and a consequent reduction in noise emissions. The following data were extracted from the second simulation carried out using the NoiseModelling software, based on the hypothesis of a reduction in light and heavy vehicles flows along the section of road corresponding to Via Mercato, from:

- 350 to 175 light vehicles per hour and from 17 to 0 heavy vehicles per hour during the daytime period (06:00–18:00),
- 100 to 50 light vehicles per hour and from 2 to 0

heavy vehicles per hour in the early evening period (18:00–22:00),

- 50 to 25 light vehicles per hour and no heavy vehicles during the night-time period (22:00–06:00).

In this simulation, heavy vehicles were then excluded, as previously observed, due to their significant contribution to increased noise levels. In the calculation of the equivalent continuous sound level ( $L_{eq,A}$ ) from road traffic, each heavy vehicle is considered acoustically equivalent to approximately six light vehicles [18].

The analysis of the effects produced by this intervention was conducted by assessing the new sound levels at the same points considered in the pre-intervention analysis, as reported in Table 1. The updated equivalent sound level values for the day and night time periods are presented in Table 2, while Fig. 8 reports the comparison between pre- and post-intervention simulations and acoustic regulatory limits for Class IV and Class II. This comparison shows that the reduction in sound levels is approximately 3–4 dB at each measurement point. The halving of traffic flow resulting from the implementation of a one-way system could therefore offer significant benefits by reducing noise levels affecting the study area. However, as shown in the graphs, the reduced values still do not comply with the limits established for Class II and, evidently, not with those for Class I.

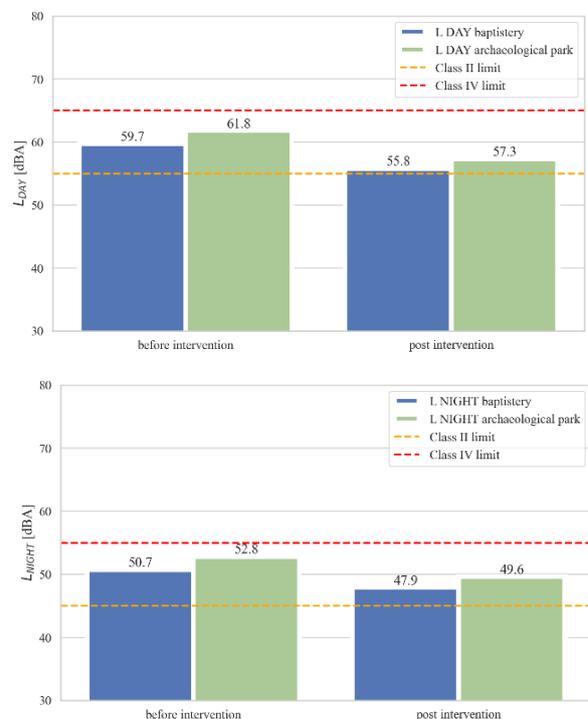


Fig. 8. Comparison between  $L_{DAY}$  (top) and  $L_{NIGHT}$  (bottom) against acoustic classes thresholds for the baptistery (blue) and the archaeological park (green).

As for the external simulation points, close to the road, the results for  $L_{DAY}$  are 60.1 dBA and 59.8 dBA while  $L_{NIGHT}$  results are 52.4 dBA and 52.1 dBA, respectively for E1 and E2, showing a similar reduction as observed in the internal points.

Table 2. Simulated levels at the inner and outer positions, close to the baptistery and the archaeological park, after the mitigation actions.

	I1 Baptistery [dBA]	I2 Park [dBA]
$L_{DAY}$	55.8	57.3
$L_{NIGHT}$	47.9	49.6

#### IV. CONCLUSIONS

The work presented in this paper focused on the exploration and analysis of the intrusion of road traffic noise in areas of historical and cultural significance, together with the issue of insufficient protection of the acoustic environment in those sites. It has been highlighted that the archaeological site under study, located in Nocera Superiore, despite being a cultural heritage site, is not adequately considered in acoustic zoning plans. This is primarily due to its proximity to both a roadway and a railway line. As a result, the assigned acoustic classification for the sites examined is relatively high, leading to regulatory noise limits that are significantly less stringent than those necessary to preserve and enhance the soundscape of the area. The study involved the simulation and analysis of sound levels simulated in the vicinity of the Baptistery of Santa Maria Maggiore and the nearby urban archaeological park, which were then compared with the regulatory immission limits. The fact that the limits corresponding to acoustic zones classified as "areas of intense human activity" are respected, while those related to "protected areas", where tranquillity is fundamental, are not, reveals a lack of real protection for these sites. Two possible interventions were proposed to reduce road traffic noise, namely the introduction of one-way traffic systems and the ban on heavy vehicles. Even if these mitigation actions reduce the expected noise levels, the regulation limits for protected areas are still not fulfilled, highlighting how complicated to deal with the soundscape of urban archaeological sites, immersed in the road network. The establishment of a fully touristic and easily accessible area, in which the soundscape, analysed using specific methodologies, plays a key role, would not only enhance the value of individual historical sites but could also have a positive impact on local tourism.

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