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NOISE POLLUTION (P ZANNIN, SECTION EDITOR)

Noise Pollution and Urban Planning

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Abstract
Noise pollution distribution in each city around the world is necessarily influenced by its own design. A lot of factor associated to urban planning have a considerable effect on volume of traffic, vehicles distribution, traffic conditions, etc. And it is know that, from a temporal and spatial point of view, the most important source of noise in cities is road traffic. For that, good relationships between urban planning and different factors such as urban density, urban morphology, urban land use, street distribution, street environment and green spaces are being founded. In this way, the fact of finding a sustainable city could be closer, at least with respect to noise pollution. A good knowledge of these relationships would allow better prediction, analysis and prevention of such pollution through an effective design of urban environments. However, although in the first decade of XXI century these relationships were treated in some works, only some aspects of these problems were considered, essentially focused on street functionality. In the last years, this topic has reached more important development and more studies focused on the analysis of the relationships between the distributions of pollution and urbanism. This work makes a revision of spatial sampling methodologies for noise pollution assessment in relation with urban planning and a review of studies that have analysed the relationships between urban noise and different specifics aspects of urban design.

Keywords Noise pollution · Sampling methods · Urban planning

Introduction

The migration of population from rural to urban areas has meant a high growth of cities around the world. According to data from the World Bank [1], the percentage of world's urban population has increased from 33.6 to 54.3% between 1960 and 2016. This emigration is associated with the shift towards an economy based on industry, technology and services. There is a greater opportunity in cities for employment and basic services such as education and health. However, in many cases, this explosive population growth in cities has not been accompanied by an adequate urban design. Cities have grown in size with a deficient public transport. This has led to an increase in private transport generating various environmental problems, among which is noise.

Noise was considered for the first time as an important agent of pollution at the World Environment Congress held in Stockholm in 1972 [2]. Subsequently, the World Health Organization produced numerous reports based on studies by researchers from around the world that demonstrated the harmful effect of noise pollution on the health of human beings [3–7]. In this regard, acoustic pollution was also considered by the World Health Organization as one of the most important environmental stressors that has a negative impact on public health in 2011 [3].

Therefore, noise has gone from being a poorly valued pollutant, considered as an unpleasant consequence of the progress with which one had to learn to live, to be one of the main objectives for different public and government administrations. This change in perception is largely due to the numerous current studies that show that exposure to environmental noise can have negative effects on health [8–10]: cardiovascular diseases [11–15], sleep disturbances [16, 17], cognitive impairment in children [18, 19], psychological disorders [20, 21], negative effects on the auditory system [22–24], obesity [25, 26], etc.

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Any approach to improve this environmental situation and look for solutions requires a knowledge of reality to try to reduce the levels of noise pollution in those cases where it is convenient. This approach has been taken up by the European Community and the USA [26–28]. Noise map is one of the most used tools to analyse the acoustic situation of urban environments. Perhaps, the generalization of the use of noise maps is due to the fact that the Environmental Noise European Directive (END) [26] considers it as the main tool for evaluating environmental noise exposure. Also, this regulation is used as a reference in non-European countries [29, 30].

There are different methods for the elaboration of noise maps, and these can be classified into computation and measurement methods. On the one hand, computation methods are usually implemented in commercial software. For this purpose, different normalizations about the outdoor sound field behaviour, such as ISO 9613 standards [31, 32], are considered. However, it is also advisable to use numerical calculation methods (BEM, FEM, etc.) in studies with a smaller spatial scale, due to their high computational cost [33, 34]. On the other hand, the measurement procedure is standardized [35–37], but measurement methods differ in methodological aspects associated with the selection of sampling points. ISO 1996 [35, 36] and ANSI S12 [37–40] are international standards that include calculation models and procedures to carry out sound pressure level measurements in outdoor environments. Therefore, they have been taken as a reference for developing national and international legislation and to elaborate noise maps.

In connection with this issue, it is necessary to indicate that noise map is a cartographic representation whose objectives are not necessarily in this order:

- To assess the noise pollution
- To estimate the noise annoyance degree suffered by the population
- To determine the number of exposed population in each band of noise levels [26].
- To be used as a basis to propose interventions which can improve the current situation

To know the noise level to which population is exposed in their homes, workplaces, schools, hospitals, etc., the evaluation of the incident sound field on the façade of buildings is essential. To this end, both methodologies described above can be used. However, to assess the incident sound energy on the facade of the dwelling under consideration with the highest possible precision, it must be taken into account not only the sound source (geometry, situation, power, spectrum, etc.) and the urban environment (geometry, configuration, elements, materials, etc.) but also the specific situation of the evaluation point [41–44]. Recent studies even indicate that other variable aspects of the road not considered until now, such as the presence of parking lines, can significantly influence the levels of exposure to noise in homes [43, 45].

With respect to the use of noise mapping information to propose interventions which improve the current situation, only computation methods allow to estimate the effectiveness of proposed actions. However, nothing but the use of "in situ" measurements allows knowing the actual effectivity of a developed action plan with the appropriate accuracy.

Although both methodologies can be used in the elaboration of noise maps as it is stated in international standards [36, 46] and national legislation emanating from international directives, noise maps through measurements are becoming less used to that made through simulation. In fact, some studies only use traffic flow data to make noise maps by computation [47, 48]. But the computation methods make approximations to reality [49, 50]: simplification of terrain models, streets and building geometry, approximations about the behaviour of acoustic field in its propagation and interaction with the boundary surfaces, approximations in the geometry of the sound source and in its field of radiation, etc. Therefore, noise maps made by computation methods require sound measurements in an essential way, both for the calibration or validation of the model and for the verification of its estimations [51]. In addition, given the simplification of the reality that is done in noise maps, time-space sampling methods may arise that can generate noise maps with similar quality to that of calculated noise maps. Moreover, the development of affordable technology allowing for fixed measurement positions for noise may be shifting the balance, especially when long-term exposure is required.

Currently, there is no consensus regarding the methodology to be applied for developing noise maps nor with respect to the uncertainties that the different methodologies can have associated. This fact is important when the affected population is compared between different countries and in the design of action plans that can be applied successfully in an international level. With respect to computational methods, progress is being made in the development of common noise assessment methods in Europe: CNOSSOS-EU [52]. In this regard, the Harmonoise calculation method was previously tried and it had its limitations [53]. To avoid this, Annex II of END was modified so that EU member states adopt the necessary measures to implement the CNOSSOS-EU method [54].

In conclusion, measurement methods are important for the verification of computerized noise maps or as an alternative for making noise maps. In addition, noise pollution assessment methodologies and estimation of their impact on the population appear that take into account in this framework the possible relationships between urban structure and sound levels. This relationship will have a special interest in the integration of noise pollution in urban planning. Therefore, a revision of spatial sampling methodologies for noise pollution assessment in relation with urban planning is firstly made in this work. Secondly, a review of studies that analysed the relationships between noise pollution and specific aspects of urban design, such as urban forms, green spaces, street environment, road networks and building designs, was made.

Urban Planning and Spatial Sampling for Noise Pollution Assessment

Initial Situation

The spatial variation of the ranges of sound levels obtained in a city is represented in noise maps. Therefore, the search for a methodology that accurately registers the spatial variability of noise levels is a line of research in continuous development. In this regard, it is necessary to highlight the revision of spatial measurement methodologies carried out by Brown and Lam in 1987 [55]. This work has been used as a reference in many of the current studies. Brown and Lam show four types of spatial noise sampling: random sampling, sampling by land use category, receiver-oriented sampling and source-oriented sampling.

The random sampling is a technique used in different areas of science. In relation to its application to urban noise sampling, stratified random sampling is usually used instead of simple random sampling. In this last case, all points of area under study have the same probability of being selected. In systematic random sampling, the points are selected using a regular pattern throughout the study area, usually using a grid of square cells. This technique, also known as the grid method, is in fact the only measurement method that appears in international standards [36, 46], and it provides uniform coverage of the study area [56–58]. However, it has no relation with the urban design of cities, so it is not sufficient for the establishment of relationships between urban planning and noise levels. In addition, some studies show that the representation of their results depends to a large extent on the density of sampling points and the urban characteristics of the study area [55, 59]. In this sense, the necessary density of points can become, in fact, unapproachable with an acceptable cost.

The urban zoning by land uses is used in regulations to establish the limit levels of sound exposure. Sampling by land use category is an urban noise sampling methodology directly related to certain aspects of urban design in cities. To be applied, an urban zoning is carried out first by the researcher according to the following uses: residential, industrial, recreational, commercial, etc. Then, the measurement points are arbitrarily or randomly distributed in these categories. However, these land use categories are not spatially differentiated or the residential category is so extensive in some cities that it is the only category of interest for evaluation. Therefore, this sampling should be based on random sampling. In addition, different studies [60, 61], show that the land use categories are not strata but conglomerates, from an acoustic point of view. So, again, this method of spatial sampling has no interest on its own for the establishment of relationships between urban planning and noise levels.

Receiver-oriented sampling, traditionally, is applied to small environments: hospitals, colleges, etc. Logically, this approach of use hardly allows the search of relations between urban planning and noise pollution. But it really is the aim of any evaluation of the impact of noise on the population and, in particular, of noise maps. Finally, to this end, it is necessary to know sound levels in the receiver position. Under this approach of a study of a city or of large areas of a city, it is clear that this sampling strategy has the same problem that the previous in large-scale studies. The support of other sampling techniques is necessary [62]. Finally, a random sampling strategy is the common election.

In the case of the source-oriented sampling, at least in a first phase, it does not allow to know the levels of exposure to which the population is subjected, which is the final goal of noise maps. But it would allow a characterization of the source which can subsequently be used for purposes deemed appropriate. In particular, methods of calculation for making noise maps are directly related to this type of sampling. Although, the volume of traffic is generally the data used, neither the sound level nor the sound power is generated. Naturally, the locations of measurements points must be carried out again by a random selection in this type of sampling for large-scale studies.

The different sampling methodologies proposed by Brown and Lam [55] have in common the use of random sampling whenever they are used for the study of large areas. Consequently, they present the problem of not allowing to find relations between urban planning and noise pollution. But in this paper, Brown and Lam made an important annotation that can be the basis of a new approach of noise sampling methodology for noise maps: "The design of urban noise surveys should take into account that the underlying structure of urban noise is largely determined by the disposition of transportation, and in particular, road traffic, noise sources […] stratification of the noise field according to proximity to the dominant transportation sources will be more successful than stratification using land uses […]".

But this approach was not studied till some decades after. The first international paper in this line was a work of Barrigón et al. [63]. Nowadays, it can be showed that different researches have opted for a stratified sampling of roads. These aspects will be analysed in the next section.

Stratified Urban Road Sampling

The great spatial variability of noise in an urban environment leads to thinking about stratification strategies to reduce uncertainty and increase the accuracy of the type of sampling selected. For this purpose, it is important to determine the main variables related to urban noise variability. The main source of urban noise, both from a temporal and spatial point of view, is road traffic. The flow, speed and composition of traffic are the variables that most influence the variability of noise levels [64]. However, in turn, these variables necessarily have a relationship with the structure of the city, with its design, for example, with the location, importance and existing mix of residential, industrial, service areas, etc., or with the urbanistic characteristics of the roads and the surrounding environment. Therefore, the quality of the stratification of noise that is reached depends on the degree of understanding that we can achieve from the relationship between the behaviour of road traffic and the structure or design of cities or the urbanistic characteristics of their streets. In other words, we need to know where, when and how people move along the city, as usual for any traffic model.

Some of these ideas begin to show in some works, such as those of Purkis [65], Brown and Lam [55] or Sánchez and González [66]. Purkis conducted a study of the sound levels recorded in the day and night periods in different groups of urban roads in London. Also, as the title of the work indicates, “Transport noise and town planning”, Purkis analyses the relationship between noise pollution and urban planning. The first proposal on a sampling by urbanistic criteria is carried out by Sánchez and González, who carried out a record of the sound levels in categories of roads obtained from the city of Valladolid [66]. This research line is continued in a work by Barrigón et al. [67], in which urban roads are classified in different categories according to their use as a communication path. Finally, Barrigón et al. performed an analysis in 2002 [68] by inferential statistics of the stratification of road categories according to their use in communicating the different zones of the city of Cáceres (Spain) in the categorization method.

This method is a stratified sampling of urban roads (categories) based in the concept of functionality. So, urban roads are classified in different categories according to their use as a communication path between different parts of the city and between the city and other urban areas in the country. As an example, the categorization of the city of Concepción (Chile) is shown in Fig. 1.

This technique began to be applied in Spanish cities with geographical and urban differences [69, 70] through attended samplings during the day. The demography of these cities ranged between 55,000 and 220,000 inhabitants. Results of these studies showed a highly significant correlation coefficient between sound level and traffic flow and a significant stratification of the different categories.

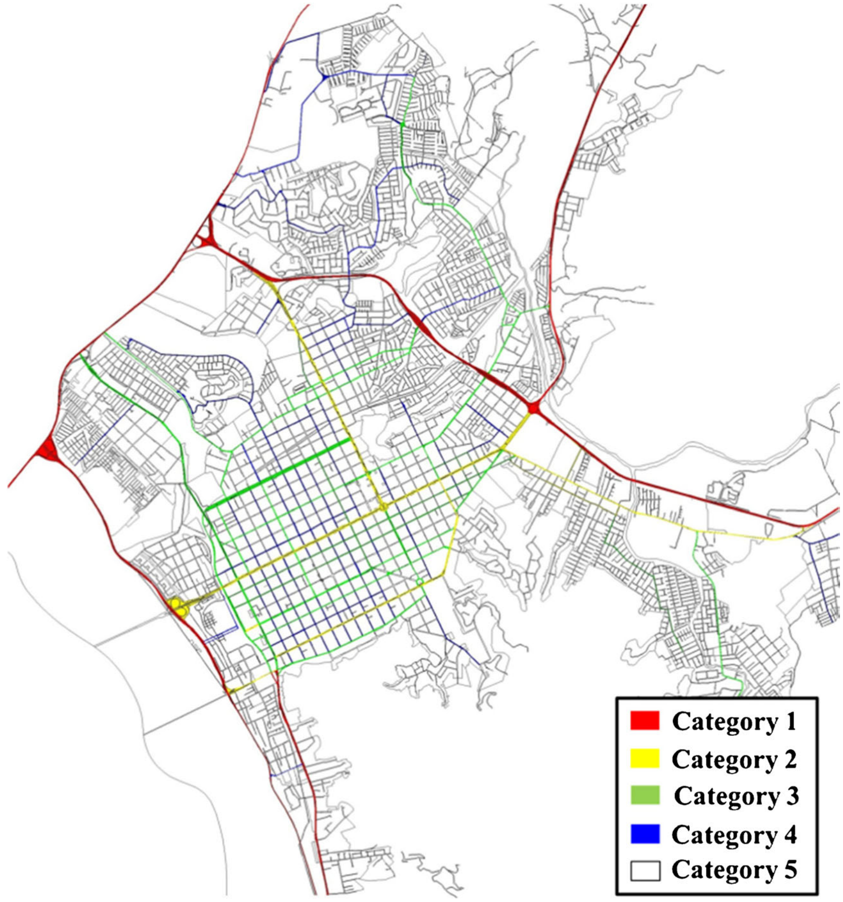
After these works, some researchers carried out studies with the idea of developing a previous classification of the streets. Moraes et al. [71] carried out a classification of the streets of Belem taking into account architectural characteristics of the streets, traffic flow data and estimated sound levels. Jiménez et al. [72] applied a method to estimate nocturnal sound levels of road traffic from the performance of sound measurements during the daytime period. For this, they used the following classification: urban ring roads, main streets and ordinary streets. In spite of the problems of significant stratification of sound values recorded in this typology of roads in some cities, estimation errors are significantly lower when using the classification. In this line, Ausejo et al. [73] analysed the reduction of uncertainty in a noise map by increasing the number of road type categorization. If the number of categories increased from categories 3 to 4–5, the error decreased by half if the map was not calibrated and to a quarter, if it was calibrated.

In contrast to the lack of continuity of some of these studies, despite the benefits in estimating sound levels that involved the use of a classification of urban roads [71–73], the stratification proposed by Barrigón et al. [68–70], the categorization method, is developed in different studies and theses [74–76] reaching a continuity in new published results. In particular, in successive studies [29, 77–80], the method extended its application to cities of very different population sizes (from 2000 to 700,000 inhabitants) and geographical situation. The aim was to make the categorization method applicable to any type of city, regardless of its size or its sociodemographic and urbanistic characteristics. Without a doubt, this fact would give a utility for a design of the cities taking into account forecasts on the sound levels that could be reached in the different streets depending on the category to which they belonged.

Results showed that the recorded average sound values decreased significantly from category 1 to category 5 [69, 70] (see Table 1). In addition, the sensitivity, non-specificity and prediction capacity for each category were analysed through the ROC curves. Table 2 shows the predictive capacity of the categories in different cities. It can be verified that the categorization method has high sensitivity and prediction capacity and low non-specificity [80].

The END indicates that the sound measurements must be of 1 year duration or representative of this period when its duration is shorter [54]. The high temporal and technical cost to carry out measures of 1 year mean that measurement periods of some minutes or hours are used in most studies of urban noise [84, 85]. However, to analyse the representativeness of short-term measures, studies analysing the variability and structure of environmental noise based on continuous 1-year measures are needed. These annual sound level recordings were scarce until very recently, and authors estimated and extrapolated the results to months or years from short-term sound level measurements [69, 86, 87]. Due to the incorporation of noise sensors in environmental monitoring stations and the development of their autonomy, nowadays a greater number of long-term measures are available [88–90].

Fig. 1 Categories for the city of Concepción (Chile)



In this line of work, Rey Gozalo et al. [81, 82] carried out simultaneously short-term measures and a continuous 1-week sound record in different locations in the cities of Cáceres and Plasencia. The results showed the significant stratification of the sound indicators Ld, Le, Ln and Lden between the different categories and the high percentage of predictive capacity (see Table 2). Therefore, the categorization method was validated in weekly sound measurements. Also, in these studies, non-statistically significant differences were found between short-term and continuous measurements (daytime). Thus, the urban stratification of noise evidenced in previous studies using short-term measurements was validated by continuous measurements. In this regard, Romeu et al. [61] demonstrated the correct working of road classification in different temporal periods and, also, that they could estimate the sound values continuously obtained during the daytime period through short-term measures [91].

Then, in the development of the categorization method, the annual average sound levels and the temporal variability were analysed in Madrid [83]. The sound measurements were carried out in 21 environmental monitoring stations in which road traffic was the main noise source. Results show that the proposed categories highlight the spatial noise stratification of the studied city in each period of the day (day, evening and night). Significant differences were found between the categories for both night and daytime levels, demonstrating, in both cases, the existence of a stratification in the sound levels associated with the functionality of the road. This stratification, given the definitions of the categories, implies that the categories numbered with lower values, are those that present higher sound levels for Ld, Le, Ln, Ldn, Lden and L24. ROC classification showed that the categories have a good predictive capacity for non-measured values (see Table 2).

In summary, results show that the concept of functionality enables to obtain a good information about the distribution of noise levels in cities for all periods of the day. Therefore, it can be a good tool for town planning and the design of pollution prevention policies for noise as well as other traffic-related pollutants.

As shown in the review of the mentioned works, the urbanistic characteristics are important for determining the type of road classification. In addition, the stratification of urban roads has similarities with the road classifications proposed by urban or transport agencies in many cases [92–98]. This legislative road classification has a clear connection with the functional design of urban environments. Therefore, this indicates that the existence of a relationship between urban design and noise pollution is possible.

Table 1 Average value of Leq (dBA) for each category in different Spanish cities

City	Inhabitants (thousands)	Category					Ref.
		1	2	3	4	5	
Castuera	7	68.5	64.5	63.0	58.6	52.3	[80]
Olivenza	12	70.0	67.4	64.6	61.3	57.1	[79]
Navalmoral	17	70.5	66.4	65.0	61.3	55.0	[80]
Plasencia	40	69.7	67.8	65.8	62.7	55.8	[81]
Cáceres	92	70.8	68.4	63.1	62.0	58.1	[82]
Badajoz	150	72.7	71.4	67.7	65.9	63.9	[70]
Vitoria	221	74.0	71.5	71.2	69.3	63.3	[69]
Valladolid	318	75.5	73.0	71.6	68.5	60.8	[78]
Sevilla	700	76.5	73.7	72.2	67.8	61.9	[80]
Madrid	3000	74.6	71.4	68.5	66.7	65.2	[83]

The classification of urban roads brought benefits in other aspects as well as for the evaluation of urban noise. In recent works, the classification of minor roads was used to estimate the exposure to road traffic noise for epidemiological studies [97]. Also, road classification has been used for urban aspects in other studies. Xie et al. [99] conclude that national highways had a greater effect on urban growth than provincial roads with the same environmental characteristics.

A Brief Comparison of Urban Noise Sampling Methods

In the revision of the sampling methods previously carried out, three methods have been highlighted: grid method, urban road classification and categorization method. Although there are fewer and fewer studies that currently use the grid method, it is the only method that is included in an international standard [36, 46] The ISO 1996-2 standard is widely used as a guide for the measurement procedure. For this reason, the grid method was chosen to be compared with the categorization method. This comparative study was carried out in cities of different countries (Spain and Portugal) with different sociodemographic and urban-architectural characteristics [79, 100]. In the analysis of their predictive capacity, both methods gave low values (less than 1 dBA) of the mean total prediction error, indicative of their suitability for the evaluation of the overall noise situation of a town. Nevertheless, results showed that the categorization method had a lower uncertainty in the estimation of sound levels. Generally, the estimation errors of the categories did not present significant differences with respect to the null value and were significantly lower than those registered by the grid method. The median prediction errors of the categorization method are generally not significantly different from zero. However, this finding only occurs in certain categories for the grid method. One particularly important finding is that the grid method has greater prediction errors in the noisier categories (for which the impact of noise on the population is most relevant). In this sense, [79] showed the difficulties of the grid method to estimate the population exposed to noise. These advantages of the categorization method with respect to the grid method have also been recently verified in cities of Chile [29].

Table 2 Predictive value (%) obtained from ROC analysis for the Leq (dBA) values of the categories in different cities

City	Country	Category					Ref.
		1	2	3	4	5	
Valladolid	Spain	88.9	53.9	85.7	78.6	100.0	[78]
Plasencia	Spain	90.0	88.9	88.9	77.8	81.8	[81]
Campo Maior	Portugal	100.0	75.0	88.9	83.3	100.0	[80]
Valdivia	Chile	100.0	72.7	81.8	100.0	100.0	[80]
Cáceres	Spain	100.0	100.0	100.0	100.0	100.0	[82]
Madrid	Spain	100.0	100.0	100.0	80.0	80.0	[83]
Talca	Chile	88.9	87.5	90.0	100.0	100.0	[29]

Nevertheless, recent studies tend to classify urban roads previously to random or arbitrary sound sampling. In most of them, the road classification made by the corresponding transport or urban agency is used [95, 98, 101]. However, these legislative road types present problems of significant sound stratification [101]. Rey and Barrigón [29] carried out a comparative study between the method of categorization and legislative road types used by the Ministry of Transportation and Telecommunications (MTT) in Chile [102]. The results showed that the stratification of sound values in road categories has a significantly lower prediction error and a higher capacity for discrimination and prediction than in the legislative road types [29]. The MTT road types have a low percentage of sensitivity and predictive capacity and a high percentage of non-specificity (except for the local road type for all the sound descriptors that has values lower than 10%). This low discrimination and predictive capacity is caused, among other factors, by the lack of significant differentiation of sound values registered in trunk and service road types and by the high variability of the sound values of the local road type. Average sound values in the different road categories of the categorization method have highly significant statistical differences. The road categories also have a high percentage of sensitivity (> 75%) and predictive capacity (> 80%) and a very low percentage of specificity (< 5%). The prediction errors of the categorization method are lower than those of the MTT method for the different urban roads analysed. These differences in the prediction of sound values involve differences in the estimation of exposure levels and percentage of annoyance. According to the MTT method, 10% of the population is exposed to Lden > 65 dB, whereas this is 23% of population according to the categorization method. Therefore, the categorization method is a more appropriate method to assess the impact of noise on the urban population.

In sum, this review of the proposed and analysed temporal sampling methodologies, in the works published so far, seem to indicate the wide possibilities of the categorization method to establish relationships between urban structure and planning with the existing sound levels in streets and the exposure to noise of the population in urban areas. But other approaches have been proposed in the literature that are not directly related to the approach of sampling sound levels, in which studies are also carried out to analyse the relationships between urban planning and sound levels. This will be the objective of the following section.

Urban Design, Urban Planning and Street Noise Levels

The development of increasingly precise sampling methods will have a direct relation in determining the population exposed to noise, and with this, we will be able to better understand the causes of their negative effects on health. Also, it will have a direct influence on the application of computational methods, given the need for measures to calibrate them. Specifically, stratified road sampling provides the ability to calibrate predictive models and verify their sound estimates [51], with a small number of measurements. Studies, based on a previous stratification of urban roads and the use of GIS, have demonstrated a clear competition to traditional calculation methods [94, 103].

Noise has become a priority environmental problem for urban managers and planners. In this sense, the relationship between noise and urbanism takes on great relevance. Barrigón et al. [77] analysed the relationship between urban noise registered in the different categories of 20 Spanish cities with different urban characteristics (population, extent and population density) taking as reference previous studies that related noise to population density [104, 105]. The results showed how the extension of a city was the variable that significantly explained the highest percentage of variability in recorded sound levels. Also, as Rey Gozalo [74] shows, the percentage of explanation increases significantly, if this relationship analysis is done by categories. This is an indicator of how the planning of the current cities has encouraged their expansion as well as their linkage to road traffic as a means of connection.

Road traffic represents the main source of noise variability in cities. The different sampling methods are centred on this source of noise. Some important features to consider are the flow and type of vehicles, the speed, the type of pavement, etc. [106, 107]. However, the monitoring of these characteristics of road traffic can be of similar cost as the sampling of sound levels. In this aspect, the urbanistic characteristics, geometry of the street, pavement type, street width, average building height, etc., are factors with influence on the use of a street. This use will determine the functionality of the road, which has a relationship with the sound levels. This fact has currently led to the realization of different studies around the world whose objective was the determination of the relationship between sound levels and urban characteristics.

The influence of urban forms on vehicle transport or on street environment has been studied in different works. Tang and Wang [108] analysed the ways that urban forms, based on land use and urban geometries (e.g., building layouts, road networks or street configurations), influence vehicle transport and street environment. They conclude that the effects of another urban characteristics as building designs, green spaces, noise barriers, traffic control schemes, etc., should be considered. In addition, Wang and Kang [109] study the effects of urban morphology (building form and traffic pattern), urban land use and urban densities on the traffic noise distribution. They made a comparative study between some cities in UK and China. They found a considerable effect of urban morphology on the traffic noise distribution patterns but that it is necessary to use other simulation techniques to obtain more detailed spatial noise distribution and find more correlation patterns between noise distribution and urban morphology. In two works, Torija et al. [110] describes the development of some model to characterize urban sound environments and how to make a selection of variables that will help to make decisions in the characterization of environmental urban noise. The developed models of urban noise use not only some urbanistic variables but also data associated to traffic, traffic flow, traffic conditions, etc.

Based on models with only urban variables, some studies have determined a significant percentage of variability in noise levels [111]. Guedes et al. [50] also made a study about the influence of urban shapes on environmental noise in a city. The results of this study conclude that the physical characteristics of the urban shape, construction density, existence of open spaces or shape and physical position of buildings have a significant influence on environmental noise. Salomons and Berghauser [112] made a study on influence of some urban variables as population density and shape of building blocks over the spatial distribution of traffic noise in idealized urban fabrics. As a result of this work is reached that average sound level in an urban area decreases with increasing population and building density and that the shape of buildings blocks has a large effect on the sound level at the quiet façade but not at the most-exposed facade. Some studies have showed that other aspects associated to the urban design near of buildings as green wall [113] or the presence of parking lines [43] can have a non-considered effect on population exposure to noise. Other interesting aspects of the relationship between urban design and noise pollutions is studied in the work of Hammad et al. [114] analyse the best location for facilities in urban regions with the objective of minimising urban noise levels. Ryu et al. [115] develop a statistical model for to predict noise level of traffic in urban areas. Traffic variables are employed and found that have a significant impact on the noise levels. Also, the fraction of industrial area has a significant impact. Margaritis and Kang [116] have studied in eight cities the relationship between some aspect of urban design related to urban green spaces, urban morphology (buildings and streets) and geodemographic, with noise level. The study structures the city in three scales (macro, meso and micro-scale). As results, it was found that at each scale features of urban morphology were related to traffic noise levels to a different extent. And at the micro-scale, areas with the same building coverage can have different noise levels. In another work, also Margaritis and Kang [117] investigate the effect of green space-related variables on noise pollution in three levels (agglomeration, urban and kernel). They found that the relationship between noise and green spaces variables can vary from one level to another. In the urban level, a negative correlations was found. It is suggested to emphasize more on the ratio between green space and built-up surfaces, better than to the green space coverage itself.

Finally, the interest in the influence of urban design on the acoustic environment has another aspect in which the focus is more on the overall sound environment than, specifically, on acoustic pollution. In different published works, the relationship between sound environments or between soundscape and urbanism is analysed [118–120]. This is another interesting approach and a further proof of the current interest in establishing relationships between urban planning and sound environment with the final objective of being able to design the urban environment to integrate the sound aspects that are inherent to it and to pursue a higher quality of life for the citizens.

Thus, we can see that studies of relationships between urban characteristics and noise throughout the world have been made. It is clear, therefore, that this line of work is, right now, of great interest but that it requires many more works to understand to what extent the relations are global or local, if it depends on the area of the world to study or if some characteristics are global and other locals.

Conclusions

The noise pollution excess in some parts of a city compared to other quieter is inherent to the city design, in many cases, especially in cities created a long time ago, not planned and even totally away from the current mobility needs of the citizens. If we take into account the health damage caused by this noise pollution, for many years, the citizens have been demanding from the authorities' mechanisms of evaluation and control.

The in-depth study of noise distribution is a long and expensive process. For this reason, calculation systems are being imposed against the direct measurement of noise levels. However, the calculation methods have different uncertainty factors, so they also need measurements in order to be validated.

The possibility that the spatial structure of urban noise is related to urban planning or urban structure has given rise to new approaches to the study of urban noise. In this sense, the use of the concept of street functionality has given rise to a stratified sampling that has proved to be useful in the study of urban noise, allowing the use of the categorization method, with a small number of sampling points, to provide high overall knowledge of the acoustic situation of the city. Moreover, the categorization method has high sensitivity and prediction capacity and low non-specificity.

Besides, in recent years, several studies have been carried out to connect noise levels with urban planning and urban morphology, such as functional aspects of the city, urban green spaces areas of interest, lane numbers, parking areas and the presence of traffic lights. The results obtained are very promising, so it is expected to be able to predict the noise levels in an area based on a series of urban elements. The modification of these elements will suppose a reduction of the acoustic contamination. Traditional areas may not be able to modify everything that is desirable to achieve acceptable noise pollution targets, but new areas may be clearly favoured if the elements that determine the noise levels are taken into account by those responsible for the new urban design.

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Compliance with Ethical Standards

Conflict of Interest The authors declare that they have no conflict of interest.

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