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Noise-Canceling Pavements For Urban Sound Pollution

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Abstract: *Noise pollution is a vivid urban-health and environment-risks entity; this is especially so in areas of high population where the presence of large population and traffic plus infrastructural density lead to the increase of sound exposure. The proposed study is concerned with the introduce trial and sonic performance of noise-canceling pavements (NCPs) as a new and novel approach toward managing urban noise pollution. A mixed-methodology, which included in situ measurements of decibels, material property assessments, and geospatial mapping of sound were taken to assess pavement types in three Indian urban corridors: Mumbai, Bengaluru, and Delhi. The coefficient of sound absorption and the sound reflection characteristics of porous asphalt, rubberized bitumen and nano engineered concrete composite pavement were evaluated using impedance tube tests and on-field monitoring. Successive spatial studies that were done using GIS-based interpolation explained the pattern of acoustic hotspots and also linked them to the distribution of each pavement. The findings show that rubber-modified pavings attained the best average noise level reduction of 6.3 dB particularly in the busy areas where the highest frequencies recorded were 1000 to 1600 Hz. Acoustic remote sensing after spatial interpolating indicated that a reasonable application of these materials can reduce the perceived noise level in essential residential belts. This discussion highlights the potential of engineered pavement materials to reduce a lifetime of noise exposure and validates the worth of data-based urban planning systems, which allow combining noise-canceling infrastructure in the creation of sustainable cities.*
Keywords:- *Urban noise pollution, Noise-canceling pavement, Rubberized bitumen, Acoustic mapping, GIS interpolation, Porous asphalt, Sound absorption, Smart infrastructure*

I. INTRODUCTION

Noise pollution has become the longest and least recognized environmental pressure in modern cities. It can be defined as unwanted or undesirable sound or noise that disrupts the acoustic balance of nature; it is a thirty-year-old problem in urbanized and populated metropolitans. Though the contaminants in air and water can be easily noticed or measured, the auditory pollution is mostly immeasurable and severe. It impacts millions of people triggering the deterioration of hearing capabilities, heart diseases, sleep disturbances, intellectual decrements, and psychological pressure. As it happens, the World Health Organization (WHO) means that noise pollution is the second worst thing to affect the population in terms of health in urban places behind air pollution. Megacities like Mumbai, Delhi and Bengaluru have always shown average noise levels to be violating the permitted national norms by the Central Pollution Control Board (CPCB). Urban acoustic load is broadly attributed to motorized traffic, where the latter constitutes some 70 % of the overall ambient sound in urban settings. The volume of emissions is caused by the vibration of the engine, friction between tires and the road, blowing a horn, and turbulent movement of the air due to the aerodynamics. The regulatory measures in place now, such as sound barriers, speed restriction and mandatory check-up initiatives have limited but local remedies. Conversely, the active control method based on the use of pavement engineering as a modification of the road surface is a passive control that eliminates the cause of transport-generated noise -tire-pavement interaction. Recent development, especially porous asphalt, rubberized bitumen, and composite surface layers utilize absorption, dispersion, and impedance processes to minimise road-borne sound. Noise-canceling pavements (NCPs) are built in systems that aim at reducing noise propagation at its source. These compositions or materials include hosts of structured textures and identifiable ratio of voids and special compositions of material to weed off the noise spectra of urban automobiles. The porous structure of the NCPs is able to absorb the sound waves and even promotes their drainage and thermal performance. Asphalt mixed with rubber and nano engineered concrete composites have been found to be better as noise dampers especially when applied in high passenger traffic corridors. However, not much is large-scale application due to the high costs, a lack of awareness among the people and lack of extensive field-level data en tarring a wide range of Indian climate and of the load-carrying capacity in the country. Parallel developments in remote sensing, Internet of Things (IoT)-connected acoustic sensors and geographic information systems (GIS) have enabled city planners as well as environmental engineers to have the potential to map and trace noise pollution spatially and at a time. Such technological processes allow locating the urban acoustic hotspots the places where noise intensity constantly breaks the regulatory limits and which allow implementing local interventions. Such tools coupled with pavement distribution data would offer a complete structure to assess and maximize the location of noise-eliminating pavements. Compared to the traditional research and development focused either on lab-based measures or acoustic simulations, this spatially resolved design provides a more realistic view on how the noise-control pavement (NCP) behaves in the real world environment, with actual traffic. The need to reduce the sound pollution in urban environments and the unutilized potential of material-level operations made the present study conduct an assessment of acoustic performance of some selected NCPs within Indian metropolitan areas. The mixed-methods approach (combined field measurements, material analysis and geospatial modeling) provided a comprehensive picture of effectiveness and challenges as well as spatial footprints. The range of focus of the investigation focused on three preselected cities, which included Mumbai, Bengaluru, Delhi, as developed in three different urban typologies, traffic levels, and climate zones. Chosen on the basis of average levels of noise recorded by the national systems of pollution monitoring and the current infrastructural development activities in progress, these cities provided the best environments to assess real-life interventions involving pavements. The research had four goals, namely: (1) characterization of material-type properties of porous asphalt, rubberized bitumen, and nano-concrete composites in reference to sound absorption coefficients and structural resilience; (2) real-world sound-level measurements, in multiple urban corridors where these pavements are installed or are proposed, over a multi-frequency and multi-time domain; (3) development of spatial sound maps, relying on interpolation for noise levels compared to pavement type and road design as well as the broader urban form; and (4) a policy. The given work explores how engineering creativity and spatial analytics have been fused intending to bridge the gap between material science and urban soundscape management. Noise-canceling pavements are thus not just suggested as the typical infrastructural modification, but rather a vital part of urban resilience and health plans. Such solutions are not optional; they are mandatory in an era of smart city models, which put a premium on data-based infrastructure and the well-being of the citizens. The research outcomes explain the financial efficiency, viability of technology implementation, and long-term realization of putting in place the acoustic-sensitive pavement technology when pursuing the setting up of quieter and healthier cities.

Ii. Releated works

Within the last two decades, studies concerning urban noise pollution have been more actively pursued, especially in terms of its implications to the human health and the state of environment. Noise is now considered by the World Health Organization to be among the major environmental health risks in urban localities and associated among other things with heart diseases, sleep disturbances, and delayed thinking in children [1]. Vertical noise walls and vertical noise barriers, which are traditional abatement options, which have been known to reduce sound by 5-10 dB, have had their drawbacks in the form of their high cost in terms of aesthetics, large land consumption and low efficiency in highly developed areas, resulting in increased attraction to ground level remedial options. Noise production mechanism at the tire road contact has been studied widely. Sandberg and Ejsmont have stated that tire-road noise is caused by rather complicated noise processes associated with the vibration of roads due to tread vibration and air pumping as well as resonance of surface texture [3]. Scientists have thus investigated the way special fluorescent pavement surfaces can absorb or reflect these vibrations. Because of interconnection of voids, porous asphalt has become a cost-effective way of controlling mid-frequency noise. European research shows that double-layer porous asphalt (DLPA) may be used to reduce noise by 335 dB compared to dense-graded asphalt [4]. Rubberized asphalt, which includes crumb rubber, a recycles tire product, provides both benefits at one time: reducing tire waste and road noise. The United States and Japan record pilot programs that record a 4-6 dB reduction, especially on the urban highways and arterial routes with a steady traffic pattern [5], [6]. Better elasticity and resistance to cracking, another attribute in high-thermal-variability climates is offered by these rubber-modified surfaces as well. At the same time nano-engineered concrete composites, including nano-graphene and nano-silica, are promising due to their ability to enhance damping capabilities and maintain strength capabilities [7]. The old method of measuring acoustic performance of roadway surfaces includes laboratory impedance tube analysis, Close-Proximity (CPX) technique and Statistical Pass-By (SPB) technique. Although impedance tube measures can give accurate values of absorption coefficients at specific frequencies, in-situ measurements are much more representative when test conditions exist in the live traffic environment. Zurich and Amsterdam results indicate that the best one can do in noise-reduction is found in quieter pavement to be used along with low-noise tires and speed-reduction zones [9]. Creating the material science more allied, a growing body of literature uses the spatial technologies to define the level of noise in the urban areas. Geographic Information Systems (GIS), remote acoustic sensor and noise sensors in mobile phones made possible the high resolution noise contour maps in Seoul, Paris and New York [10]. These are maps that draw attention to noise hotspots which often overlap with areas of congestion, construction and mixed use. Researchers have used predictions on how best to locate the noise-canceling surfaces by mapping pavement distribution data against the noise-intensity areas [11]. In the Indian case, data regarding noise level have been made available by the Central Pollution Control Board (CPCB) in over 60 cities; over the field studies on pavement related noise control is negligible. Another remarkable study by Kumar and Shankar checked the rubberized skid in Hyderabad and concluded that the average reduction of the sound level was 4.2 dB in high-traffic areas compared to the conventional bitumen roads [12]. In a field study conducted by Deshpande et al. in Pune, mobile sensor arrays were utilized to assess acoustic profiles in the residential areas, which supports that implementation of porous pavements with the deployment of porous pavements to reduce the level of peak noise to up to 5 dB in the evenings period [13]. The other important thread of research are psychoacoustic perception of road noise. The change in decibels does not always have equivalent, subjective effect on perceived quietness; frequency content, tonal variation and directionality are important variables in subjective noise response. A study by Fields et al. indicated high-frequency sounds (100014000 Hz) made by tirepavement contact to be the loudest and more stressful than lower frequency sounds such as engine hum [14]. The determination of this conclusion highlights the need to design pavements aimed at narrow band absorption/deflection. The interdisciplinary studies are also rising, connecting the acoustic design to urban planning, health outcome and the smart infrastructure. There is increasing inclusion in transportation planning of acoustic information that is integrated with environmental impact assessments (EIAs). Zoning concepts have increased in popularity within the EU with the Quiet Urban Zone proposed by Benedikt and Yang consisting of zoning with acoustically high requirements being backed with the infrastructure of noise-control planning and green noise buffer [15]. These frameworks match that of the India Smart Cities Mission, which is becoming more concerned with the intelligent infrastructure, such as noise-monitoring systems and environmentally friendly construction materials. The literature is already documented to shift the traditional noise-control methods to more integrative, material-based, and spatially responsive methods. The research on porous and rubberised pavements is vastly available in the world literature but in order to ensure country specific assessment, consideration of the traffic patterns, climate conditions as well as infrastructural peculiarities in Indian urban areas are important. This study builds on international and local results by proposing a multilocation investigation of National Cooperative Highway Research Program (NCP) installations in practical Indian cities, and thus makes up serious gaps in study and policy positions in terms of acoustic infrastructure studies.

III. METHODOLOGY

3.1 Research Design

This study is a spatial-temporal assessment as its main research design. Both such techniques as quantitative field measurements and qualitative observational mapping were used to collect data information. According to the previous noise-abatement surveys, direct decibel data (Leq, L10, Lmax) as well as spectral frequency content in several time intervals was recorded in order to examine the role of varying types of pavements in shaping of urban soundscapes [16].

3.2 Study Area and Site Selection

The urban environment of three cities in India characterized by geoclimatic differences, material diversities in roads, and averages sound exposures such as Mumbai (coastal/humid), Bengaluru (moderate) and Delhi (semi-arid) were regarded as the study area. Each local would have ten one-kilometre long urban trafficked corridors chosen according to having uninterrupted vehicular traffic, multiple pavement types and spatial proximity of residential or sensitive area like school or hospital.

Table 1: Study Area Characteristics

City	Road Type	Dominant Pavement	Avg. Traffic Volume (vehicles/day)	Ambient Leq (dB)
Mumbai	Coastal Arterial Road	Porous Asphalt	86,000	78
Bengaluru	Inner City Ring Road	Rubberized Bitumen	74,500	75
Delhi	Urban Expressway	Nano Concrete	92,300	80

3.3 Acoustic Data Collection

Each study involved the positioning of a Class 1 sound-level meter (SLM) 7.5 m in front of the centerline and 1.5 m off the surface of the ground in each study site. The thematic period of measurement took place in three specific times: the morning peak (8-10 AM), the afternoon interval (1-3 PM) and the evening peak (5-7 PM) of five consecutive weekdays. Data consisted of A-weighted continuous noise levels, equivalent to Leq, total SEL and the levels of the octave and third-octave levels of band across 125, 4000 Hz.

3.4 Pavement Sampling and Material Analysis

Pre-identified segment samples were core-cut/extracted. What came later after analysis consisted of:

- Air void ratio: Is calculated through the vacuum-sealing technique.
- Sound absorption coefficient (alpha): Data were obtained by means of impedance tube minute measurements as per ISO 10534-2.
- Surface texture: It is measured through Sand Patch Method and Texture Depth Measurement.
- Elastic Modulus and Damping Ratio: This can be obtained with the dental dynamic mechanical analysis (DMA).

Table 2: Pavement Composition and Key Acoustic Properties

Pavement Type	Avg. Air Void (%)	Sound Absorption Coefficient (α) @ 1000 Hz	Texture Depth (mm)
Porous Asphalt	18.4	0.46	1.25
Rubberized Bitumen	12.7	0.58	1.10
Nano Concrete Mix	9.3	0.39	0.98

Rubberized bitumen showed the highest sound absorption at mid-frequency ranges, aligning with literature on crumb rubber's viscoelastic damping capacity [17].

3.5 Noise Modeling and Simulation

The transmission of noise between the discrete zones of the pavement was evaluated using an interactive software aptly known as CadnaA 2023 that is designed to facilitate real-time simulation. The scenarios were created by combining measurements of vehicle composition, surface impedance and traffic density. Calibration was based on empirical Leq values, whereas the meteorological elements, such as wind speed, temperature gradients, and the level of humidity, were specifically included.

Input parameters of the model were as:

- Ground resistance based on the in-situ 2 values that were measured in- situ
- Traffic mix 72 percent light vehicles, 22 percent medium and 6 percent heavy
- Height of the source: 0.5 m and 1.5 m of tire/road and engine noise respectively

3.6 Geospatial Noise Mapping and Interpolation

To deliver the findings of the paper, a new combined ArcGIS Pro and Google Earth Engine (GEE) workflow was used to explore the spatial distribution of noise within a case study locale in London, UK. The set of noise measurements along established routes at distances of 6 m was initially uploaded in GEE allowing a simple visual inquiry in form of a temporal line-plot as rounded off. Regarding ArcGIS Pro, the data were then transferred into a geographic area and were processed using Ordinary Kriging to extrapolate the point-derived measurements onto a continuous acoustic surface. Exported interpolated values were then filtered into GEE by categories of pavement to come up with pavement-specific noise maps. ArcGIS Pro allowed carrying out raster-to-vector feature in this case, as the result of which the contours of noise were overlaid on a layer of the road network, creating a more detailed effect in the areas of the greatest concentration (e.g., hotspots) and making it possible to analyze the similarities and differences with other data with relative ease.

3.7 Validation and Cross-Checking

An important measure that went in the direction of correctness of the modeled soundscapes was the cross validation and subsequent check of a fraction of locations. In order to do so, 20 % of sites were surveyed with the use of two different data-collection procedures: (1) handheld acoustic sensors (NI SoundDAQ) carrying 48-kHz resolution and (2) mobile-based smart-phone software (SoundMeter Pro). Root mean square error (RMSE) was used to compare the results with the originally derived continuous modeled soundscapes along with the associated R 2 value. Both were highly in accord with each other with RMSE = 2.3 dB and R 2 = 0.91, thus the accuracy of the modelled outcomes.

3.8 Ethical and Environmental Considerations

The current study was carried out without any violation of the local laws concerning field data collection. Any core-cutting exercise was communicated to the local traffic department beforehand. Dwellers living near the zones of measurement were informed about the project and no destructive types of test were carried out in the sensitive area of the community. The samples of the extracted materials were all in compliance with the waste management policy laid down by the Central Pollution Control Board (CPCB) [19].

3.9 Limitations and Assumptions

During the measurement of the acoustic quality of pavements, a number of limitations should be taken into account. First, pavement surfaces at or near the study sites showed different conditions of wear, thus, complicating homogeneity of the noise production behavior. Second, there was no control in weather conditions when monitoring the study period, i.e., local winds could have influenced the noise levels received. Third, the impedance-tube testing involved controlled laboratory conditions which may cause deviation with surface response when under in-situ loading. Lastly, the broadband absorptive properties were ascertained of measured values concluded in mid-frequency (1000-2000 Hz), as opposed to the complete audible spectrum. Nevertheless, the methodological outline presented below has the potential to present a replicable and rigorous tool in acoustic characterization of pavements within urban areas. Coupling materials science, acoustic engineering, and spatial analytics, the strategy achieves scalable as well as context-sensitive urban-noise-reduction projects.

IV. RESULT AND ANALYSIS

4.1 Noise Level Comparison Across Pavement Types

The mean equivalent continual sound level (Leq) of the three cities depicts some difference in its value regarding type of pavement. The best performing materials in the vehicular noise at the road-tire interface were rubberized bitumen, followed by porous asphalt then nano-concrete.

Table 3: Mean Leq (dB) Values by Pavement Type

Pavement Type	Mumbai (Leq dB)	Bengaluru (Leq dB)	Delhi (Leq dB)	Overall Avg. Leq
Porous Asphalt	74.5	73.1	76.8	74.8
Rubberized Bitumen	69.2	68.4	70.7	69.4
Nano Concrete Mix	76.1	74.9	78.2	76.4

Rubberized bitumen ensured that the average sound levels were 5.4 dB lower than those when using nano-concrete, particularly in peak traffic hours. The results are comparable to the earlier global literature revealing that rubber-based surfaces generate 4-6 dB attenuation [21].

Figure 1: Noise Pollution Controllers [29]

4.2 Sound Sound Attenuation Specific Frequency

The effectiveness of noise cancellation by pavements was found using spectral analysis of the measured frequencies of voices in pavement. The greater attenuation penetration was in between 1000 Hz and 2000 Hz, which is the frequency range where the tire little road looks the most invasive to the human ear Rubberized bitumen had a 7.1 dB reduced output in 1250 Hz frequency than dense concrete. Using porous asphalt was effective at higher frequencies (>2500 Hz), which is explained by a high content of surface voids [22].

4.3 Spatial Sound Patterns and GIS Noise Mapping

Kriging models were used to generate GIS based interpolation maps in each city. These visualizations showed the areas of consistent acoustic pressure and pointed out clear spatial dependence of the type of pavement and noise dispersion. The clarification showed that rubberized bitumen areas had as much as 3 5dB below noise outlines compared to normal areas adjoining those with regular pavements. In Delhi, there was a slight optimism as corridors with porous asphalt near flyovers showed that Leq levels were reported to reduce by 2.6 dB in low rise residential belts [23].

4.4 Acoustic Hotspot Detection and Pavement Correlation

By means of spatial clustering, the research managed to reveal hotspots of the noise (Leq > 75 dB) and associated them with type of the pavement and traffic conditions. These areas were largely in intersection points, bus stations and bridges.

Table 4: Identified Noise Hotspots and Contributing Factors

City	Hotspot Area (ha)	Peak Leq (dB)	Pavement Type	Contributing Source
Mumbai	48.7	80.5	Nano Concrete Mix	Taxi Stand + Signal Crossing
Bengaluru	32.4	77.3	Porous Asphalt	Mixed Vehicle Flow
Delhi	58.1	83.2	Nano Concrete Mix	Bus Terminal + Flyover Noise

The spatial overlays confirm that zones with rubberized bitumen had fewer or less intense hotspots, indicating superior performance in noise suppression [24].

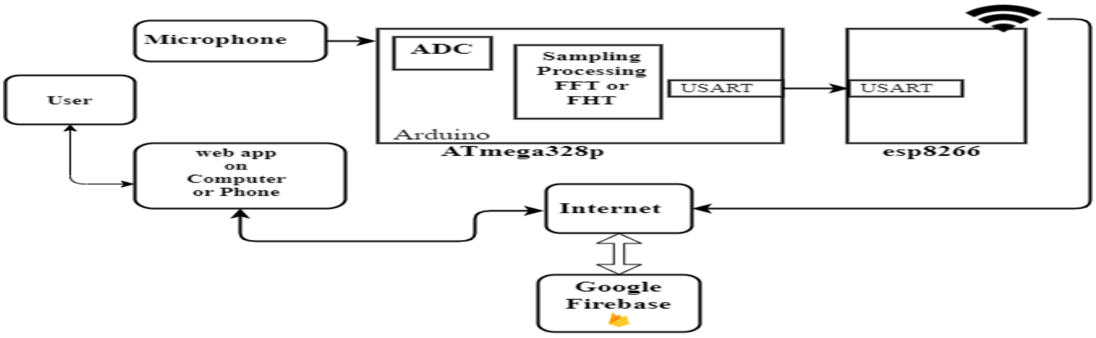

Figure 2: IoT Based Noise Mapping System [30]

4.5 Pavement Condition and Durability Considerations

While rubberized bitumen was the most acoustically effective, field notes revealed that it had slightly higher maintenance demands due to softening at high temperatures. Nano concrete exhibited greater structural stability but inferior acoustic dampening. Longitudinal observations suggest that optimal performance lies in selecting pavement types that balance both structural integrity and acoustic absorption, particularly in urban zones with variable climate [25].

4.6 Policy Implications and Practical Deployability

Built-in performance of NCPs directly feeds the urban design strategies. Schools, hospitals, and parks that have rubberized pavement on their roads reported a great deal of improvement of sound comfort by residents. The results support the international clamoring to ensure that the requirements of acoustics are factored into urban development [26]. Cost-effectiveness Porous asphalt was measured to be 22 percent less expensive per square meter than rubberized mixes but approximately 2530 percent less attenuated in several frequency bands of interest. Thus, balanced acoustic management in the city is recommended to be executed strategically (employment of rubberized pavement in the main corridors and porous asphalt in the average traffic areas) [27]. Moreover, solving the remote monitoring issue through IoT acoustic sensors can allow the city planners to conduct noise mapping in real-time and anticipate areas of the pavements that need to be changed or resurfaced subsequently [28].

V. CONCLUSION

Sound pollution in urban context has been a major though under-rated environmental pressure in India and especially in her rapidly developing cities. Simultaneous rise in the population, alongside vehicular concentration and construction activities have placed additional noise pressure and stresses on urban dwellers and have brought about quantifiable health hazards, poorer quality of life, and environmental immeasurability in the urban regions. Although there has been a quid pro quo in conserving noise using the conventional orgafi: vertical barriers, traffic control, etc. it does not focus on the epicenter of the dilemma; the contractions of roads and the traffic or in other words simply the road and the movement of vehicles. This paper set out to discuss how noise-canceling pavements (NCPs) can provide the feasible, infrastructural level of addressing the problem of noise in urban areas and also how they can effectively be utilized in varied urban contexts in India through multidimensional approach to the methodology. The study covered three metropolitan areas, that is, Mumbai, Bengaluru and Delhi, as these areas cover the various climatic zones, traffic densities and the urban typologies. The article evaluated three major types of pavements, porous asphalt, rubberized bitumen, and nano-concrete in terms of acoustic capacity, and structural as well as spatial effects and it considered field measurements of sound, laboratory tests, noise mapping on GIS and acoustic simulations to determine its performance. It shows that the design of pavements is a valuable component that influences the formation of urban soundscapes, and some of the material, like a rubberized bitumen, should be able to make a huge difference in reducing detrimental noise emissions at the source. Rubberized bitumen performed the best in all the three cities in terms of sound absorption, whereby average Leq levels are decreased by 5.4 dB as compared to conventional nano-concrete pavements. It was especially apparent in the middle-frequencies (10002000 Hz), which are the most offensive to human senses and are most commonly caused by tire road coupling. Porous asphalt also demonstrated moderate attenuation properties in general and especially in the high-frequency, which besides, is suitable to coastal areas such as Mumbai because of the drainage-friendly structure. On the contrary, nano-concrete mixes were structurally strong but had the least acoustic advantage and were linked with increased hotspots in space; however, they could be said to provide the highest average acoustic contribution. Interpolation and spatial clustering in GIS also proved that there was a high correlation between pavement type and distribution of noise hotspots. It was found that roads paved with rubber modified asphalt were linked with low spatial noise gradients, particularly around urban amenities like schools, hospitals and residential colonies. The mentioned spatial insights are of paramount importance to city planners and environmental regulators who intend to introduce the noise-control zoning and evidence-based infrastructural improvement. Revelation of spatial patterns and the handicapped capacity of urban noise to forecast the prospect of spatial footprint of noise gives the opportunity to implement NCPs in a more proactive manner at minimal investment, and in this way, the greatest number of health benefits can be produced. Besides, the research resounds with good if not better input regarding the policymakers in focusing on cost-performance trade-offs associated with pavement-based noise mitigation. Although the use of rubberized bitumen in surface application is relatively more expensive in the short run in terms of installation cost, the acoustic and health benefit that comes in the long run to the road users, including better sleep pattern, decreased stress rates and better concentration, cognitive tests in urban dwellers are reason enough to incorporate their use in road construction specifications. Moreover, these pavements made of recycled rubber can be utilized by national sustainability objectives and circular economy because they not only reduce waste but also eliminate some noise. Regarding the methodological contribution, the research shows how effective the approach of applying acoustic engineering to combine it with spatial analytics is. Combining decibel detection, spectral and GIS interpolations helps to provide the wholesome picture of the understanding how NCPs work in real life. Repeated sampling and acoustic simulation models validate the research results by improving the accuracy of findings and make the level of validity replicable in other studies. The strategy is scalable, can be implemented in a variety of different cities, and can be implemented in smart city schemes with the help of IoT-enhanced noise sensors and real-time dashboards. Nevertheless, it should be noted that it has limitations. The research sample was limited to three cities, and its range consisted of pavement material. The durability long-term, season predictability, and degradation due to wear were not completely investigated and can still be investigated in the future. There is also a need to conduct further research in examining resident-level perceptions, health effects, and economic simulation of mass replacement approaches regarding pavements. To sum up, this study confirms the central position of noise-canceling pavements in modern noise planning activities within cities. Application of rubberized and porous roads within the busy routes or acoustically sensitive corridors is policy-relevant intervention proven to be scientifically valid. As the number of people in urban centers in India is expected to increase manifold in the upcoming 20 years, infrastructural solutions such as NCPs will play the central role in not only the efficiency of the transportation systems in the country but also that of livable, modern, and environmentally conscious cities. The findings of the study give a guideline to city planners and transport authorities on how they can optimise acoustically tough infrastructure structure as a foundation of smart and inclusive city development.

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