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THE LIFE SILENT PROJECT: ADVANCING SUSTAINABLE SOLUTIONS TO MITIGATE NOISE IN URBAN ENVIRONMENTS

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ABSTRACT

In this paper an overview of the LIFE SILENT Project and its preliminary results is presented. The project aims to develop and implement sustainable solutions for mitigating noise in complex urban scenarios affected by the coexistence of multiple and diverse noise sources, typically from road and railway traffic, in proximity to densely populated areas. In such contexts, conventional noise mitigation solutions, such as noise barriers, are often unsuitable due to their impact on nearby receivers. However, high noise barriers can reduce visibility, hinder air circulation, and alter the microclimate, potentially leading to social opposition.
To address these challenges, at-source solutions are recommended. For roads, low-noise pavements are proposed, while railways are encouraged to adopt measures such as dampers, rail grinding, and silent brakes. However, these solutions are often limited by issues such as durability and high implementation and installation costs. The LIFE SILENT Project seeks to overcome these challenges by developing and testing innovative solutions, including low-noise pavements and low-height noise barriers incorporating metamaterials, designed to deliver enhanced environmental performance and improved durability.
Finally, to facilitate the coordinated implementation of these solutions by infrastructure owners and managers, the project aims to define a dedicated management procedure.

Keywords: *low-noise pavements, low-height noise barriers, metamaterials, innovative mitigation measures, management procedures.*

1. INTRODUCTION

Urban areas are frequently affected by noise pollution stemming from various simultaneous sources, predominantly road and railway infrastructures. Commonly adopted solutions, such as noise barriers or extensive structural installations, can significantly impact the local environment. These intrusive methods often disrupt visibility, impede airflow, alter microclimates, and negatively influence the overall urban aesthetics, consequently leading to dissatisfaction and opposition among local communities.
In response to such issues, more effective strategies aim to mitigate noise directly at the source. Approaches like low-noise pavements and vibration dampers, rail grinding, and silent braking systems for railways, are

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promising but can face challenges related to durability or substantial implementation costs.
Consequently, it is essential to explore sustainable and less intrusive noise-mitigation techniques that balance effectiveness with minimal environmental and social impact. To this end, the LIFE SILENT project aims to develop and test advanced, durable, and environmentally friendly solutions, and to provide comprehensive guidelines to transport infrastructure owners for managing noise mitigation measures in a synergistic way.

2. THE LIFE SILENT PROJECT

The LIFE SILENT project [1] specifically aims to address three key areas:

- sustainable Low-Noise Pavements (LNP);
- compact Low-Height Noise Barriers (LHNBs);
- and coordinated implementation strategies.

The idea of developing and exploring these three areas stems from the following considerations.

Low-noise pavements. Despite the effectiveness of traditional low-noise pavements in reducing noise (approximately 3-5 dB), existing solutions often face durability and sustainability issues. Projects like PERSUADE, LIFE NEREIDE [2][3], LIFE C-LOW-N, LIFE E-VIA, LIFE SNEAK, and IASNAF [4] have advanced research in this area. Particularly notable is the project IASNAF, demonstrating the effectiveness of functionalized cellulose fibres in enhancing pavement durability. However, most studies remain limited to laboratory conditions. LIFE SILENT aims to overcome these limitations by validating durable, sustainable pavements using recycled and eco-friendly materials in real-world settings, improving durability, reducing CO2 emissions, costs, and health impacts, while maintaining optimal acoustic performance.

Low-height noise barriers. Low-Height Noise Barriers have gained popularity as cost-effective solutions, providing noise reductions between 5 and 10 dB [5][6][7]. Typically installed directly onto rail infrastructure, LHNBs eliminate the need for costly foundations, making them economically advantageous and visually appealing. Studies, including numerical simulations and scale-model tests, have demonstrated the effectiveness of LHNBs through optimized designs developed using boundary element methods (BEM) [6]. However, real-world trials have reported noise attenuation ranging from 1.5 to 5 dB(A) [8][9][10][11], primarily limited by multiple sound reflections between LHNB surfaces and train bodies. The LIFE SILENT project aims to address this limitation by integrating metamaterials to enhance LHNBs' sound-absorbing properties, thereby reducing multiple reflections and providing improved durability over time.

Figure 1. LHNB built by Kraiburg STRAIL in San Cugat (Spain).

Noise mitigation synergistic procedures. Effective noise management in complex urban environments, impacted by multiple noise sources, needs coordinated actions among diverse infrastructure stakeholders, as mandated by European and Italian regulations (DPCM 29/11/2000, Directive 2002/49/CE [7], Legislative Decree 42/2017). However, the absence of detailed operational guidelines has hindered effective implementation. LIFE SILENT addresses this gap by developing practical methodologies to facilitate integrated, collaborative solutions across different transportation entities, ensuring sustainable, comprehensive, and regulatory-compliant noise mitigation strategies.

2.1 Project's objectives

Following the previous considerations, the LIFE SILENT project sets out three main goals aimed at innovative noise mitigation strategies.
Firstly, it seeks to enhance road pavement durability and resistance while reducing costs by integrating cellulose fibres derived from recycled waste materials like textiles, paper, and cardboard into bitumen mixtures. This

approach aims to improve fatigue performance, extending pavement lifespan.

Secondly, the project aims to design and implement advanced Low-Height Noise Barriers (LHNB) by using metamaterial technology and a significant proportion (approximately 85%) of recycled materials. These materials will be specifically designed to maximize acoustic absorption and durability, overcoming the limitations of traditional fibrous components, which degrade rapidly. Particular attention will be given to sustainability, ease of maintenance, and structural integrity.

Lastly, LIFE SILENT will establish comprehensive guidelines and procedures for the management and implementation of noise mitigation measures, especially in complex and environmentally sensitive contexts. This will ensure efficient implementation and consistent performance of noise solutions in different scenarios.

3. METHODOLOGY

The methodology adopted by the LIFE SILENT project involves a systematic, multi-phase approach structured into five sequential stages (Figure 2). Initially, the innovative solutions are conceptualized and developed. Then, these solutions are designed and implemented in a dedicated pilot area. Following installation, rigorous impact monitoring and performance evaluation are conducted. The sustainability of the proposed interventions is then thoroughly assessed. Finally, the developed prototypes undergo a formal certification process to confirm their compliance with relevant standards and their effectiveness in real-world conditions [1].

3.1 Development of innovative solutions

The initial phase of the LIFE SILENT project is structured around three core activities:

- Defining procedures and guidelines to support the synergistic implementation of noise mitigation measures.
- Development and design of the innovative LNP:
- Development and design of the LHNB.

The first core activity involves identifying methodologies and preparing guidelines to implement synergistic noise mitigation measures in challenging environmental contexts. This entails the analysis of complex scenarios and existing conditions to ensure effective integration of noise mitigation solutions.

The design and characterization of the innovative low-noise pavements is based on previous findings from the IASNAF project. This approach involves developing a sustainable asphalt mixture incorporating cellulose fibres obtained from recycled textiles, paper, and cardboard. Through iterative laboratory tests and subsequent real-world trials, the project aims to optimize pavement formulations, enhancing durability by approximately 20% compared to current state-of-the-art options, without compromising acoustic and safety performance. This strategy is expected to reduce long-term costs and significantly lower environmental impacts by decreasing reliance on virgin materials and minimizing landfill waste.

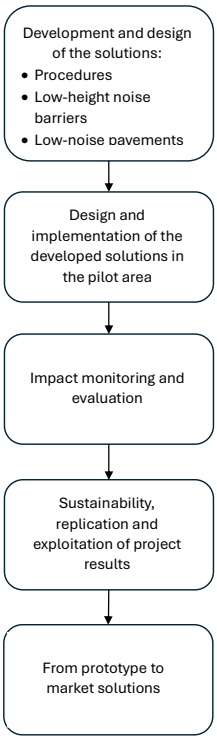

Figure 2. Flow-chart of the main steps of the project.

Lastly, the LIFE SILENT project targets the development and characterization of advanced Low-Height Noise Barriers. Insights from prior research, particularly the experiences from the Kraiburg STRAIL prototype, guide the selection of suitable recycled materials evaluated against EN 15804 standards. Additionally, metamaterials will be employed to significantly improve acoustic absorption characteristics, surpassing traditional fibrous materials in

both performance and durability. Ensuring structural integrity, safety, and ease of maintenance is also a critical component of this barrier design phase, supplemented by fatigue testing and innovative acoustic performance assessment methodologies.

3.2 Implementation of the developed solutions in the pilot area

The innovative solutions developed and tested through initial laboratory testing will subsequently be implemented at a real-world pilot site located in a densely populated urban area (Muratella, Rome, Italy), characterized by proximity to both road and railway infrastructures (see Figure 3). Specifically situated within Rome's XI District, the selected area is crossed by the Rome-Fiumicino Airport railway line and the A91 motorway. This predominantly residential zone includes buildings typically comprising three to four floors, primarily positioned on the northern side of the roadway. Approximately 170 buildings, housing a population of nearly 19,769 residents, students, hospital personnel, and patients, are exposed to noise levels exceeding 55 dB(A) Lden.

Figure 3. View of the pilot area (Muratella, Rome) crossed by the A91 Motorway and the railway line Rome – Fiumicino Airport.

Prior to the full-scale implementation, comprehensive baseline measurements will be conducted to accurately assess subsequent improvements resulting from the new low-noise pavement and low-height noise barrier. This assessment will involve a detailed measurement campaign designed to calibrate the noise propagation model and refine strategies for effective noise mitigation.

The campaign includes five distinct measurement procedures:

- Road vehicle noise emissions measured following ISO standard 11819, with both Close Proximity and Statistical Pass-By methods, including the backing board approach, to assess the influence of pavement characteristics on noise generation.
- Noise level recordings at sensitive receiver locations based on the Italian decree DM 16/03/1998, essential for validating the acoustic propagation model.
- Ex-ante evaluation of the effectiveness of LHNBs using the methodology specifically developed within the project.
- Assessment of pavement surface texture and mechanical impedance following standards UNI CEN 13036-1 and UNI EN ISO 7626-5.
- Preliminary evaluations of community noise annoyance through psychoacoustic methodologies and social surveys aligned with guidelines established in the LIFE NEREiDE project.

The collected data are then used to calibrate an acoustic model that simulates various acoustic scenarios, offering insights into total noise exposure and identifying individual noise source contributions. The measurement results will guide the project's design phase, integrating newly established management procedures to harmonize and optimize noise mitigation efforts by road and rail infrastructure authorities.

To mitigate noise impact, a 200-meter LHNB will be installed adjacent to the railway tracks, primarily targeting sensitive areas on the southern side. The barrier's design prioritizes easy maintenance and structural stability while minimizing visual disruption and preserving views for residents and train passengers.

Additionally, a 1.9 km section of newly formulated low-noise pavement will be implemented on the A91 motorway. Its design will consider urban-specific factors such as road safety, geometric layout, and logistical considerations related to asphalt production and application processes.

The design phase will focus on optimizing asphalt mixtures, refining material compositions and proportions, improving supply chain efficiency, and implementing rigorous quality control measures. Environmental protection will also be a

key priority, achieved through reduced toxic emissions, and strict adherence to safety standards.

3.3 Performance assessment of the implemented solutions

A comprehensive monitoring campaign will be conducted to assess the acoustic effectiveness and long-term performance of the implemented noise mitigation solutions. Specifically, the acoustic durability of the new low-noise pavement will be evaluated through four measurement sessions scheduled at intervals of 3, 6, 12, and 18 months after the laying of the new mixtures. To accurately characterize the pavement durability, data on rolling noise emissions, traffic volume, and weather conditions will be collected even beyond the project's duration of 60 months. The performance assessment for the pavement will also include Statistical Pass-By noise measurements, Close Proximity evaluations, and non-acoustic indicators such as surface texture, frictional properties, and mechanical impedance. These combined data sets will feed fatigue test validation and provide essential inputs for Life Cycle Assessment (LCA) and Life Cycle Cost (LCC) analyses.
The effectiveness of the installed low-height noise barriers will similarly be evaluated through targeted acoustic measurements conducted according to the methodology developed specifically within this project. Additionally, regular visual inspections and periodic testing of the barriers will be performed to monitor structural integrity and material durability.
Further impact assessments will involve detailed measurements of noise levels at sensitive receiver locations, according to the Italian decree DM 16/03/1998. Additionally, psychoacoustic studies and structured social surveys will measure public perception and evaluate community acceptance and response to the implemented noise mitigation strategies.
Finally, the established procedures for managing noise mitigation actions will be continuously evaluated to monitor their effectiveness and efficiency, from the initial strategy formulation to the practical implementation phase. This evaluation will systematically identify potential challenges, recommend corrective actions, and refine the methodology based on feedback from citizens, stakeholders, and public institutions involved in the process.

3.4 Sustainability analysis of the newly developed solutions

The sustainability of the LIFE SILENT approach will be assessed with a focus on the solutions implemented in the pilot area, ensuring a comprehensive analysis of their long-term effectiveness. In addition to the traditional environmental, social, and economic dimensions, the assessment will also consider technical aspects.
The technical evaluation will be performed using standardized methodologies and protocols. Specifically, EN 1794-1/2 will be employed to assess the non-acoustic performance of road traffic noise-reducing devices, while EN 14389 will be used to evaluate their long-term non-acoustic performance. In the railway sector, the non-acoustic performance of noise barriers and related devices will be analysed according to EN 16727-1/2/3.
The assessment of environmental, social, and economic impacts across the life cycle of each technology will be conducted using the Life Cycle Sustainability Assessment (LCSA) framework. This integrated approach combines Life Cycle Assessment (LCA), Social Life Cycle Assessment (S-LCA), and Life Cycle Costing (LCC), in alignment with ISO EN 14040/14044, EN 15804, and the UNEP/SETAC Guidelines for Social Life Cycle Assessment of Products.
The LCSA methodology follows a structured four-stage process: (i) definition of objectives and scope; (ii) inventory compilation; (iii) impact assessment; and (iv) interpretation of results. Additionally, public perception of both conventional and the newly developed noise mitigation technologies will be analysed through a mixed-methods approach, incorporating qualitative and quantitative data collection techniques, such as structured surveys and in-depth interviews.
By integrating technical, environmental, social, and economic considerations, this comprehensive approach ensures a robust sustainability evaluation of the project's solutions. A Multi-Criteria Decision Making (MCDM) framework will be applied to compare the LIFE SILENT noise reduction solutions against an Optimal Hypothetical Ideal Solution (OHIS), which will serve as a reference benchmark. The final assessment will generate an Overall Sustainability Index (OSI), ranging from 0 to 1, quantifying the proximity of the LIFE SILENT solutions to the OHIS.

3.5 Prototypes certification

To ensure the validation of the developed technologies and enhance their market potential, both the newly designed low-noise pavement and the low-height noise barriers will undergo Environmental Product Declaration (EPD) certification. This certification process aims to support the deployment of environmentally sustainable technologies by providing technology developers, manufacturers, and investors with independent third-party verification of their

environmental performance. Achieving EPD certification will attest the reliability of the LIFE SILENT solutions, fostering greater confidence among potential stakeholders and accelerating their adoption and large-scale implementation.

4. EXPECTED OUTCOMES AND IMPACTS

The expected outcomes and impacts of the project are classified into three main domains: low-noise pavements, low-height noise barriers, and advanced methodologies for the management and implementation of noise mitigation measures in complex environmental settings.

4.1 Low-noise pavements

The adoption of low-noise pavement technologies is expected to bring substantial environmental and functional improvements to road infrastructure. One of the main advantages is a projected 4 dB reduction in noise levels, achieved through modifications in surface texture, optimized aggregate gradation, and the incorporation of crumb rubber. This is designed to meet EU Green Public Procurement Criteria, ensuring CPX noise levels around 86±1 dB(A) at 50 km/h.

Beyond noise reduction, the durability of these pavements is anticipated to improve by 20% compared to conventional solutions, thanks to the integration of functionalized cellulose fibres. This enhancement not only extends the pavement's lifespan but also contributes to sustainability by lowering the carbon footprint by 17%, which translates to an annual reduction of approximately 420 tons of CO_2 per kilometre. Additionally, the use of 16 tons of recycled materials per kilometre aligns with circular economy principles.

The implementation of these mixture is also expected to reduce volatile organic compounds (VOC) and polycyclic aromatic hydrocarbons (PAH) emissions, leading to better air quality in road-adjacent areas. From an economic perspective, the extended lifespan of the pavement is projected to result in a 14% cost reduction, reinforcing the technology's role in promoting sustainable and cost-efficient road infrastructure.

4.2 Low-height noise barriers

The Low-Height Noise Barrier represents an innovative solution that integrates environmental sustainability, social acceptance, acoustic efficiency, durability, and cost-effectiveness into a novel design paradigm. Composed of 85% recycled rubber, the LHNB is strategically developed to enhance the circular economy, significantly reducing the environmental impact associated with traditional noise barriers. Due to its low-profile design (0.5 meters in height), it is anticipated to achieve twice the level of public acceptance compared to conventional barriers, primarily due to its minimal visual intrusion into the surrounding landscape.

Despite its compact dimensions, the LHNB employs metamaterial technology to enhance sound absorption and an estimated noise reduction of 5 dB. Engineered for a service life exceeding 15 years, the barrier is also linked to the development of a novel acoustic testing methodology, currently under refinement, with the potential to serve as a future standardization framework.

From a structural perspective, the LHNB is designed for ease of installation and maintenance, benefiting from its lightweight composition and modular assembly. To ensure long-term reliability, the barrier will be subjected to comprehensive fatigue resistance testing, assessing its ability to withstand mechanical stress and environmental degradation.

Economically, the LHNB is projected to deliver a 30% improvement in the benefit-cost ratio compared to conventional barriers, positioning it as a pioneering solution in noise mitigation that effectively addresses spatial, aesthetic, and economic constraints while maintaining superior performance standards.

4.3 Advanced methodologies for the management and implementation of noise mitigation measures

The LIFE SILENT project is also dedicated to developing a systematic methodology for the coordination and implementation of diverse noise mitigation strategies, including low-noise pavements and low-height noise barriers, to optimize their effectiveness. This approach is designed to facilitate collaboration among key stakeholders, such as public transport operators and infrastructure managers, ensuring that their interventions align with broader urban planning frameworks. By fostering coherent and integrated action plans, the initiative aims to enhance noise reduction in urban and suburban environments, contributing to a more sustainable acoustic landscape.

A key component of the project is the development of guidelines to facilitate compliance with legislative requirements, particularly those related to the formulation of Action Plans under European Directive 2002/49/EC. These guidelines are expected to benefit all designated agglomerations covered by the Directive, as well as other European cities seeking to implement more effective noise mitigation strategies.

For infrastructure owners, the project provides clear and structured implementation frameworks, facilitating cost-effective planning, construction, and maintenance of noise-reducing devices. It is estimated that this methodology could lead to a 50% reduction in costs for adjacent infrastructure development, significantly improving the economic feasibility of noise control interventions.

In the pilot area of Muratella (Italy), the project seeks to substantially reduce noise exposure for approximately 19,769 residents, including vulnerable groups in hospitals and schools. This will be achieved through the deployment of 1.9 km of low-noise pavement and a 200-meter low-height noise barrier, with the objective of reducing the annoyed population by 12%, equivalent to 2,464 individuals.

Furthermore, the project emphasizes community engagement and social acceptance, incorporating co-design methodologies that actively involve residents in the planning and design of mitigation measures. By fostering public participation, the initiative enhances community support for noise reduction solutions, ensuring their long-term success and integration into the urban landscape.

5. CONCLUSIONS

The LIFE SILENT project represents a significant step forward in the development and implementation of innovative noise mitigation strategies that address both environmental and societal challenges associated with urban noise pollution. By integrating low-noise pavements, low-height noise barriers, and a coordinated management approach, the project provides a comprehensive and sustainable framework for reducing noise exposure in complex urban environments.

The project's findings demonstrate that low-noise pavements, incorporating recycled and eco-friendly materials, can effectively reduce noise emissions while enhancing durability and sustainability. Similarly, the low-height noise barriers, using metamaterial technology, have shown promising noise attenuation capabilities while maintaining a low visual and spatial footprint, ensuring higher public acceptance. Additionally, the development of standardized methodologies for noise mitigation planning and implementation will facilitate more effective collaboration among stakeholders, enhancing the feasibility of large-scale adoption.

The pilot implementation in Muratella, Italy, highlights the potential impact of these solutions, with an expected 12% reduction in noise-exposed people and significant cost savings for infrastructure owners. The systematic evaluation process, including acoustic performance assessments, environmental impact analyses, and stakeholder engagement strategies, further ensures the long-term viability and replicability of these interventions across various urban settings.

Moving forward, the project's methodological approach and technological advancements will provide a blueprint for future noise reduction policies and urban planning strategies. The integration of sustainable materials, advanced acoustic engineering, and participatory design principles sets a new benchmark for noise mitigation efforts, fostering greener, more liveable urban environments.

By bridging scientific innovation, regulatory compliance, and public engagement, the LIFE SILENT project offers a scalable and transferable model for tackling urban noise pollution, reinforcing its potential as a pioneering initiative in sustainable infrastructure development.

6. ACKNOWLEDGMENTS

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