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Building and environmental acoustics in obsolete residential neighbourhoods: The case of San Pablo, Spain

S. Girón [a,*], J. Martel [a], M. Galindo [a], R. Herrera-Limones [b]

[a] Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), Departamento de Física Aplicada II, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Avenida Reina Mercedes 2, 41012, Seville, Spain

[b] Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), Departamento de Construcciones Arquitectónicas I, Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Avenida Reina Mercedes 2, 41012, Seville, Spain

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ABSTRACT

In order to establish an agreement between the objectives of acoustic quality in the outdoor environment and the acoustic insulation in a building as required in the current legislation in Spain, the acoustic insulation of typical social housing has been studied in the residential neighbourhood of San Pablo in Seville. Field measurements based on acoustic sonometry have been performed in its public areas, together with the consultations to the strategic noise maps prepared by the administration of the city and with data from a questionnaire answered by neighbours on the perception of environmental and domestic noise. These inputs have enabled calculations of airborne and impact noise insulation in a typical dwelling of the neighbourhood. The neighbourhood presents various kinds of obsolescence, as do many residential estates built in Europe in the same period, mainly in terms of its low quality of construction and structural solutions, its energy poverty, and its typology. Results on acoustic insulation indicate that the requirements of current Spanish legislation have not been met, $D_{\mathrm{nt,A}} = 49$ dBA, $L'_{\mathrm{nT,w}} = 80$ dB. However, thanks not only to the urban layout of the various types of housing blocks in the neighbourhood, but also to the breadth and abundance of green and common areas and to their roads, the existing environmental sound levels remain below the established limit: $L_{\mathrm{d}} < 60$ dBA. Hence, the calculation for the external noise insulation in façades indicates that the requirements are met, $D_{\mathrm{2m,nT,Atr}} = 33$ dBA. In the acoustic survey, most people consider the environmental acoustic conditions of the neighbourhood to be acceptable or good and believe that they are barely affected by the domestic noise of next-door neighbours. The research found that social heritage neighbourhoods of the 1960s and 1970s, laid out with cul-de-sacs, curved layouts, and small pockets of parking, significantly improve their urban acoustic performance.

1. Introduction

Human activity linked to industrialisation and post-industrialisation has brought with it the problem of noise pollution, due to the increase of undesirable sounds with high levels of noise. Populations have grown significantly in cities and their transport infrastructures have multiplied, which constitute one of the main causes of urban noise [1,2]. The noise to which people are exposed in

* Corresponding author. Instituto Universitario de Arquitectura y Ciencias de la Construcción (IUACC), Escuela Técnica Superior de Arquitectura, Universidad de Sevilla, Av. Reina Mercedes 2, 41012, Seville, Spain.

E-mail addresses: sgiron@us.es (S. Girón), martel@us.es (J. Martel), mgalindo@us.es (M. Galindo), herrera@us.es (R. Herrera-Limones).

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their homes is generated both outdoors, as environmental noise, and indoors, as neighbourhood noise. The former is mainly due to road traffic and rail and air transport, industrial activities, civil works, building construction [3,4], and to commercial, sports-recreational, and leisure activities. Neighbourhood noise is due to noisy activities that occur within the dwellings themselves.

Noise pollution in cities can affect health and deteriorate quality of life, since exposure to high levels of noise causes effects on the hearing system and on other psychological functions [5,6]. Noise pollution is considered by the World Health Organization [7] to be one of the main environmental problems in cities and the second-most significant problem in a series of environmental stressors due to its impact on public health in a selection of European countries.

In this regard, European Directive 2002/49/EC of the European Parliament and of the Council of 06/25/2002 [8] established the development of strategic noise maps (SNM) as a tool to evaluate environmental noise, not only to help in ascertaining which urban areas are exposed to unacceptable noise levels, but also to determine the percentage of the population affected by such noise levels, and to provide action plans (AP) for the member states based on the results of said noise maps. The objective of these plans is to prevent and reduce environmental noise, especially where exposure levels can have harmful effects on human health, and to maintain the quality of the acoustic environment when it is satisfactory.

In addition to noise maps, the Directive requires a psychosocial report on noise annoyance. The current literature contains many studies in this regard [9,10]. Two of the references for the evaluation of noise pollution outdoors are the international standards ISO 1996-1: 2003 and ISO 1996-2: 2007 [11,12], which describe aspects related to the calculation and measurement procedures of the outdoor sound pressure level, and are used as references for noise mapping by the European Noise Directive.

Before 2003, Spain had no basic law on noise pollution, and the regulation of this issue had hitherto been dispersed across various legal texts and regulations [13]. In order to improve this situation, the drafting of a basic law at state level was promoted which, taking into account the new focus of anti-noise policies in the European Union, would exclusively regulate noise pollution adjusted to the characteristics, customs, and status of the environment of Spain. This law on noise, known as Law 37/2003, was approved and published on 18th November 2003 [14]. The noise law has been developed through regulation in two phases that culminated in the publication of various regulations: the RD 1513/2005 regulation [15] on the regulation and management of environmental noise; RD 1367/2007 on zoning, quality objectives, and acoustic emissions [16]; and RD 1371/2007, which approves the basic document DB-HR protection against noise of the Building Technical Code [17].

Before and during the production of the European directive on environmental noise, various pioneering studies on environmental acoustics were carried out in several Spanish cities by an outstanding group of acoustic researchers whose work has been published in the scientific literature. The publication by García and Faues [18] is worthy of special attention since it presents a statistical analysis of A-weighted noise levels measured over a 24 h period of seven Spanish cities, with the objective of studying whether sampling over a long period of time can be substituted by a simpler short-time measurement technique without losing important information. These authors also carried out the first aircraft noise survey answered by 1800 people living in areas neighbouring six major Spanish airports [19].

Arana and García [20] correlate the results of a social survey on noise annoyance and the measured noise levels in the Spanish city of Pamplona. Likewise, Martín et al. [21] evaluate the effect of the annoyance produced by traffic noise in the city of Valladolid and how its residents value the economic and social cost of noise reduction. Furthermore, in the city of Malaga, Martín et al. [22] carry out a psychosociological survey on a large sample of people with a stratification of the sample into homogeneous groups to evaluate the perception/annoyance of noise in order to be able to address the action plans proposed by the European directive.

However, it is the group from the Cáceres Polytechnic Teaching Centre that has devoted the greatest effort and scientific contribution to the study of environmental noise from road noise in two cities of Extremadura, Cáceres [23] and Badajoz [24], as well as of environmental noise from the historical centre of Cáceres, where traffic is restricted and where other types of sound emitters can produce noise pollution [25,26].

These authors have delved into other aspects of the environmental noise measurement procedure wherein a critical review and research proposals of standard measurement methods are highlighted for their improvements in the precision of the perceived doses of noise [27]. In densely populated metropolitan areas Tobias et al. [28] study the effect of traffic noise on public health in the city of Madrid, and Lagonigro et al. [29] assess noise levels through real measurements and simulations in order to construct the noise database at façade level for the 10 districts of the city of Barcelona.

In today's world, due to the increase in motorised vehicles and the densification of cities, numerous studies have emerged in the scientific literature on data from the five continents that address the acoustic insulation of the construction elements of façades and partitions. Regarding these issues, to mention just a few, Davy [30] presents a prediction model of sound insulation in walls wherein the theoretical equations are compared with experimental data with good correlation for a number of gypsum plasterboard walls. Moreover, in the work by Meza et al. [31], the authors measure the airborne sound insulation of façades according to standardised metrics in 120 homes in Chile, and through statistical analysis the sound insulation is estimated for various façade configurations.

With a certain similarity to the procedures used in this work, several articles deserve mention: those which associate acoustic measurements in building structures with surveys or interviews with neighbours in their flats; the critical review by Vardaxis et al. [32] on airborne, impact noise and outdoor and induced vibration and acoustic comfort; and that by Vardaxis and Bard [33], which is concerned with impact noise and subjective responses in laboratory tests. Very recently there is the work by Andargie et al. [34], who carry out field measurements of impact and airborne sound insulation in Ontario, Canada, for 5 types of multi-unit residential buildings and their correlation with the perception of annoyance of their occupants.

Despite the proliferation of research related to urban and domestic noise and its solutions, in the scientific literature no studies of a similar nature have been published on the environmental acoustics of the city of Seville.

This paper therefore analyses both the degree of acoustic insulation of a basic social dwelling in a working-class neighbourhood in the city of Seville and the environmental acoustics of public spaces in said neighbourhood. The objective results are correlated with the data of the strategic noise maps produced by the environmental services of the city council, and with the results of a sociological survey carried out on the neighbours. This neighbourhood presents various types of precariousness and obsolescence, as analyzed below, and requires urban regeneration. Likewise, it is also considered one of the most vulnerable neighbourhoods of Spain [35]. These urban interventions would be in connection with the 17 Objectives of Sustainable Development.

2. Obsolescence in social neighbourhoods

The obsolescence of residential neighbourhoods in Europe has its origin in the oil crises that began in the last third of the twentieth century. The 1970 oil crisis largely affected the industrial fabric, while the crisis of 1990 affected the residential area, with special incidence in social housing built between 1950 and 1970. In Spain, social housing complexes are framed in polygons: huge extensions of land that were planned, urbanised, and built outside the urban fabric of the city. These polygons are currently affected by various types of obsolescence and precariousness: the material (low quality of construction and structural solutions); urban function (distance from the rest of the city, absence of economic activities, degradation of public space); typology (failure to adapt housing to contemporary lifestyles); energy poverty (lack of thermal and acoustic insulation); and social aspects (ageing population with few resources).

Similarly, ever since the 2008 economic crisis, the scarcity of public resources has meant that rehabilitation of these neighbourhoods is seen as a necessary complement to the construction of new social housing [36].

These large neighbourhoods of social housing were designed to meet the basic housing needs of the working class of the 1950s. The profile of the person currently seeking housing differs widely from the profile of that time. Similarly, the increase in housing standards and the new social dynamics (variety of family units, reduction in the number of people per household, etc.) questions the validity of these 1950s housing typologies for current collective housing [37].

The present acoustic work on the analysis of the acoustic insulation of its basic housing and the environmental acoustics of the public spaces of the San Pablo neighbourhood in Seville forms part of a broader project of research into deficiencies and the search for housing solutions for urban regeneration. This research is based on the concurrence with various editions of the prestigious Solar Decathlon Contest and also on the development of transdisciplinary strategic lines: materiality rehabilitation, energy poverty, social identity, and health [38,39].

In Spain, this model for the implementation of new working-class neighbourhoods was established in the civil post-war period, at which time the National Housing Institute issued several laws in charge of regulating the protected housing that was under construction. The large number of projects carried out at that time due to the major demand for housing meant that errors occurred in

Fig. 1. Map of the San Pablo estate showing the Sports centre and the various surrounding sub-neighbourhoods. Source: A. Seco-López, E. Do Campo-González [39]. The strip under study, comprising part of sub-neighbourhoods A and B, is shown.

many cases and these projects are now obsolete and in precarious condition.

Regarding acoustics in obsolete neighbourhoods, research remains scarce since acoustic studies are usually linked to entire cities. As cases of interest where the authors use similar methodologies to those presented here, the work by Said et al. [40] can be cited, where a series of uninterrupted urban noise measurements for one week at five measurement points are carried out in the city of Buenos Aires during COVID-19 social isolation. In the residential area under study, the sound levels registered fall below 60 dBA only between the hours of 02:00 and 05:00. Furthermore, in Seto et al. [41], traffic data from the city of San Francisco is employed to model noise exposure per neighbourhood and road type (arterial and non-arterial) with a GIS-based noise model for the evaluation of the health impacts of environmental noise. Furthermore, Ureta [42] carries out a series of interviews in a social housing estate located in Santiago, Chile and concludes that, as a physical phenomenon, noise is related to the poor sound isolation provided by the low-quality building materials and the proximity of the noise source to dwellings. As a social phenomenon, noise is related to the lack of solidarity and of agreements between the neighbours involved.

2.1. History and urban planning of the San Pablo estate

The San Pablo neighbourhood was designed to accommodate 11,500 flats divided into five sub-neighbourhoods, called A, B, C, D, and E, with approximately 2000 homes each [43]. In turn, each of these sub-neighbourhoods was subdivided into neighbourhood units of approximately 300 dwellings, grouped 6 by 6. The main objective of its urbanisation in setting up neighbourhood units was to make each neighbourhood a living environment. Each neighbourhood unit was related through small commercial centres and common landscaped areas, whereby the neighbourhood units were related to each other through educational centres and nurseries. The sub-neighbourhoods were related to the neighbourhood units through religious, social, and commercial centres on a larger scale, as well as through a large Sports centre, see Fig. 1.

The project began in September 1961, whereby the first sub-neighbourhood to be built was sub-neighbourhood A due to its proximity to the existing city (between 1964 and 1966, 2006 homes were built), followed by the construction of sub-neighbourhood B (1920 homes), and sub-neighbourhood E (1498 homes). Sub-neighbourhood D was built between 1963 and 1968 and sub-neighbourhood C (1600 dwellings) between 1974 and 1976 (Fig. 1).

The location of the various buildings on the site was designed so that the tallest buildings, located on the edge, would act as a protective screen against the large avenues, while the lowest blocks were located in the centre of the estate, thereby establishing a certain hierarchy that intensified the pedestrian spaces and promoted the internal relations within the neighbourhoods (Fig. 1).

Two main types of buildings can be found: H-blocks and double-bay blocks.

- The H blocks, responding to the first category, are located on the perimeter of the San Pablo estate and are the tallest buildings. These blocks are defined by containing four flats per floor connected to a core of central stairs.

- The double-bay blocks, in series, correspond to the second category (9 storeys and 70.26 m^2) and social housing (5 storeys and 54.95 m^2). These have less height and dimension and are located inside the neighbourhood.

For the study of the neighbourhood in the various aforementioned aspects, a strip has been selected that includes part of the sub-neighbourhoods A and B crossed by an important sinusoidal street, Soleá Street, see Fig. 1, and which, starting from Kansas City Avenue, is bounded by Petenera Street, Cristo de Velázquez Street, Tarso Street, Jabera Street, Toná Plaza, and Seguidilla Street, see Figs. 1 and 4.

In this work, it is ascertained whether the materiality and technical characteristics of the type of social housing of the neighbourhood (ground floor plus four storeys) are in accordance with current housing regulations in terms of acoustic insulation, and a prospection and diagnosis of the environmental acoustics of the neighbourhood are provided with respect to the immediate physical environment surrounding the houses. The analysis is completed with the results of a questionnaire answered by the neighbours involved in reference largely to their evaluation of the sound quality and noise level of their public spaces.

3. Noise pollution in cities

3.1. Environmental noise indicators

The acoustic field in a city is made up of an enormous variety of sound sources with numerous characteristics: several are continuous, and others work sporadically or intermittently; they emit in the same place or far from the point of reception; they present variations in intensity; and their spectrum of frequencies can be wide or narrow. Furthermore, their contribution to the acoustic environment of a city depends on the urban configuration of the immediate environment. A fundamental aspect in the evaluation and management of environmental noise involves the application of homogeneous parameters and criteria that allow one to compare the noise data obtained in different territorial areas. To this end, acoustic legislation sets the noise indicators that must be used in each case. Like any other physical quantity, noise can be evaluated from different forms and theoretical approaches: propagation, attenuation, absorption, diffraction, time evolution, etc. An additional complexity to that of the noise itself involves the reference to the damage and sensations of the person carrying out the evaluation. The scientific community has established metrological procedures that enable quantification of the levels of sound energy produced by the sound source and of that propagated and received by the medium and the receiver. Therefore, 4 levels can be highlighted: the equivalent continuous level, $L_{\mathrm{Aeq},T}$ for a period T; the percentile levels, L_{AN}; the sound exposure level, L_{Asel}; and the L_{Aeq} for a period of 24 h, L_{den}.

The European Directive 2002/49/CE (and the Royal National Decree 1513/2005 by which it is transposed) selects the day-evening-night noise index L_{den} and the noise index of the night period L_{n} for the preparation of strategic maps of noise. On the other hand, Royal

Decree 1367/2007, which partially develops the Noise Law, establishes the noise indices for the day (L_d), evening (L_e), and night (L_n) periods to assess the acoustic quality objectives for the different types of acoustic areas (residential, health, educational, tertiary, etc.), and establishes other additional indicators to assess compliance with the limit values set for the acoustic emitters (an acoustic emitter includes any activity, infrastructure, equipment, machinery, or behaviour that generates noise pollution).

Therefore, in order to assess environmental noise, indicators of long-term average sound levels are mainly used, which are suitable for planning and for the application of an integrated approach to residential areas, cities, and agglomerations, but these are not appropriate for short-term situations, which are largely associated with specific complaints and claims.

In the regulations, according to the evaluation period: L_d is the A-weighting equivalent sound-level indicator associated with the day and is determined as the average sound level throughout all daytime periods of a year, for which the period extends from 7 a.m. to 7 p.m.; L_e is defined as the A-weighting average equivalent sound level determined throughout all evening periods of a year, for which the period extends from 7:00 p.m. to 11:00 p.m.; and L_n is defined as the A-weighting average sound level determined throughout all night periods of a year, for which the night period extends from 11 p.m. to 7 a.m.

L_{den} is an indicator of the global noise level during the day, evening, and night, utilised for the determination of the annoyance related to noise exposure. This parameter aims to give an idea of the noise level throughout the 24 h of the day and takes into consideration the fact that at night the population becomes more sensitive to noise whereby, although sound levels usually decrease to a certain extent during that period, their relative importance increases.

3.2. Acoustic insulation in buildings

Architectural acoustics are focused on assessing the behaviour of materials and constructive solutions that allow compliance with the minimum insulation required and that guarantee comfort to the users of the premises. It should be remembered that in residential buildings, the enclosures can be classified into the following four types:

a) Protected areas: lounges and bedrooms.
b) Habitable areas: kitchens, bathrooms, and transit areas (lobbies, corridors …).
c) Facility enclosures (pump room, elevator motor room …).
d) Activity areas: areas dedicated to a use other than the usual use of the building. In the case of residential buildings, commercial or leisure premises that occupy the ground floor of the buildings are usually considered activity venues.

Spanish regulations, through the basic document for noise protection (DB-HR) associated with the Technical Building Code (CTE) [44], distinguish three types of acoustic insulation coefficients depending on the nature of the noise source, its origin, the type of enclosure where the emitting source is located, and the type of receiving enclosure to be protected:

a) *Airborne-noise insulation* between adjoining rooms of different dwellings that share an interior partition. The DB-HR proposes the difference in standardised levels $D_{nT,i}$, at a frequency value f_i. These measurements must be made in situ following the ISO 16283-1 standard [45].

For practical purposes, a single global index is calculated that takes two factors into account: first, that the usual noise in the emitting area in homes can be likened to pink noise; and second, A-weighting must be considered to adjust the sound level to the human ear's perception of sound. Therefore, the DB-HR proposes the A-weighting standardised difference in levels, $D_{nT,A,}$ as an integrated global index.

Table 1 shows the minimum values that the DB-HR requires for $D_{nT,A}$ when the receiving room shares no doors or windows with the emitting room.

b) *Impact-noise insulation* between rooms of different dwellings that share a partition or at least a common edge. In this case, it is a matter of assessing the insulation against structural noise. To this end, the DB-HR uses the standardised impact-noise pressure level, $L'_{nT,i,}$ for which the procedure is described in standard ISO 140-7 [46].

The global impact-noise pressure level, $L'_{nT,w}$ is obtained by applying the procedure of the ISO 717-2 standard [47] from the values of $L'_{nT,i}$ for each frequency f_i. Table 1 shows the maximum values allowed by the DB-HR for $L'_{nT,w}$ depending on the type of emitting and receiving rooms.

Table 1
Minimum requirement for $D_{nT,A}$ index and maximum requirement for $L'_{nT,w}$ index established by the DB-HR.

Emitter enclosure	Receiving enclosure	$D_{nT,A}$ (dBA)	$L'_{nT,w}$ (dB)
Protected or unprotected (from another dwelling other than the receiver)	Protected	50	65
	Unprotected	45	There is no requirement
Of facilities or activities	Protected	55	60
	Unprotected	45	60

c) *Acoustic insulation against aerial noise of façades,* which considers the insulation between the exterior and an area separated from it by the building façade. For this last case, the DB-HR uses the standardised difference in levels in façades, $D_{2m,nT,i}$ at frequency f_i. The corresponding measurements must be carried out following the guidelines established by the ISO 140-5 standard [48].

In order to calculate the corresponding global index, it must be taken into account whether the dominant external noise comes from traffic noise, the passage of aircraft, or the proximity of a train station. In the case at hand, the dominant noise usually comes from traffic. Thus, to obtain the standardised A-weighting difference in levels in façades with external traffic noise, $D_{2m,nT,Atr}$, the A-weighting value of the noise spectrum of cars must be considered for frequency f_i, $L_{Atr,i}$.

More details on the final calculation of $D_{2m,nT,Atr}$ can be found in ISO 717-1: 1997/A1:2006 [49]. The DB-HR requirement for the minimum value that $D_{2m,nT,Atr}$ must have in residential and hospital buildings depends on the type of receiving area (bedroom or living room) and the daytime noise level, L_d (dBA), outside, which can be obtained from direct measurements or from strategic noise maps drawn up by city councils. Table 2 summarises the requirements for the minimum value of the $D_{2m,nT,Atr}$ parameter.

3.3. *Strategic noise maps in Seville*

The city of Seville, located in the southwest of the Iberian Peninsula, is the capital of the autonomous community of Andalusia and is located in the alluvial plain of Guadalquivir, in the middle of the Guadalquivir depression, just 6 m above sea level, in the middle of Vega and Campiña of the Guadalquivir River, and on its banks. Seville's climate is Mediterranean, slightly continental, with variable rainfall, very hot dry summers, and mild winters. In the population nucleus of Seville, the neighbourhood under study forms part of District 8: San Pablo-Santa Justa district, see Fig. 2.

The methodological aspects used for the preparation of the Strategic Noise Maps by the city council of the city of Seville are in accordance with those defined in Law 37/2003 on Noise and in Royal Decree 1513/2005 for its development. They were implemented in 2007 and revised in 2012 and 2017.

The methodology [50] has been designed in several phases; one of these phases is the performance of the on-site measurements at 40 points in the city in order to carry out the calibration of the acoustic simulation model. The software used is PREDICTOR ANALYST TYPE 7810 from BRUEL&KJAER, specific for the calculation and evaluation of noise pollution generated by various noise sources (road, rail, and air traffic, and industrial sources) using calculation models recommended by the Directive on Management and Evaluation of Environmental Noise 2002/49/CE, and by the Spanish regulations specified in the Commission Recommendation 2003/613/CE. Sound level maps are isoline maps that represent the emission levels of environmental noise sources. This yields the graphic representation of the areas exposed to certain noise. They are presented as a series of plans on a scale of 1:10,000 and can be consulted for the various noise sources and indicators of the city.

From these sound level maps, it is possible to calculate the area in km^2 that is exposed to the different noise levels L_d, L_e, L_n, and L_{den}, in each established range and for the different sources of noise. It is also possible to obtain information on the affected population by crossing the data from the population layers and the façade receptors. Data processing enables the number of people exposed to noise, in hundreds, to be calculated from the information obtained from the receivers located on the façades of buildings at a height of 4 m. The summary document concludes that in the city of Seville, the main emission source and that which presents the greatest relevance for the population is road traffic. More than 70% of the population living near the roads are subjected to levels that are above 65 dB during the day, and these percentages are also maintained during the evening. The effect in the night period shows that approximately 60% of the population near road sources in Seville are affected by values above 55 dB.

4. Methods

This section describes the different stages of the methodology employed, which are summarised in the flowchart at the end of the section, see Fig. 7.

4.1. *Measurements of environmental noise*

The acoustic research of the San Pablo neighbourhood began with a soundwalk on a working day (without home confinement or mobility restrictions due to the Covid-19 pandemic) from noon to 14:00 by several researchers along the limit of the strip under study as specified in Figs. 1 and 4, and in its interior in order to establish a survey diagnosis of the most common sounds and noises in the neighbourhood and of where these sources are located.

Table 2
DB-HR requirements for the minimum value of $D_{2m,nT,Atr}$ in residential and hospital buildings.

Daytime noise level, L_d (dBA)	Minimum value $D_{2m,nT,Atr}$ (bedrooms) (dBA)	Minimum value $D_{2m,nT,Atr}$ (living rooms) (dBA)
$L_d < 60$	30	30
$60 < L_d < 65$	32	30
$65 < L_d < 70$	37	32
$70 < L_d < 75$	42	37
$L_d > 75$	47	42

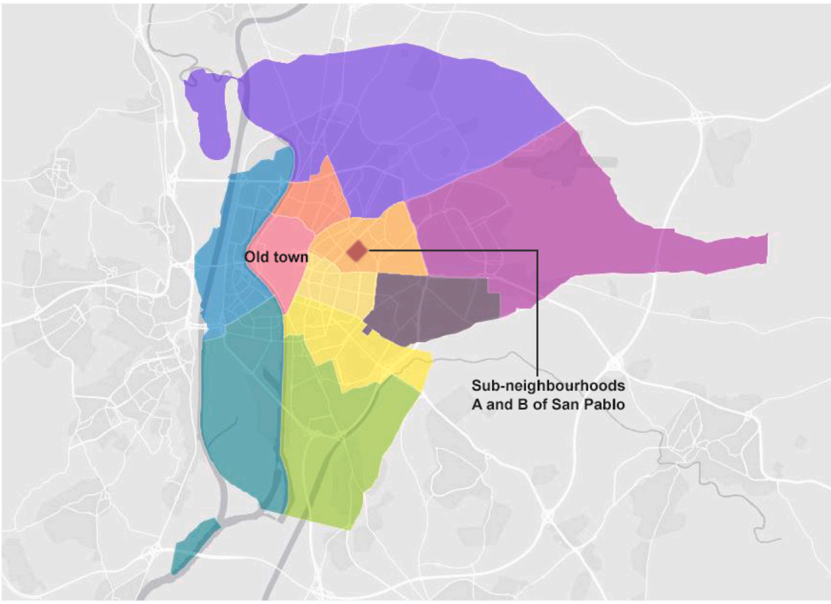


Fig. 2. The 11 districts of the city of Seville (Source: http://sig.urbanismosevilla.org/). [50].

The sounds were identified as caused by the traffic on Petenera Street, Soleá Street, and there was some machinery noise due to construction, many birds' chirping since the streets contain many trees, and the occasional barking of dogs. On working days in the morning, churches are closed and no bells chime. The sound of metal chairs being dragged on the terraces of bars on Plaza de la Toná is also highly significant, since for health reasons, customers prefer to be outdoors.

The strip under study incorporates a large social housing area of 5-storey buildings with major accessibility problems since, in addition to not having a lift, the main entrance hallway of the houses lies below the level of the street. This form of access to housing exists only in neighbourhood A [43], since these accesses have been corrected in the social housing typology in neighbourhoods B, C, D, and E.

An objective assessment of the sounds in the neighbourhood has been carried out through physical measurements associated with the propagation of waves that can be measured objectively (in dB).

Measurements were taken according to ISO 1996-2 [11] guidelines, via a PCE-430 Class 1 sound-level meter (degree of precision defined in IEC 61672), equipped with an AD converter of 24 bits, suitable to measure environmental and traffic noise. With frequency response 10 Hz-20 kHz with a linearity range of 22 dBA-136 dBA, the microphone supplied is a MPA231T Class 1 with sensitivity 40 mV/Pa and frequency range 3 Hz–20 kHz. An integral period measurement of 6 min with a tripod and windshield have been employed. Calibration was performed at 93.7 dB by using a 4231 B&K sound calibrator. The sources of sound and noise were determined in situ

Fig. 3. (a) Measurements in La Debla Plaza, Receiver 12; (b) Behind the dwelling whose acoustic insulation has been studied, Receiver 11. For its acoustics data see Section 5.2. Tables 5 and 6.

(cars, buses, and motorcycles, people in bars and shops, municipal and domestic workers, pedestrians, meteorological phenomena, birds, dogs, etc.) during sampling and other relevant information.

The sound level meter microphone was placed 1.5 m from the ground and in the centre of the plazas (Fig. 3(a) and (b)). The following 16 points of measurement were proposed:

(1) Exaltación de Baco Plaza, near a perimetral street with car circulation, Tarso Street; (2) Venus del Espejo Plaza-1; (3) Cristo de Velázquez Plaza, two plazas inside the neighbourhood with no streets; (4) Venus del Espejo Plaza-2 near a playground; (5) Cristo y Alma Plaza next to Soleá Street; (6) Petenera-Soleá Crossroads of two streets with flow of cars; (7) Petenera-Malagueña Crossroads near Petenera Street and a shop zone in the crossroad of two streets with car circulation; (8) Tarantos Plaza near a bar and a shop; (9) Rondeña Plaza; (10) Saeta Street in front of the prototype dwelling studied, near a public school; (11) Granaina Street behind the prototype dwelling and near a public school; (12) Debla Plaza-1; (13) Debla Plaza-2, both points near Kansas City Avenue, a street with a lot of traffic; (14) Toná Plaza, with many bars and shops; (15) Mirabrás Plaza, an interior plaza with no streets; and (16) Jabera Street, used for parking cars near Tarso Street, see Fig. 4.

Measurements were carried out on a sunny day, and meteorological environmental conditions were recorded during the measurements with a PCE-THA 10 thermo-hygro-anemometer. Temperature, and humidity conditions remained in the range of operation of the sound level meter with 10°C-50 °C and 20%–90% relative humidity, and wind speed to install the windshield. The wind speed recorded was 0 m/s at all locations, except certain gusts of a prevailing easterly wind at certain reception points: 1.5 m/s in Debla Plaza, and 1.3 m/s in Petenera-Soleá Crossroads and Tarantos Plaza.

The recorded sound levels included the equivalent continuous level in dBA (L_{Aeq}), the statistical study of noise through the percentile levels (L_N) with special emphasis on the levels L_{10}, L_{50}, and L_{90}, and the maximum and minimum levels (L_{Amax} and L_{Amin}). Temporal fluctuations, 1/3-band frequency analysis, and global levels were measured. The time weighting used in the sampling measurements was fast (F, 125 ms), and frequency weightings A, B, C, and Z were available.

4.2. Acoustic insulation in standard social housing

As mentioned above, one of the partial objectives of this work involves the evaluation of the situation regarding the acoustic insulation in the social housing of the San Pablo Estate, which consists of a double-bay structure with a ground floor and four additional storeys. Specifically, the authors have focused on the building located at 1 Saeta Street. Although the results have been presented for this selected dwelling, the constructive solutions, materials, and distribution of this dwelling are common to all instances of the typology of ground floor plus four storeys (GF+4-storeys). This typology exists in the neighbourhood in great number: sub-neighbourhood A contains 160 blocks out of a total of 183 blocks, and sub-neighbourhood B has 159 blocks out of a total of 175 blocks. Consequently, the dwelling studied is very typical in the San Pablo estate (Fig. 1), and in other social neighbourhoods of Seville, although it is not applicable to the environmental conditions.

1 Exaltación de Baco Plaza
2 Venus del Espejo Plaza-1
3 Cristo de Velázquez Plaza
4 Venus del Espejo Plaza-2
5 Cristo y Alma Plaza
6 Petenera-Soleá Crossroads
7 Petenera-Malagueña Crossroads
8 Tarantos Plaza
9 Rondeña Plaza
10 Saeta Street
11 Granaina Street
12 Debla Plaza-1
13 Debla Plaza-2
14 La Toná Plaza
15 Mirabrás Plaza
16 Jabera Street

Fig. 4. Points of reception in the zone of study of San Pablo neighbourhood. Its boundary streets are also shown. (Image from Google Earth).

In Fig. 5(a) and (b), it can be observed that the façade of the building overlooks a closed square that serves as a collective parking area. Both the noise map and the measurements carried out outdoors verify that it is an acoustically quiet area, where a daytime noise level of less than 60 dBA can be assumed.

Fig. 6 shows one of the floors of the building, which consists of two dwellings. It can be seen that the living rooms of the two dwellings are not adjoining (they are separated by the stair hallway and the staircase itself), and hence the two units only adjoin by means of the bathroom and the kitchens at the back of each dwelling. It is worth remembering that bathrooms and kitchens are habitable but are not protected areas, and hence the insulation between these areas is not a priority. The study will therefore be focused on the one hand, on the living room area (for which the dimensions are given), and on the insulation against airborne noise and impact noise between the rooms on the second and third floors (these would be two protected and adjacent rooms, where the separation surface is the slab between floors) and, on the other hand, on noise insulation on the façades. This involves verifying whether a social construction built during the 1960s that has undergone little or no reformation, meets the requirements of current regulations.

Given the difficulties in carrying out an on-site experimental procedure, the computer tool that the DB-HR provides to architects and designers has been employed to obtain the indices mentioned in Section 3.2 and for their comparison with Tables 1 and 2 In the tool, in addition to the dimensions and layout of the rooms involved as shown in Section 5.3, it is necessary to ascertain the construction typology and the values of the A-weighted acoustic reduction index R_A (dBA) (R_{Atr} for the façades), the surface mass density, m (kg/m^2), and, in the case of floors and slabs, the global standardised impact level, $L_{nT,w}$. These parameters are measured in the laboratory where there is no sound propagation by flanks.

In this case, the values of slabs between floors, the interior partition, and the partition wall with the stair landing are shown in Section 5.3. Moreover, for the case of insulation in the façades, the corresponding acoustic properties of the opening (basically glass and shutter box) must also be ascertained. For this case study, the values of R_A, R_{Atr}, $L_{nT,w}$, and m have been obtained from the tables for the standard construction solutions provided by the Building Technical Code that most closely resemble the real solutions of the typical building. Table 3 shows the constructive solutions of the case study and the relevant parameters from the acoustic point of view for each of these parameters.

4.3. Acoustic questionnaire

The acoustic questionnaire consists of two sections. In the first section, several sociological items of data of the respondent are asked: Age; Gender; Sub-neighbourhood where the neighbour lives; Length of tenancy to date; Name of the street or Plaza; Number of storeys of their block; and Floor on which they live.

In the second section, the respondent must qualify 12 items (with 5 grades) regarding certain types of environmental noise, and they must identify their time slot (Table 4). At the end, 3 further questions refer to general aspects regarding quality of sleep, privacy of dwellings, and acoustic comfort of the neighbourhood.

All participants received detailed information about the study, its objectives, and the confidentiality of the data. Respondents were required to give their consent before completing the questionnaire.

The study was approved by the Valme Teaching Hospital's Clinical Research Ethics Committee, which was designated as an ethics committee of reference by the University of Seville, protocol code: 1210-N-20.

A summary of the methods employed in this Section is presented in Fig. 7.

5. Results and discussion

5.1. Strategic noise maps in San Pablo estate

The tables provided in the noise maps from the city council for the San Pablo estate can be construed as misleading, since they

Fig. 5. (a) Aerial view of the social housing blocks. (b) Block type under study (Saeta Street 1) Source: Authors' own.

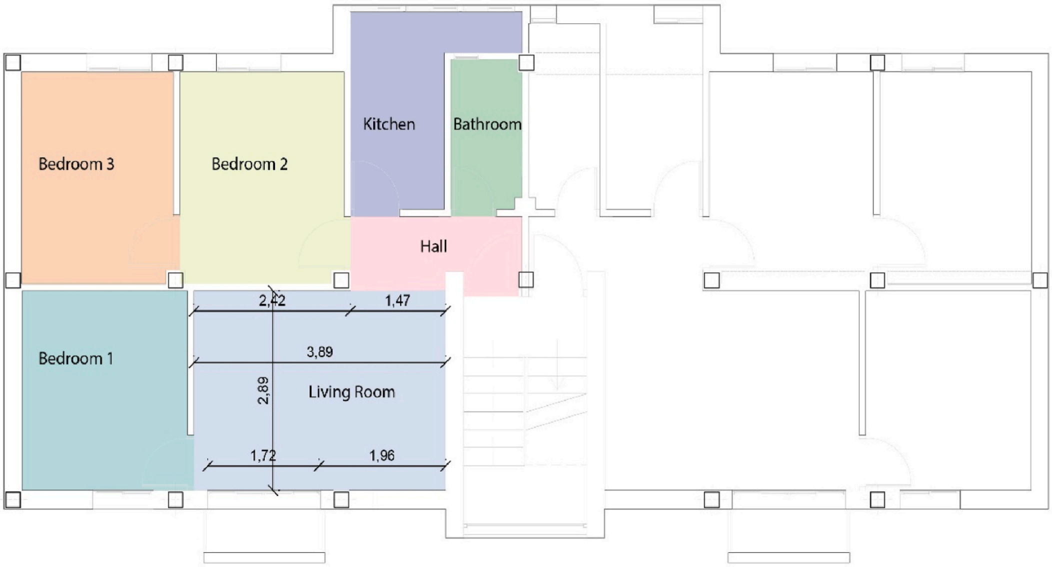


Fig. 6. Plan of the building type of social housing (ground floor+ 4 storeys). Dimensions in *m* of the living room are shown. Free height is 2.32 m. Living room area is $S_L = 10.64$ m^2 and its volume $V_L = 24.67$ m^3.

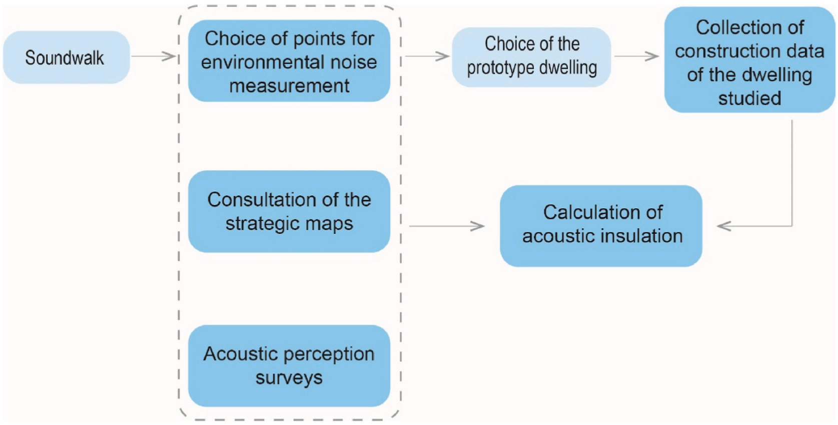


Fig. 7. Flowchart showing the various steps of the research carried out.

correspond to the results of the whole of District 8 (Fig. 2), which covers several neighbourhoods. Therefore, an analysis of these maps with zoom and with consultation of the annexed documentation has been carried out, whereby only the data related to the neighbourhood of San Pablo, Fig. 8(a) and (b) is used, thereby enabling certain conclusions to be drawn:

1. The maps corresponding to road traffic noise are identical to the general maps which consider all sources of noise in the neighbourhood. In said neighbourhood, the existing noise is that of road traffic, as there is no noise from rail, port, or air traffic (this neighbourhood contains no building façades facing the train tracks, and has no runways for planes) and there is no heavy industry.

2. The L_d and L_e parameters present very similar values in the neighbourhood, and only in the perimeter area of the neighbourhood near Kansas City Avenue and Efeso Street are there some pockets with façade levels between 60 and 65 dB, although a large part is found with levels between 55 and 60 dB, and the rest of the neighbourhood has levels below 55 dB. The same can be said for the global L_{den} level. The L_n indicator registers levels between 50 and 55 dB on a narrow border of the neighbourhood adjacent to Kansas City Avenue and Ephesus Street. The rest of the neighbourhood presents levels below 50 dB (Fig. 8(a) and (b)).

3. Annexes of tables and graphs extracted from city noise maps show that there are many streets in neighbourhoods A and B of San Pablo included in the municipal street map as quiet streets. This also holds true in neighbourhoods D and E, but not in neighbourhood C. It should be noted that the information from the strategic noise maps of Seville City Council statistically assesses the results in terms of districts and fails to consider the details of the different areas of the individual neighbourhoods, and hence the need for a more detailed acoustic study of the public spaces in the area of the neighbourhood under study.

Table 3
Diagram of the constructive solutions of the case study and their properties from the point of view of acoustic insulation.

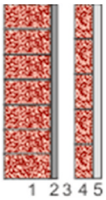
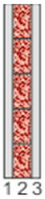
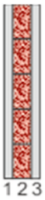
Façade	Material and thickness (mm)		m (kg/m^2)	R_A (dBA)		R_{Atr} (dBA)
	1-Perforated brick	115	220	47		44
	2-Mortar rendering	20				
	3-Air chamber	50				
	4- Hollow brick	70				
	5-Gypsum plaster	15				
Vertical separation element	Material and thickness (mm)		m (kg/m^2)	R_A (dBA)		R_{Atr} (dBA)
	1-Gypsum plaster	15	89	36		
	2-Hollow brick partition	0				
	3-Gypsum plaster	15				
Internal partition	Material and thickness (mm)		m (kg/m^2)	R_A (dBA)		R_{Atr} (dBA)
	1-Gypsum plaster	10	64	32		
	2- Hollow brick partition	50				
	3-Gypsum plaster	10				
Horizontal separation	Material and thickness (mm)		m (kg/m^2)	R_A (dBA)	R_{Atr} (dBA)	$L_{nT,w}$ (dB)
	1-Ceramic tile	20	300	52	48	77
	2-Mortar layer	20				
	3-Ceramic slab	200				
	4-Gypsum plaster	10				
Window	Glass thickness (mm)		m (kg/m^2)	R_A (dBA)		R_{Atr} (dBA)
Single glass slider	6			26		26
Shutter box with wooden profiles						25

Table 4
Section 2 of the acoustic questionnaire: 12 items and 3 additional questions on overall acoustic perception.

I1. Road traffic coming from perimeter streets: Kansas City, Tarso, El Greco. Specify type, such as sirens, buses …:
I2. Traffic coming from other interior streets: Soleá, Petenera … Specify:
I3. Aircraft and/or train traffic:
I4. Noise of construction work in homes of nearby neighbours:
I5. Noise of construction and roadworks:
I6. Noise from air-conditioning devices:
I7. Noise from establishments and services (such as shops, bars, nightclubs, restaurants, and associations):
I8. Noise of school activities (schools, children's recreation areas in plazas):
I9. Noise from pets in homes or outside:
I10. Other noises of interest (rubbish collection, street cleaning, street sweepers, loading and unloading in shops, others):
I11. Domestic noise from upstairs neighbours:
I12. Domestic noise from next-door neighbours:

1 (None or very quiet)	2 Quiet	3 Acceptable	4 Loud	5 Very loud

Overall acoustics aspects
1 Some of these or other noises have made it impossible for you to sleep and/or concentrate on your tasks:
2 Degree of privacy of your home:
3 Qualify the acoustic comfort of the neighbourhood:

1 Very Bad	2 Bad	3 Fair	4 Good	5 Excellent

5.2. Environmental noise in San Pablo estate

Non-deterministic fluctuating signals could be determined by applying statistical techniques: in order to describe time-varying noise, the determination of noise level exceeded for a certain percentage N of the time period T have been proposed. In Table 5, the results of these percentile levels obtained in the time interval of 3 min at the 16 receiver points of the neighbourhood are shown. They highlight that the greatest noise levels, which are weighted in dBA and correspond to the data of L_{A10}, lie in the range of 51 dBA in

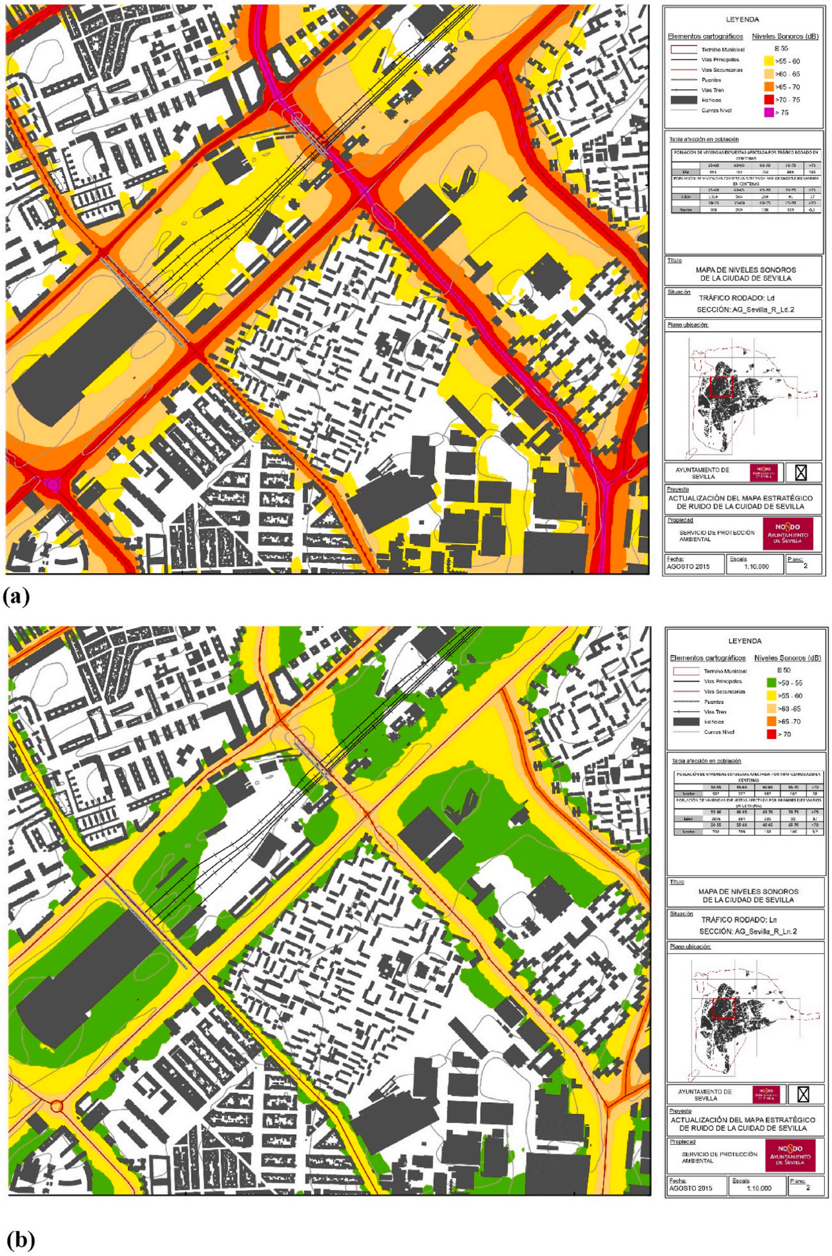


Fig. 8. Strategic noise maps of L_d (a) and L_n (b) for traffic noise in Sub-neighbourhoods A and B of San Pablo.

the Mirabrás Plaza and 69.5 dBA in the Toná Plaza, and the lowest levels valued by the indicator L_{A99} lie in the range of 42.4 dBA in the Mirabrás Plaza and 59.5 dBA in the Toná Plaza. It is also worth highlighting the highest values of noise of Receiver 10 in which the measurements were expressly made to coincide with a school breaktime in the courtyard of a nearby school. Receiver 11, on the other hand, is close to both the dwelling studied in the following section and to Receiver 10, but the high level recorded at Receiver 10 from children playing was no longer present.

Results show that for 69% of receptors, L_{A50} is below 55 dBA and for L_{A90} 94% of receptors present values $<$ 55 dBA. Furthermore, Table 6 depicts other sound levels of interest averaged over 3 min with fast temporal weighting F, and over frequency with the different weighting networks at the neighbourhood measurement points. L_{Asel}, sound exposure level; L_{Cpeak} is the highest peak of the C-weighted pressure wave. The highest L_{Amax} level is produced at Receiver 14 in the Toná Plaza (76 dBA) where many people speak loudly at the tables of the terraces of the bars and drag metal chairs on the pavement. L_{Amin} is 38.9 dBA in the Mirabrás Plaza at Receiver 15.

Likewise, the correlation between the results of the L_{Aeq} indicator and the percentile levels L_{A10}, L_{A50}, L_{A90}, and L_{A99} of this spatial distribution of the San Pablo neighbourhood has been studied. The results are shown in Fig. 9. The results of the adjustments are given in Eq. (1):

Table 5
Percentile levels in dBA at the 16 sampling points in the San Pablo neighbourhood.

Receiver	L_{A10}	L_{A20}	L_{A30}	L_{A40}	L_{A50}	L_{A60}	L_{A70}	L_{A80}	L_{A90}	L_{A99}
1	56.5	55.1	54.2	53.5	52.9	52.3	51.5	50.5	49.5	47.7
2	56.7	55.7	55.1	54.4	53.8	53.2	52.5	51.7	50.7	48.2
3	54.3	51.8	50.2	49.2	48.3	47.7	47.2	46.5	45.8	44.6
4	56.8	54.9	53.4	52	51	50.1	49.3	48.4	47.1	45.1
5	58.3	56.3	54.9	53.8	52.7	51.8	50.9	50	48.8	47.2
6	63.9	61.5	60.1	59.1	58	57.1	55.3	54.1	52.6	50.7
7	53.4	51	50	49	48.2	47.3	46.6	45.8	44.9	44
8	57	54.4	53.2	52.3	51.4	50.7	50.1	49.4	48.7	47.4
9	58.4	56.2	54.9	53.7	52.6	51.8	51.1	50.2	49.3	47
10	65	64.6	64.3	63.7	59.1	56.7	55.4	54.1	52.6	49
11	54.6	52	50.8	49.9	49.2	48.5	47.9	47.2	46.4	44.4
12	59.9	59.2	58.8	58.5	57.8	56.9	55.5	54.8	53.2	50.7
13	63.2	61.2	60.3	59.8	58.7	57	55.7	54.1	51.1	47.6
14	69.5	68.2	67.1	66	64.8	63.7	62.6	61.4	59.5	56.6
15	51	49.1	47.7	46.8	45.8	44.9	44.1	43.2	42.4	40.5
16	57.9	56.8	55.8	55	53.9	53	51.9	50.6	48.6	44.9

Table 6
Summary of other levels of interest at the 16 reception points. Subscript F corresponds to fast temporal weighting. Subscript A in dB(A), subscript B in dB(B), subscript C in dB(C), and subscript Z in dB.

Receiver	L_{Aeq}	L_{AFmax}	L_{AFmin}	L_{AFsd}	L_{AF}	L_{BF}	L_{CF}	L_{ZF}	L_{Asel}	L_{Cpeak}
1	54	68.2	46.7	2.8	54.2	60.2	68.8	71.8	76.6	83.2
2	54.3	62.7	44.8	2.3	55.5	55	59.6	63.4	76.8	86.3
3	50.7	64.2	43.6	3.4	54	56.9	59.7	62.8	73.3	87.6
4	53.3	65.2	43.4	3.9	55.4	56.1	61.4	70	75.8	80.1
5	54.6	64.2	46.3	3.7	54.4	58	63.9	67.8	77.2	82.6
6	60.5	73.8	49.4	4.3	55	60.4	71.9	79.8	83.1	95.9
7	50.5	61.9	42.9	3.5	45	49.2	59.2	65	73	81.3
8	55	69.4	46.1	4	56.4	57	60.7	62.8	77.5	85.6
9	55	66.2	45.3	3.7	57.2	57.6	59.6	67.3	77.5	81.3
10	61.8	70.4	46.1	5	65.3	65	65.4	67.5	84.4	81
11	51.4	63.9	43.4	3.5	50.8	53.9	58.3	60.3	74	75.7
12	57.7	68.2	49.5	2.6	59.5	62.3	67.5	69.1	80.3	90.8
13	59.5	65.6	46.7	4.4	61.8	66.8	75.6	77.6	82	87.3
14	66.2	76	55.3	3.8	68.5	69.2	69.9	70.2	88.8	94
15	47.9	59.7	38.9	3.6	47.3	51.6	60	64.2	70.4	76.2
16	55.3	71.2	42.8	3.6	58.1	59.5	67.1	68.8	77.8	83.7

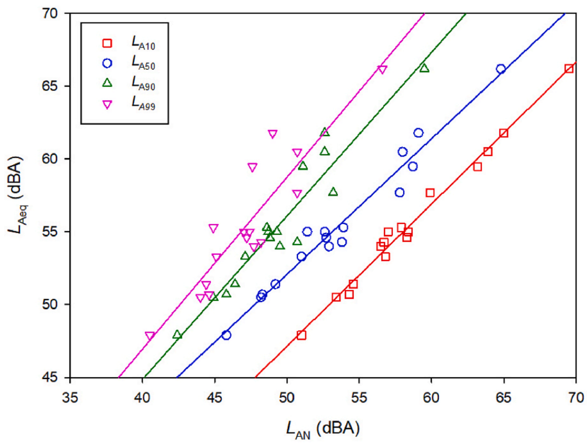


Fig. 9. L_{Aeq} level versus L_{A10}, L_{A50}, L_{A90}, and L_{A99} percentile levels. Linear regression lines of the adjustment are also shown.

$$L_{Aeq} = 1.12L_{A90} - 0.09\left(r^2 = 0.91\right); L_{Aeq} = 0.93L_{A50} + 5.52\left(r^2 = 0.97\right); \\ L_{Aeq} = 0.98L_{A10} - 1.66\left(r^2 = 0.99\right); \quad L_{Aeq} = 1.18L_{A99} - 0.31\left(r^2 = 0.83\right) \tag{1}$$

These results show that the best fit is with the L_{A10} parameter and that the traffic noise flow rate is such that $L_{A10} \cong L_{Aeq} + 3$. The lowest correlation obtained for L_{A90} and L_{A99} can be understood by considering that these levels are related to the background noise at the locations.

As for the temporal evolution of noise, Fig. 10 depicts the fluctuating noise in the 16 sampling points in a 3-min interval. The results show that the greatest coincidence takes place in the 47–57 dBA interval approximately. The prominent peak of 72.2 dBA occurs in Receiver 6 at the intersection between Petenera and Soleá Streets where the highest incidence of road traffic takes place in the neighbourhood, and where the peaks occur on the passing of a vehicle and when pedestrians speak near the microphone. These fluctuations in sound level due to the passage of vehicles are more clearly shown in Fig. 11, where the results of the temporal evolution are represented at three points: at the quietest point (15, Mirabrás Plaza), the noisiest point (14, La Toná Plaza), and in Receiver 6 at the crossroads between Petenera and Soleá streets, and this shows a typical A-weighted sound pressure level time trace of traffic noise.

Finally, Fig. 12 shows a 3D representation of the levels versus frequency at 1/3 octave bands of the neighbourhood at the 16 sampling points. With few exceptions, the spectra are very similar in all records, and, in general, present the maximum levels in the range of 400 Hz–5000 Hz. The spectra show a decrease in levels at high frequencies, which is favourable from the perceptive point of view of the human ear.

Traffic noise both on streets and roads depends on many variables: vehicle flow, vehicle speed, type, mechanical characteristics, and condition of the vehicle, driving mode, slope, condition and type of pavement, etc. [51]. The frequency spectra for road traffic vehicles show that the band of variation of the levels of heavy vehicles is higher than that of light vehicles, but they remain very similar in their frequency distribution, with low frequencies predominating over high frequencies [52]. This fact is shown in Fig. 13 where the spectra are compared at three measurement points in the neighbourhood. Receiver 14 corresponds to Plaza de la Toná, where the noises basically consist of chairs being dragged on the pavement and people talking loudly. In the quietest receiver, the increase in levels at high frequencies is noticeable, coming from the birdsong in the tree-lined square. In Receiver 6, the increase in low frequency levels from road traffic near the measurement point is also of note.

5.3. *Acoustic insulation in standard social housing*

Although the results have been presented for the selected dwelling, as commented earlier, this typology exists in the neighbourhood in great number, and consequently the dwelling studied is highly representative in the San Pablo estate, and in other social neighbourhoods of Seville, although it is not applicable to the environmental conditions.

Study 1: Insulation against airborne noise and impact noise between superimposed rooms. Fig. 14(a) shows the schema used in the DB-HR tool to calculate the value of the global indices $D_{nT,A}$ and $L'_{nt,w}$ when it is considered that the emitting enclosure is the living room on the third floor and the receiving enclosure is the living room on the second floor. This is the case of two adjacent protected enclosures that share four common edges, whereby the horizontal separation surface (HSS) is the slab between the floors. Walls W1, W2, W3, and W4 correspond to the constructive solution for the internal partition walls of the dwellings, while walls W5 and W6 correspond to the vertical separation element between the living rooms and the common area of the stairs.

Table 7 shows the results obtained, whereby rigid joints between walls, façades, and floors have been considered. As can be observed, in neither of the two cases is it expected that the insulation levels meet the current requirements of the regulations. Obviously, one of the main reasons for this result is the lack of acoustic insulation between the slab and the ceramic finish of the floor, with which rehabilitation involving a floating floor is possible. Another option, the placement of a suspended ceiling, is inadvisable in this case due to the already low free height of the house (2.32 m). In fact, the same Table 7 shows the results that would be obtained if a 12 mm mineral wool impact noise insulator were included. It is found that, for this case, the requirement for impact noise insulation would be well met, while the requirement for airborne noise insulation would almost be fulfilled.

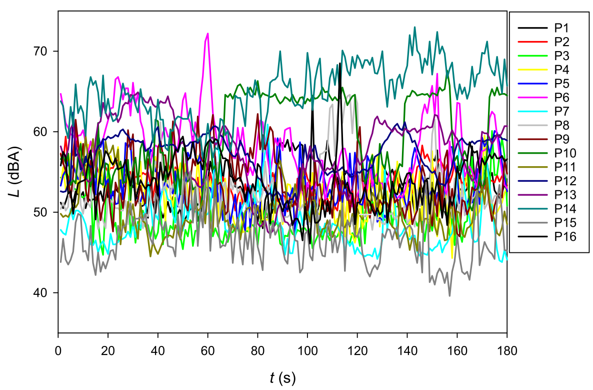


Fig. 10. Temporal evolution of the fluctuating noise at the 16 sampling points in the San Pablo neighbourhood.

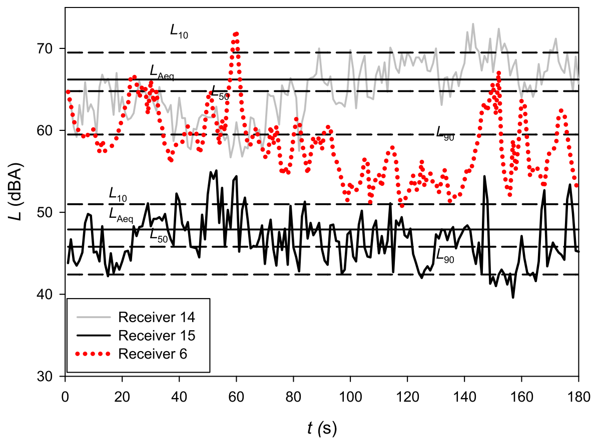


Fig. 11. Temporal evolution of the fluctuation noise at the quietest point (15, Mirabrás Plaza), the noisiest point (14, La Toná Plaza), and in Receiver 6 (Crossroads of Soleá and Petenera streets) of the sampling points in San Pablo neighbourhood. For comparison L_{Aeq} and $L_{A10,}$ L_{A50}, and L_{A90} percentile levels are also shown at the first two points.

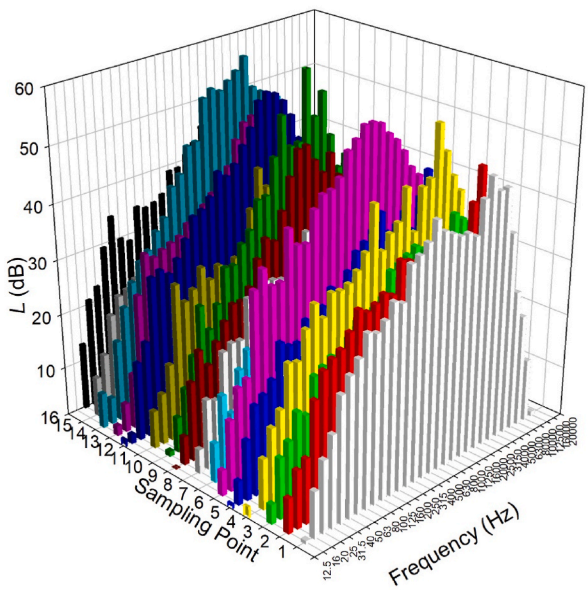


Fig. 12. Noise spectrum at 1/3 octave bands at the 16 sampling points of the neighbourhood of San Pablo in Seville.

Study 2: Insulation for exterior noise in façades. Fig. 14(b) shows the schema employed to calculate the parameter $D_{2m,nT,Atr}$, which determines whether, under current conditions, the room on the second floor of the building meets the requirements established in the regulations for insulation from external noise in the façades. In the diagram, the façades F1, F2, F3, and F4 correspond to the constructive section of the façade reflected in Table 3, while HSS represents the horizontal separation elements (slabs), W1 is the interior partition wall, and W2 the partition wall between the living room and stairs. Although all the openings have been represented, the only wall considered by the tool for the calculation of $D_{2m,nT,Atr}$ is that of the direct façade (receiving enclosure). The final result is provided in Table 8. Rigid joints between the different enclosures have again been considered, and the daytime noise level outside is L_d < 60 dBA.

As can be observed, in this case, the requirement of the regulations would be met, which is attributed to the urban layout of the majority of buildings whose façades overlook small squares in which, although they are used as parking areas, a comfortable daytime noise level is maintained.

5.4. Acoustic questionnaires from neighbours

Of the 60 people who completed the questionnaire shown in Section 4.3, 48 people live in the A-B sub-neighbourhoods (24 men and

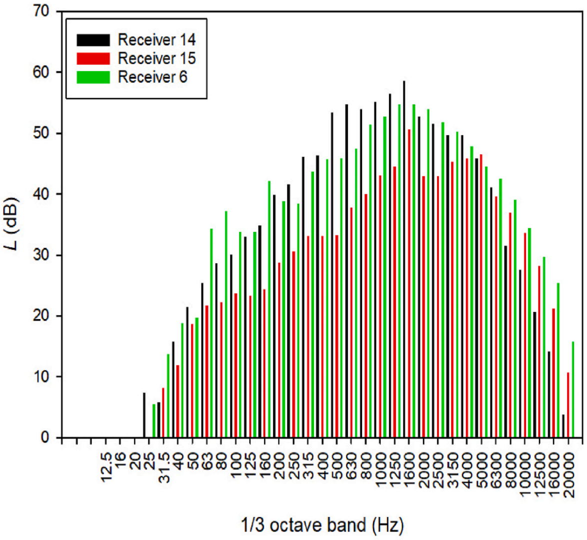


Fig. 13. Noise spectrum at 1/3 octave bands in three receivers of the sampling of San Pablo neighbourhood.

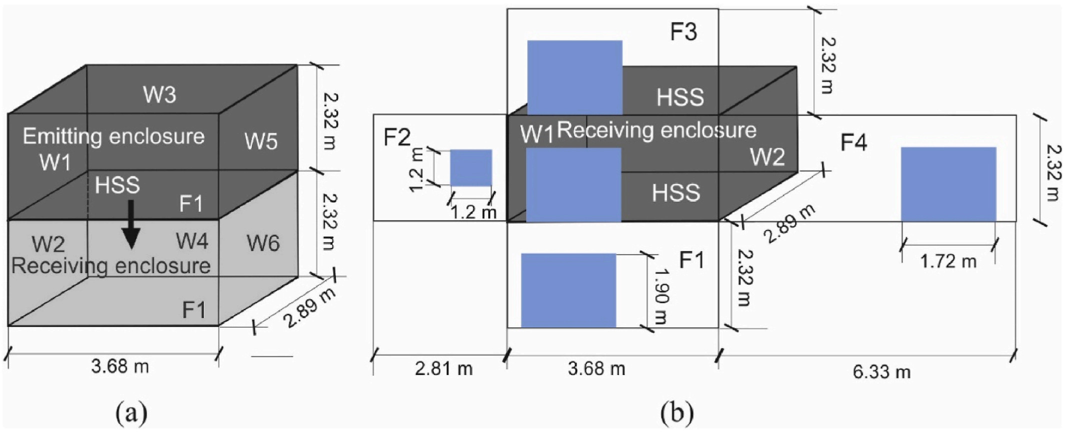


Fig. 14. (a) Schema used in the DB-HR tool to find the insulation parameters $D_{nT,A}$ and $L'_{nt,w}$ between two superimposed rooms of the building under analysis. (b) Diagram used in the DB-HR tool to find the $D_{2m,nT,Atr}$ parameter to determine the external noise insulation of the façade of the room under study.

Table 7
Results obtained with the official DB-HR calculation tool for insulation for impact noise and airborne noise between adjacent rooms of the building under study. On the right-hand-side of the table, the results are shown assuming the inclusion of a floating floor with a mineral-wool insulation for impact noise with a thickness of 12 mm.

Without floating floor			With floating floor		
$D_{nt,A}$ (dBA)	Requirement	Met/Failed	$D_{nt,A}$ (dBA)	Requirement	Met/Failed
46	>50 dBA	Failed	49	>50 dBA	Failed
$L_{nT,w}$(dB)	Requirement	Met/Failed	$L_{nT,w}$ (dB)	Requirement	Met/Failed
80	<65	Failed	53	<65 dB	Met

Table 8
Results obtained with the official DB-HR calculation tool for external noise insulation on the façade of the room under study.

Daytime noise level	$D_{2m,nT,Atr}$ (dBA)	Requirement	Met/Failed
L_d < 60 dBA	33	$D_{2m,nT,Atr}$>30 dBA	Met

24 women, aged between 21 and 87 years old, with 33 people aged over 60 years old). The respondents have been living in the neighbourhood for a long time, whereby 28 people dwell in the GF+4-storey typology, 17 are in the GF+8-storey, and 3 in the GF+12-storey typology. The statistical analysis shows that, in accordance with the variation coefficient, the sample is heterogeneous, and the results of the average values of the 12 items appear in Fig. 15 where the uncertainty of the results is exhibited through the standard error. Except for one item, mean values of the item scores are in the acceptable and quiet interval and the standard error is within the range 0.141–0.208.

The detailed results of the surveys (Fig. 16) show that, by including the first three scores (1–3) in one batch and the other two (4–5) in another, 60.4% of the respondents consider the noise of the perimeter streets to be acceptable and 39.6% consider it to be loud. For the noise of the interior streets of the neighbourhood, 81.2% of those surveyed consider it to be between quiet and acceptable, while 18.8% consider it to be loud. For the noise in the neighbourhood from airplanes and trains, 89.5% consider it quiet or acceptable, while 10.5% consider it loud. For the noise produced by construction work in neighbours' houses and that by roadworks, the proportion of respondents that consider it to be acceptable were 77.1% and 70.7% respectively, compared to 28.9% and 29.3%, respectively, who consider it to be loud or very loud. For noise from air-conditioning equipment, 81.1% consider it to be acceptable and 18.9% loud in summer. The noise corresponding to shops and bars is qualified by 70.8% of those surveyed as acceptable while 29.2% consider it loud. The noise due to schools is valued by 98.8% of those surveyed as lying within the acceptable range and 1.2% consider it loud. For the noise made by pets, 77.8% consider it non-existent, quiet, or acceptable and 22.2% loud. In other noises, 43.7% consider it acceptable and 56.3% loud. At this point, the noise produced by rubbish collection is emphasised, but only in certain surveys. In the chapter on domestic noise produced by upstairs neighbours, 86.2% consider it quiet or acceptable and 13.8% loud; for the noise produced by next-door neighbours, 94.1% consider it quiet or acceptable and 5.9% loud. It should be borne in mind that the *very loud* rating is, for the majority of items, the least chosen option by the respondents.

When asked whether their sleep is affected by environmental noise, 52.1% of the respondents answer that it had never been affected, 20.8% that sometimes, and 27.1% of neighbours that it has been affected many times. The two answers of the questionnaire corresponding to overall values of the neighbourhood (degree of acoustic privacy in the dwelling and acoustic comfort of the neighbourhood) are presented in Fig. 17.

As a general comment on the surveys, it should be noted that these questionnaires were answered by the neighbours without the presence of the interviewer. The surveys were left with a neighbourhood association that kindly offered to collaborate and were later collected once completed. Respondents have often left blank answers to important questions, such as the location of their street or plaza within the neighbourhood, the specification of the nature of noise when referring to the item involving other noises, and also regarding the type of noise that has prevented them from sleeping or that has woken them up at night, etc. Respondents have indicated at this point only whether or not it happened, and have failed to specify the nature of the noise that gave rise to such a situation. Hence, the results are very scattered and vary depending on the location of the dwelling of the respondent in the neighbourhood and the typology of housing. The residents located in the tallest blocks, which are generally close to the neighbourhood's perimetral streets or to the Soleá transversal street where buses circulate, have been more affected by traffic noise. It is worth mentioning how little the neighbours are affected by the domestic noise of next-door neighbours thanks to the small contact surface between the two flats on the same floor (see Fig. 6), and how they are more affected by noise coming from the upstairs neighbours and hence the low overall rating of the privacy of the dwellings, Fig. 17. Regarding environmental noise, it should be noted that, despite how exposed the house is to the exterior due to the double-bay structure, most people consider the environmental acoustic conditions of the neighbourhood to be acceptable or good, Fig. 17.

6. Conclusions

This paper presents an acoustic study carried out in the residential neighbourhood of San Pablo in Seville; no studies of a similar nature have previously been published on the urban acoustics of this city. This is a collective social housing neighbourhood, built by

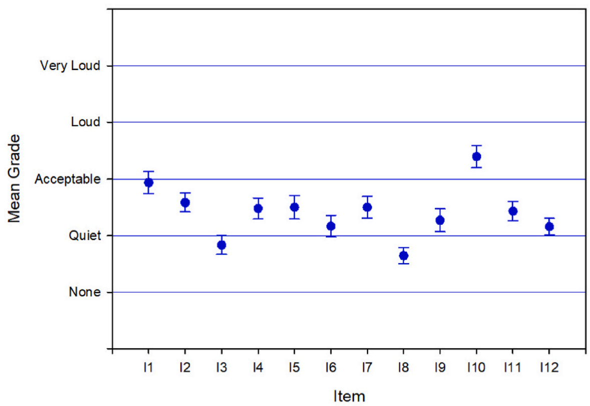


Fig. 15. Mean grade of each item of the acoustic questionnaire. Error bars correspond to the standard error.

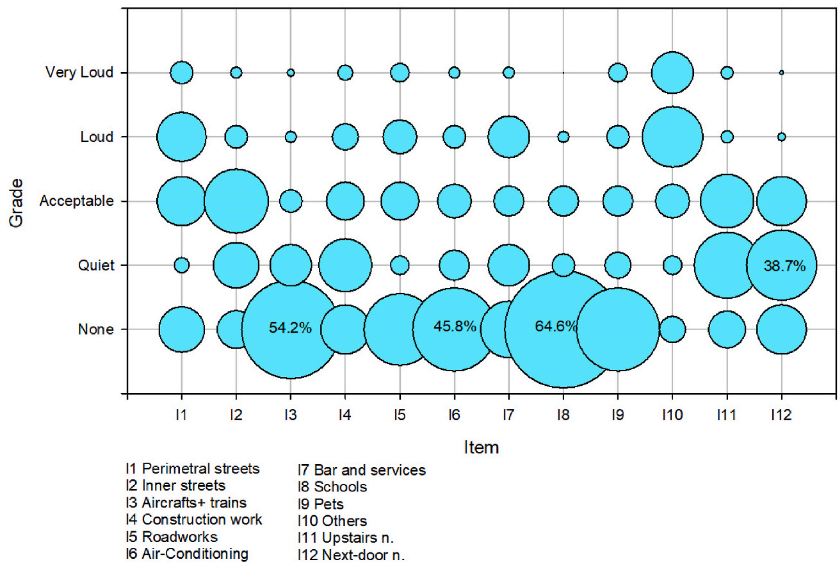


Fig. 16. Percentage of qualification for the 12 items of the questionnaire.

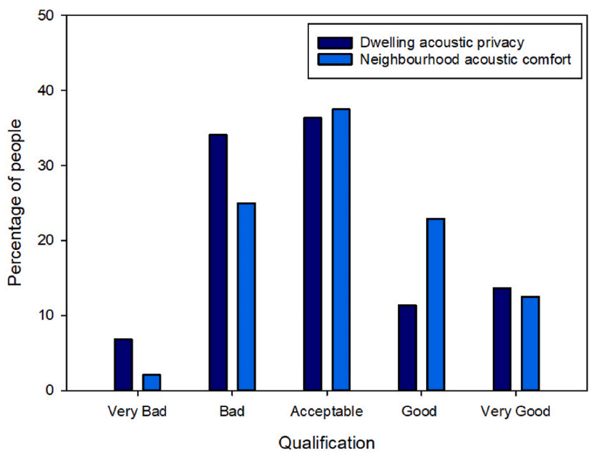


Fig. 17. Qualification by neighbours for the overall questions of the survey.

the government of the dictatorship in the years following the civil war in Spain, to satisfy the housing needs of the great rural emigration to the city of Seville in those years. The scarcity of good construction materials in Spain and the absence of regulations for acoustic and thermal conditioning at that time means that the neighbourhood currently shows various types of precariousness and obsolescence and requires building and urban regeneration measures: it has been classified in recent state studies as a vulnerable neighbourhood.

In order to establish an agreement between the acoustic quality regarding the noise of the external environment and the acoustic quality of the habitable interior space in the buildings, three types of acoustic analysis have been carried out: field measurements of environmental noise levels using short-time acoustic sonometry techniques at 16 locations in public areas of the neighbourhood, with analysis of these measurements and of the strategic noise maps drawn up by Seville city council; calculation of the standardised indices to evaluate the acoustic insulation against airborne and impact noise between adjacent living rooms, and to exterior noise on façades and their comparison with the minimum or maximum requirements of these acoustic indices established in current Spanish regulations; and finally, the results of perception surveys answered by the residents of the neighbourhood. The environmental noise spectrum results show that middle and high frequencies are predominant mainly due to speech and birdsong and that the prototype social dwelling fails to meet the requirements for airborne and impact noise insulation. However, the data on the low acoustic levels in façades extracted from the strategic noise maps and corroborated within the time interval in which the onsite measurements have been carried out for L_{Aeq}, which is certainly below the limit established for existing residential areas (65 dBA), enables the requirements of current Spanish regulations to be met for external noise insulation on the façades. Façades of social dwellings overlook small plazas, several of which are used as parking areas but still maintain a comfortable daytime and night noise level. An analysis of the environmental acoustic indicators permits many areas of the sub-neighbourhoods A and B to be classified as acoustically quiet areas (L_d < 55 dBA and L_n < 50 dBA): these are residential areas of the city where the existing environmental noise levels are lower than the established limits. The perception surveys of the neighbours also corroborate this positive assessment of the neighbourhood, despite it being part of the consolidated city and despite the exposure of the dwellings to the exterior due to the double-bay structure. This important acoustic characteristic to be preserved in accordance with European, national, regional, and local guidelines, is due not only to the absence of railway, port, airplane, and heavy industrial noise in the area, but also to the defensive urbanisation system conceived for the neighbourhood with respect to the roads with the highest traffic density and to the great availability of green public spaces and wide connections between the blocks of flats. In summary, although clear signs of general obsolescence can be seen in this neighbourhood, in the acoustic section, given the peculiarities of urban design, the environmental qualities at this point are not only not obsolete, but are also better than many much more modern neighbourhoods, whose designs are less suitable for this task.

It has been scientifically proven that the heritage neighbourhoods of the 1960's and 1970's that are urbanistically laid out in the same way in which the San Pablo Estate in Seville is planned (with cul-de-sacs, with slight turns in their layouts, small pockets of parking, etc.), enjoy a considerably improved acoustic performance in comparison with other allegedly more conventional options.

This coincides, on the other hand, with the recent contributions of the "superblock" concept that other cities, such as Barcelona, are striving to assume by eliminating road traffic from certain secondary streets, and restricting it to only the main perimeter roads.

Ethics statement

The study was approved by the Ethics Committee of CEIC Valme Teaching Hospital's Clinical Research (protocol code: 1210-N-20).

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Author contribution statement

S. Girón: Conceived and designed the experiments; Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

J. Martel: Conceived and designed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

M. Galindo, R. Herrera-Limones: Performed the experiments; Analyzed and interpreted the data; Contributed reagents, materials, analysis tools or data; Wrote the paper.

Data availability statement

Data will be made available on request.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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