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Review

Sound-Absorbing Acoustic Concretes: A Review

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Abstract: Noise is continuously treated as an annoyance to humans and indeed commotion contamination shows up within the environment, causing inconvenience. This is likewise interesting to the engineering tactic that inclines to develop this noise proliferation. The basics of the sound-retaining proliferation, sound-absorbing properties, and its variables were rarely considered by previous researchers. Thus, the acoustic performance and sound insulation of constructions have gained significance over the last five decades due to the trend for accommodating inner-city flat and multi-story residential building condominiums. Due to this dilemma, the proliferation of high-driven entertaining schemes has engaged extraordinary demands on building for its acoustic performance. Yet, construction industries worldwide have started to mainly use sound-absorbing concrete to reduce the frequency of sounds in opened-and-closed areas and increase sound insulation. As reported, the concrete acoustic properties generally rely on its density, exhibiting that the lighter ones, such as cellular concrete, will absorb more sound than high-density concretes. However, this paper has an objective to afford a wide-ranging review of sound-absorbing acoustic concretes, including the measurement techniques and insulation characteristics of building materials and the sound absorption properties of construction materials. It is also intended to extensively review to provide insights into the possible use of a typical sound-absorbing acoustic concrete in today's building industry to enhance housing occupants' efficiency, comfort, well-being, and safety.

Keywords: concrete; noise; sound; absorb acoustic concrete; cement composites

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1. Introduction

The rapid development of cities and their saturation with various transports led to an increased noise level [1]. Acoustic comfort is a feature of urban comfort, recognized by doctors, and becomes an indispensable activity for civil engineering and urban planning. Therefore, reducing ambient noise is of importance in modern society not only because of the recent awareness of noise as a significant risk to health and because of an increasingly important level and quality of life [2]. Various concretes are the primary building material of our time. The application areas of sound-absorbing concrete are quite diverse: in civil engineering, this is soundproofing the facades of buildings and interior partitions; and in town planning, for example, the creation of soundproofing fences on high-speed roads. Another critical factor is the protection against infrasound occurring near wind power stations, railway bridges, cooling towers, and inside automobiles [3–5]. In addition, the possibility of protection against infrasonic acoustic weapons has recently become important.

A sound is a wave form of energy that passes through solids, liquids, or gases. The more vibrating particles in the medium the more energy that is transmitted. Waves of the frequency range from 20–20,000 Hertz (Hz) can affect the human hearing aid and cause a sense of sound in it. However, according to [6,7], a person can hear sounds even up to 20 Hz. However, this requires a volume of 110–130 decibels (dB) (for comparison, a sound with a frequency of 3000 Hz is already audible from the volume just above 0 dB). The sound frequency below 20 Hz is called infrasound, and above 20 kilohertz (kHz) is called ultrasound. There are three types of acoustic sounds: airborne, structural, and impact (a unique form of structural noise). Airborne sounds (speech, loudspeakers, musical instruments, etc.) cause the waves to pass through the air but not through solid bodies. However, they create vibrations inside the structure that cause air particles on the opposite side to vibrate, allowing them to be heard [8]. Impact sounds (footsteps, door closing, and dropping items) vibrate through walls and floors, allowing for airborne noise to be heard in neighboring rooms [9]. The noise of human footsteps is a typical artificial low-frequency sound below 100 Hz that occurs in dwellings [10], which can adversely impact living and mental health conditions. This strong sound of impact is a form of structural sound produced when waves pass through components of a structure (for example, floors and walls in a residential building).

The wave amplitude, which determines the sound pressure level, depends on the structural material's elastic modulus and density, along with its geometric characteristics [10]. However, the structural modifications required to increase flexural strength and lower acoustic pressure levels are usually not advised because they are not economically viable [11]. It is more advisable to control the sound pressure level by structural or architectural design.

For example, when designing the Broadcasting House in Copenhagen, the acoustic characteristics of the interior were controlled by the angle of rotation of the suspended vertically perforated panels [12]. Another architectural method for controlling acoustic parameters is screening, including the use of concrete screens. The concrete screening efficiency of the sections located in direct sound hones is 3–5 dB at low frequencies and 10–15 dB at high frequencies [13]. The concepts of noise and sound are often combined, but they are quite different since noise is subjective and depends on the receptor. Noise refers to irregular fluctuations without regular dependence. This principle of subjectivity should be considered by designers, particularly in urban environments, when considering the noise in a structure. As the volume or sound level in these situations is difficult to decrease, noise reduction measures to minimize discomfort are often taken. Concrete's acoustic properties are characterized as being capable of reducing sound transmission through it. Dense barriers of standard concrete mixes with a relatively small thickness reflect sound energy. Previous studies [14,15] identified concrete as a good insulator that reflects up to 99 percent of the sound energy because of its high density. Ordinary concrete, however, is a weak sound absorber that may echo in confined areas. Lighter and porous materials can absorb noise and retain it. Many researchers have endeavored to improve the properties of hardened concrete [16,17], mainly its acoustic characteristics, which can be used in various construction fields. As reported, the acoustic properties of concrete are usually dependent on their density, exhibiting that the lighter ones, for instance, cellular concrete, will absorb sounder compared to high-density concretes [18]. Acoustic materials are also used to reach acoustic comfort, not just noise control, i.e., the objective acoustic parameters in working places, concert halls, etc. In addition, a sustainable concrete is one that is made primarily of natural or recycled materials and uses little energy to manufacture and vice versa. It uses nonrenewable resources sparingly and has a low environmental impact. However, this paper aims to present a wide-ranging review of the sound-absorbing acoustic concretes, including the measurement techniques and insulation characteristics of building materials and the sound absorption properties of construction materials. It is also intended to extensively review the literature to provide insights into the possible use of a typical sound-absorbing acoustic concrete in today's building industry to enhance the efficiency, comfort, well-being, and safety of housing occupants.

2. Representative Acoustic Absorption Indicators

The sound impulse is transmitted to the molecules of the medium (for example, air), and from them to the next molecules, etc. Accordingly, alternating zones of compaction and that are under pressure arise. In this case, there is sound pressure, which causes a sensation of sound in our ear. Under the sound, pressure understands the change in atmospheric pressure over a certain period [7,14,19]. The starting point is a pressure of 20 µPa, which is the minimum hearable threshold. Sound energy E is the sound power multiplied by the time of action. The intensity of the sound I is the sound power divided by the unit area. The audible threshold occurs at sound intensity $I_0 = 10^{-12}$ W/m^2 [4,11,20]. The sound pressure level is calculated in decibels in the following logarithmic relationship:

$$10lg\frac{I_1}{I_0} \tag{1}$$

where I_1 is the intensity of the test sound.

When the sound level (volume) increases every 10 dB, the sound will be perceived as two times louder. The amplitude of the oscillation of the sound wave determines the loudness of the sound. General considerations in acoustic energy conservation provide us with the following classic ratio:

$$E_i = E_r + E_e \tag{2}$$

where E_i—the energy of sound falling on the building envelope;

E_r—reflected sound energy;
E_e—includes both the transmission and absorption of sound energy.

The sound absorption coefficient α is defined as the ratio of the absorbed energy to the incident energy, and it can also be defined as the ratio of all unreflected energy to the incident energy:

$$\alpha = 1 - \frac{E_r}{E_i} \tag{3}$$

The presentation of the acoustic absorption coefficient as a sole value is a complex issue. This is due to the acoustic absorption coefficient α varies for each sound frequency (Table 1).

Table 1. Details and explanations of different standards for acoustic indicators.

$D_{nT,w}$	EN ISO 12354-part 1	Evident standardized rate difference index	[21–23]
$L'_{n,\ w}$	ISO 717-part 2, ISO 140-part 7, EN ISO 12354-part 2, ISO 16283-part 2	Weighted standardized effect rate of sound pressure	[22–26]
R'_w	ISO 717-part 1, ISO 140-part 4, EN ISO 12354-part 1, ISO 16283-part 1	Sound reduction index of evident airborne	[22,23]
C	ISO 717-part 1 and part 2, EN ISO 12354-part 1 and part 2	C is an A-weighted flushed noise phantom adjustment term	[21,22,27,28]
$C_{50\text{-}3150}$		C is an adjustment term, frequency limited between 20 and 2500 Hz	
L_{AFmax}			
$C_{I,AkuLite,20\ 2500}$		C is an adjustment term, frequency limited between 50 and 3150 Hz	
$C_{I,20\text{-}2500}$	JIS A-1418-part 2	The rubber ball index/impact of Japanese	[27,29,30]
STC	ASTM E 413	Airborne sound conveyance category, computed in the same way as R'_W	[24,31,32]

As a simplification, the division of the audible frequency spectrum into octaves (with a further one-third octave division) is used, as well as, for example, such characteristics as sound absorption average (SAA) and noise reduction coefficient (NRC) [3,7,33]. Table 2 shows the sound absorption coefficient of different types of materials.

Table 2. The sound absorption coefficient of different types of materials.

Type of Materials	Sound Absorption Coefficient, Hz			Refs
	500	1000	2000	
Construction and Finishing Materials				
Brick: coated, and non-glassy	0.01	0.02	0.03	[34]
Carpet: weighty, resistant with rubber backup on concrete	0.27	0.34	0.63	
Brick: non-glassy	0.03	0.04	0.07	
Concrete brick: Permeable and light	0.44	0.29	0.25	
Carpet: weighty on concrete	0.06	0.37	0.65	
Plaster: lime and smooth surface on board	0.10	0.04	0.03	
Concrete brick: Coated and impenetrable	0.05	0.07	0.08	
Plaster: lime and uneven surface on board	0.10	0.05	0.03	
Gypsum board: 13 mm fastened	0.10	0.04	0.09	
Glassy or limestone tile	0.01	0.01	0.02	
Plywood sheeting with 19 mm thick	0.22	0.09	0.11	
Carpet: weighty and froth latex on concrete	0.24	0.69	0.73	
Plaster: lime and flat surface on brick or tile	0.015	0.03	0.05	
Fabrics				
Average textile: swathed to partial zone	0.31	0.75	0.60	[35]
Un-weighty textile: Suspended straightforward in interaction with wall	0.04	0.17	0.35	
Weighty textile: swathed to partial zone	0.35	0.72	0.65	
Floors				
Timber	0.11	0.07	0.07	[34] [35]
Carpet or concrete	0.01	0.02	0.02	
Timber flooring in bitumen on concrete	0.04	0.06	0.07	
Linoleum: bitumen, latex, or plug tile on concrete	0.03	0.03	0.02	
Glass				
Traditional window cut-glass	0.25	0.12	0.04	
Big windowpanes of weighty bowl glass	0.06	0.03	0.02	
Other				
Open windows and doors	1.00	1.00	1.00	[35]
Midair per 28.32 m^3	0.20	1.20	7.40	
Swimming pool	0.08	0.15	0.25	
Results are obtained in cabins/m^2 per unit				
Fascination of audience and seats				
Audience—furnished seats, per m^2	0.74	0.96	0.85	[34]
Seats—timber or metal seats, vacant	0.19	0.39	0.30	
Folks in an area—per person only	3.0	5.0	4.0	

In general, the characteristics of sound are so multifaceted that they have to be simplified and classified. In particular, Jeon et al. [36] compiled a classification of impact noise by heavy floor in apartment buildings using an equal-interval scale. Thirty-three different sensations of sound by a human were analyzed, and accordingly, the rooms were divided into seven classes from "quiet in the room" to "it is impossible to be in the room". It is reported that entire materials can absorb certain acoustical power. Several materials, for instance, gypsum board, are poor at absorbing sound, reflecting the greatest of the power that raids their exteriors. However, other materials, for example, fiberglass insulation, can absorb most of the present sound. However, construction materials are commonly ranked by their NRC. This sole number ranking is an average of the frequency value of the typical sound-absorbing materials at 250, 500, 1000, and 2000 Hz, rounded to the adjacent 0.05 [37]. The NRC is extensively applied to common acoustical characteristics of office screens, baffles, ceiling tiles, acoustic wall partitioning, and banners. It is also rarely used to evaluate construction materials and coverings of the floor.

3. Determination Methods for Acoustic Characteristics of Building Materials

The investigational determination of acoustic characteristics of materials used in the construction of buildings has remained as a substantial assignment earning greater significance attributable to the need for appropriate materials for structures in locations with an extraordinary level of noise [7] (Table 3), generally in municipal areas and places near by zones with heavy traffic, such as highways, railways, and industries.

Table 3. Standards for determining acoustic characteristics in construction.

Refs	Standard	Measured Characteristics	Range	Measurement Devices	Application	Limitation and Advantages
[38]	ASTM C423-17 "Standard Test Method for Sound Absorption and Sound Absorption Coefficient by the Reverberation Room Method"	Sound absorption coefficient α, Noise reduction coefficient, NRC Sound absorption average, SAA	0.0–1.0 0.0–1.0 0.0–1.0	Reverberation room, sound sources, microphones	Measure the room absorption, the object absorption, such as an office screen, and the coefficient for sound absorption of a sound absorption material specimen, such as acoustic ceiling tile.	The volume of the reverb chamber is 150 to 500 m^3. The sample area for testing should be from 10 to 12 m^2.
[33]	ISO 354:2003 "Acoustics—Measurement of sound absorption in a reverberation room"	Sound absorption coefficient α, Reverberation time T [s]	0.0–1.0 0.4–5.0	Reverberation room, sound sources, microphones	Measurement of sound absorption in a reverberation room.	At frequencies below 100 Hz, accurate measurement results cannot be obtained due to the low density of modes (natural frequencies) of the vibrations of the reverberation chamber.
[39]	ISO 3382-2:2008 Acoustics. Measurement of room acoustic parameters. Reverberation time in ordinary rooms"	Reverberation time T [s]	0.4–5.0	Reverberation room, sound sources, microphones	Correction of other acoustic measurements, e.g., sound pressure level from sound sources or measurements of sound insulation, and for comparison with requirements for reverberation time in rooms.	At frequencies below 100 Hz, accurate measurement results cannot be obtained due to the low density of modes (natural frequencies) of the vibrations of the reverberation chamber.
[1,33,40,41]	ISO 10534-2:1998 "Acoustics—Determination of sound absorption coefficient and impedance in impedance tubes"	Sound absorption coefficient α, Z—normal surface impedance [m^2], Airborne sound insulation index R_w, dB	0.0–1.0 > 20 26–74	An impedance tube, two microphone locations, and a digital frequency analysis system	Determination of sound absorption coefficient and impedance in impedance tubes.	This standard does not purport to address all of the safety concerns, if any, associated with its use.
[42]	ASTM C384-04(2016) "Standard Test Method for Impedance and Absorption of Acoustical Materials by Impedance Tube Method"	Sound absorption coefficient α, Z—normal surface impedance, Airborne sound insulation index R_w, dB	0.0–1.0 > 20 26–74	An impedance tube, two microphone locations, and a digital frequency analysis system	Measurement of impedance ratios and the normal incidence sound absorption coefficient of acoustic materials.	This standard does not purport to address all of the safety concerns, if any, associated with its use.

Table 3. *Cont.*

Refs	Standard	Measured Characteristics	Range	Measurement Devices	Application	Limitation and Advantages
[43]	ASTM E1050-19 "Standard Test Method for Impedance and Absorption of Acoustical Materials Using a Tube, Two Microphones and a Digital Frequency Analysis System"	Sound absorption coefficient α, Z—normal surface impedance, Airborne sound insulation index R_w, dB	0.0–1.0 > 20 26–74	- Impedance tube - 2 microphone places - Digital frequency analysis system	Determination of normal sound absorption incidence coefficient and normal common sound impedance ratios.	- 0 to 1600 Hz frequency. - Fixed impedance tube diameter.
[33]	ISO 717-1:2006 "Acoustics. Rating of sound insulation in buildings and of building elements. Airborne sound insulation"	Airborne sound insulation index R_w, dB	33–56	The purpose of this standard is to establish a method by which the parameters of airborne noise insulation in frequency bands can be converted into a single number that gives an integrated assessment of the soundproofing properties of the structure being evaluated	(a) Describes single-number airborne sound insulation amounts of constructions and building components, such as walls, floors, doors, and windows; (b) takes into account the different sounder rates spectra in various noise sources, such as in-building noise sources and traffic outside the house; (c) establishes rules for the determination of these quantities for measurements performed in 1/3 octave bands in accordance with ISO 10140-2 and ISO 140-4&5.	1/3 octave bands to calculate the single-number quantities.
[34]	ISO/DIS 16717-1 "Acoustics. Evaluation of sound insulation spectra by single numbers. Airborne sound insulation"	R_{living} R_{speech} $R_{traffic}$	0–30 0–30 0–30	Loudspeaker	The reference noise range is specified by the standard rating proposal on airborne sound isolation in buildings.	The possibility to measure, in the laboratory, sound reduction index below 100 Hz with current measurement standards
[23]	EN 12354-1:2000 "Building acoustics—Estimation of acoustic performance of buildings from the performance of elements—Part 1: Airborne sound insulation between rooms"	Airborne sound insulation index R_w	26–74	Calculation	Design methods for assessing the sound insulation of airborne noise propagating between buildings.	The calculation model is simplified and has several limitations.

Table 3. *Cont.*

Refs	Standard	Measured Characteristics	Range	Measurement Devices	Application	Limitation and Advantages
[44,45]	ISO 10,140 series "Acoustics. Laboratory measurement of sound insulation of building elements"	Sound reduction index R		Sound transmission is blocked via flanking routes.	Methods of laboratory measurements for floor assembly sound insulation effect. Test results can be used to compare building elements' sound insulation characteristics, classify building elements in accordance with sound insulation capabilities, and support the design of building products requiring certain acoustic features.	- Improve laboratory measurements layout; - Ensure consistency and simplify future changes; - Mounting conditions of test elements in laboratory and field measurements.
[46]	ISO 140-5. "Acoustics—Measurement of Sound Insulation in Buildings and Building Elements—Part 5: Field Measurements of Airborne Sound Insulation of Façade Elements and Façades"	Reverberation time T [s] Sound absorption coefficient α,	0.4–5.0 0.0–1.0	Global loudspeaker	Specifies two series of methods for determining the airborne sound insulation of façade elements (element methods) and entire façades (global methods). The methods of the elements are to measure a façade's sound-reducing index, such as a window.	Canceled in 2016 and replaced by ISO 16283-1:2014 and ISO 16283-3:2016.
	ISO/DIS 16283-1:2012. "Acoustics—Field measurement of sound insulation in buildings and building elements—Part 1: Airborne sound insulation"	Sound pressure level [dB] Reverberation time T [s] Background noise	0–140 0.4–5.0	Global loudspeaker	The findings can be used to measure, analyze, and compare the airborne sound insulation in unfurnished or furnished spaces where the sound field may approximate a diffuse field or may not be approximate.	This part of ISO 16283 is to determine the airborne sound insulation between two rooms in the building using sound pressure measurements. The techniques are designed for room volumes ranging between 10.0 m^3 and 250.0 m^3 within the 50.0 Hz and 5000 Hz frequency ranges.

Table 3. *Cont.*

Refs	Standard	Measured Characteristics	Range	Measurement Devices	Application	Limitation and Advantages
	ISO 16283-3. "Acoustics—Field Measurement of Sound Insulation in Buildings and of Building Elements—Part 3: Façade Sound Insulation"	Airborne sound insulation index R_w	26–74	"Manually scanned microphone" method	The results of the tests may be used for the quantification, measurement, and comparison of the airborne sound insulation in unequipped or equipped spaces, where the sound field is approximated to a diffuse field or not.	This part of ISO 16283 is to determine the airborne sound insulation between two rooms in the building using sound pressure measurements. The techniques are designed for room volumes ranging between 10.0 m^3 and 250.0 m^3 within the 50.0 Hz and 5000 Hz frequency ranges.
[47]	ISO 15186-2 "Acoustics—Measurement of Sound Insulation in Buildings and of Building Elements Using Sound Intensity—Part 2: Field Measurements"	Sound absorption coefficient α, Reverberation time T [s]	0.0–1.0 0.4–5.0	The measurement uncertainty is to be measured in a single number of airborne sound insulation quantities.	Specifics a method for the acoustic intensity of the walls, floors, doors, windows, and small building elements to be determined in situ. It is for tests to be carried out in the presence of flank transmission. It can be used for the treatment of a flanking transmission or the calculation of flanking acoustic parameters.	In measuring one single small and large building feature, the reproducibility of the intensity procedure is estimated to be equal to or better than that of ISO 140-10 and ISO 140-4.
	ISO 15186-3:2002 "Acoustics. Measurement of sound insulation in buildings and of building elements using sound intensity. Laboratory measurements at low frequencies"	Sound absorption coefficient α, Reverberation time T [s]	0.0–1.0	The measurement uncertainty is to be measured in the single number of airborne sound insulation quantities.	Indicates a formula for sound intensity to determine the index of acoustic reduction and the element-normalized level difference of the construction components at small frequencies.	For all frequencies, the reproducibility of this process is measured at or above 100 Hz with the ISO 140-3 protocol. The production is similar to values determined between rooms with volumes greater than 300 m^3, depending on the room dimensions of the laboratory. This ISO 15186 component is appropriate for the 50 Hz to 160 Hz frequency range and mainly for the 50 Hz to 80 Hz frequency range.

Table 3. *Cont.*

Refs	Standard	Measured Characteristics	Range	Measurement Devices	Application	Limitation and Advantages
[48]	EN 1793-2:2011 "Road traffic noise reducing devices. Test method for determining the acoustic performance. Intrinsic characteristics of airborne sound insulation under diffuse sound field conditions"	Sound absorption coefficient α	0.0–1.0	Test approach for acoustic efficiency determination.	Specifies the method of laboratory assessment of the sound insulation output in reverberated conditions on-road noise reduction devices.	This approach aims not to determine the essential characteristics of airborne sound insulation in non-reversible conditions of noise reduction devices to be mounted on roads.
[49]	ISO 1996-2. "Acoustics—Description, Measurement and Assessment of Environmental Noise—Part 2: Determination of Sound Pressure Levels"	Equivalent Sound Pressure Level L_{eq}, impulse noise, low-frequency noise, residual noise	wide range	Provide reliable 13-octave (survey) measurement techniques to determine the existence of audible sounds, if contested.	Can be used to measure with any frequency weighting or in any frequency band.	The consumer calculates the measuring effort, and therefore the measurement uncertainty, as calculated and recorded in each case in a highly flexible way. No maximum permissible uncertainty limits are thus defined.
[50]	ISO 18233. "Acoustics—Application of New Measurement Methods in Building and Room Acoustics"	Average sound pressure level L_1 in point S, transfer coefficient, transient characteristic	wide range	Transfer function methods	For measures such as sound-isolating airborne between the rooms and façades, reverberation time calculation and other acoustic parameters of the buildings, sound absorption measurement of reverberation spaces, vibration level variations, and loss factor measurement.	Compared to well-known traditional approaches, the new methods offer several benefits, such as background noise reduction and extended range. However, if specific procedures are not followed, there is also the possibility of inaccurate outcomes. The new methods can be more sensitive than traditional methods to time variations and changes in environmental conditions.
[51]	ASTM E1007-19. "Standard Test Method for Field Measurement of Tapping Machine Impact Sound Transmission Through Floor-Ceiling Assemblies and Associated Support Structures"	Impact noise characteristics	wide range	Standard tapping machine	This approach covers calculating the impact sound transmitted through floor-ceiling assemblies and associated supporting structures in field situations through a regular tapping unit.	Findings can be measured for all sorts of floor-ceiling units such as float- or suspended ceiling elements, or both, as well as the floor-ceiling units.

3.1. Measuring in a Reverberation Room

Measuring a room's absorption, the absorption of an object such as an office screen while a specimen's sound absorption coefficient is that of acoustic ceiling tiles (Figure 1), the average reverberation time is determined in the reverberation chamber with and without a sample. Based on the results of reverberation time measurements, the equivalent sound absorption area of sample A_T is calculated according to the Sabine formula [14,52–56]. Suppose the sample is evenly distributed over the surface of the chamber (for example, a flat sound absorber or several objects). In that case, the sound absorption coefficient is defined as the ratio of the value of the equivalent sound absorption area A_T to the sample area *S*. According to ASTM C 423-17 [37] and ISO 354: 2003 [51], measurements are done in one-third octave bands with the following geometric mean frequencies, in Hz: 100, 125, 160, 200, 250, 315, 400, 500, 630, 800, 1000, 1250, 1600, 2000, 2500, 3150, 4000, and 5000. At low frequencies (below 100 Hz), it must be noted that accurate measurement results cannot be obtained due to the low mode density (natural frequencies) of the reverberation camera oscillations. The volume of the reverb chamber is 150 to 500 m^3. To ensure a satisfactory degree of diffusion of the sound field, stationary or suspended diffusers or rotating blades are used regardless of the shape of the camera. The sample area for testing should be from 10 to 12 m^2. However, for example, in the article [57], the sample area was reduced to 1.87 m^2, while the results may be adequate, given that the room volume provides a rather diffuse sound field. The reverberation time T, s-time required for the average spatial density of sound energy to fall in a limited volume by 60 dB from the original level after turning off the radiation source is measured according to ISO 354: 2003 [22], ISO 3382-2: 2008 [58]. There are several reasons for measuring the reverb time. First, the sound pressure level of noise sources, the intelligibility of speech, and the confidentiality conditions in the room are strongly dependent on the reverberation time. The premises can be seen as living rooms, staircases, spans, production workshops, classrooms, offices, restaurants, exhibition centers, sports halls, railway stations, and airports. Secondly, the reverberation time is measured to determine in the room the sound absorption corrections necessary for various acoustic measurements, such as the sound insulation measurement according to ISO 140 (all parts) and the sound power of noise sources according to ISO 3740 [54]. Uncertainties due to reproducibility concerns are crucial for the reverberation room method [59].

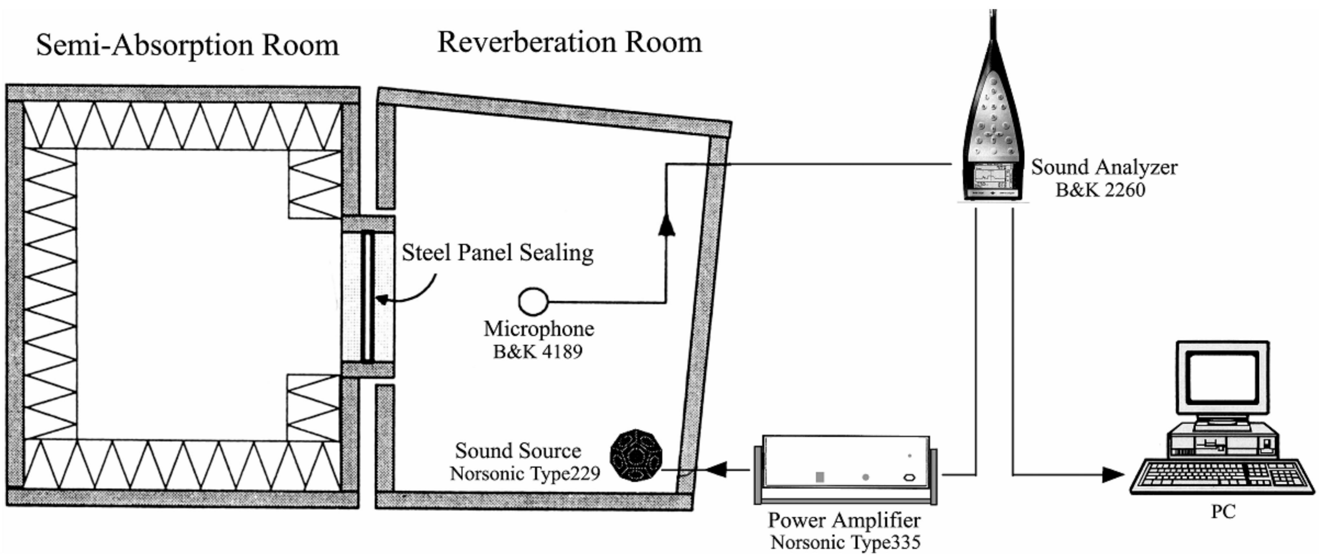

Figure 1. System of testing measurement in reverberation room [60]. Reprinted with permission from Elsevier.

3.2. Determination of Sound Absorption Coefficient and Impedance in Impedance Tubes

The test method according to ISO 10534-2: 1998 [61] and ASTM C 384-04 [62] includes the use of an impedance tube (Kundt tube), two microphone locations, and a digital frequency analysis system to determine the sound absorption coefficient of sound absorbers with normal sound dropping (Figure 2). It can also be used to determine the acoustic surface impedance. Acoustic impedance is the complex acoustic impedance of the medium, which is the ratio of the complex amplitudes of the sound pressure to the vibrational volume velocity (the complex velocity of the sound particles) at a particular frequency in the reference plane. The measurements defined in this test method can be used for basic research and the development of sound-absorbent materials since the impedance ratios of sound-absorbing material are related to its physical properties, including airflow resistance, porosity, elasticity, and density. The method was first applied by Iwase et al. [63] using three microphones (two in front of the sample and a third downstream. The edges of the samples were sealed with Teflon tape and a thin layer of Vaseline. Feng [64] modified this method. In the standard configuration, the impedance tube rests on a rigid plate (standard ISO 10534 [61], therefore the transmission is eliminated, and in a modified tube with an end inserted in the anechoic room, the sound energy is transmitted through the sample, as evidenced by the transmission coefficient, t. The real absorption and transmission coefficient can thus be distinguished using the Feng method. The frequency range for sound absorption coefficient determinations when using impedance tubing is 250–5000 Hz. The high-frequency component is limited due to its fixed diameter and the uncertainty concerning the minor phase variations at low frequencies. The uncertainty of the sound absorption coefficient is higher as the frequency value tends to be zero due to the mistake induced by phase and magnitude. This utilized method (ISO 10534-2 [61]) is dependent on the definition of the phase variation in the microphone positions. The wavelength tends to be infinite if the frequency approaches zero and the phase ratio tends to zero.

An alternative method that overcame the limitations of the impedance tube and full-scale reverberation room has been proposed by Shtrepi and Prato [65]. The proposed method is called small-scale reverberation rooms (SSRR), which evaluates the random-incidence sound absorption coefficient. It is concluded that SSRR is considered a reliable alternative for the sound absorption characterization, leading to several benefits. Among them, samples with reduced size can be evaluated with cheaper equipment in a short time, increasing the overall economic sustainability of the measurement process; in turn, this can encourage designers and architects to perform acoustical measurements from the very early research and development phase, leading to an overall reduction of design costs and improved product quality.

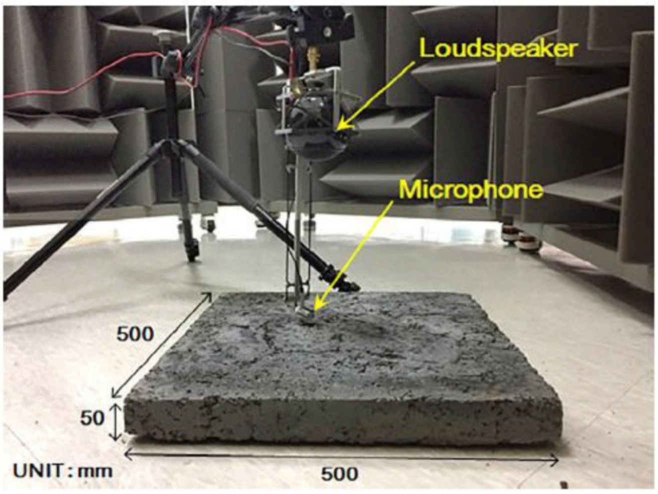

Figure 2. Impedance tube [66]. Reprinted with permission from Elsevier [66].

3.3. Assessment of Building's Acoustic Performance from Element Performance

The ISO 717-1 [67] method determines the number of airborne sound insulation parameters in buildings by construction elements (e.g., walls, floors, doors, and windows). It takes into account different noise sources within and outside of the building. The airborne sound insulation index, R_w, is considered a fundamental parameter for the laboratory testing of building envelopes. This index considers the frequency range in the 1/one-third octave band, from 100 Hz to 3150 Hz, which may not be enough to describe the behavior at low and high frequencies satisfactorily. To consider the behavior extended in frequency concerning normalized noise spectra, the terms adaptation of the C and C_{tr} spectra (pink noise and road noise, respectively) were introduced. In the draft standard ISO/DIS 16717-1 [68], the new version of the standard used, three indices were considered: R_{living}, R_{speech}, and $R_{traffic}$, replacing the "old" concept of an airborne sound insulation index. R_{living} and $R_{traffic}$ are not new indices because they are equal (R_w + $C_{50\text{-}5000}$) and (R_w + $C_{tr,\ 50\text{-}5000}$), respectively. Granzotto and Di Bella [34] and Mašović et al. [68] report that this makes it possible to measure in the laboratory the rate of sound reduction below 100 Hz using modern measurement standards. In particular, Granzotto and Di Bella [34] note that measuring sound insulation from airborne sound at frequencies of 50–100 Hz presents several problems. At low frequency, problems arise due to modes, including in fairly large laboratory rooms. In many cases, a diffuse sound field cannot be provided at low frequencies, and the measurement methods of the ISO 10140 series [67] of standards can only be used for "additional information". The ISO 10140 series provides an overestimation of R, at frequencies below 100 Hz compared to the values obtained from the sound intensity measurements. However, while the use of the intensity method is possible, it is not easy. ISO/DIS 16717-1 [68] considers a range of only 50–5000 Hz for one number only for single-digit expressions. A possible solution to all these problems would be considering new indices from 100 Hz to 5000 Hz with the possibility of expansion to 50 Hz. Standard procedures for field sound insulation measurements between rooms are currently described in international standards of the ISO 140 series. However, they are used in rooms with sound fields that approach diffuse fields (Table 4). In practice, many dwellings have rooms with a volume of less than 25 m^3, where the absence of a scattered sound field at low frequencies, combined with the selection of sound pressure in the central zone of the room, makes measurements less reliable and less relevant for residents of the building. Considering that sound insulation in the low-frequency range (especially below 100 Hz) is important in all buildings, especially in wooden frame buildings, Hopkins and Turner's [13] studies have given impetus to identify new procedural changes to improve the reliability and relevance of sound insulation measurements in the field. These procedural changes were subsequently used in the proposal for the revision of four International Standards for Soundproofing (ISO 140, parts 4, 5, 7, and 14) at the plenary session of ISO TC43 SC2 [69] in Korea (November 2009). This proposal was accepted, and Karl Hopkins became the organizer of the work packages for writing these new standards. The first international standard ISO/DIS 16283-1 [70] was written for field measurements of airborne soundproofing and was distributed to all countries as a draft for comments in 2012. As a result, ISO 140-4: 1998 [71] was replaced by ISO 16283-1: 2014 [70], which introduces new approaches for source directivity, a limit of 8 dB between adjacent 1/3 octave bands in the source room, a means for calculating "level differences" and a low-frequency procedure sound pressure level measurements not included in ISO 140-4. For the default procedure, ISO 16283-1 introduces the ability to use the "manually scanned microphone" method, also not included in ISO 140-4 [6]. ISO 16283-3 establishes methods for determining airborne sound insulation by facade elements (elemental methods) and the entire facade (global methods) using sound pressure level measurements. These methods are intended for the volume of premises from 10 m^3 to 250 m^3 in the frequency range with geometric mean frequencies of one-third octave bands from 50 Hz to 5000 Hz. The comparison of the measurement results in terms of impact noise level and sound insulation, in accordance with ISO 140 and ISO 15186 [72], shows their inconsistency, especially at low frequencies.

This can be explained by the fact that, at low frequencies, where room resonances can occur, the accurate determination of the reverberation time is difficult. The EN 10848 series [73] standard defines methods for the laboratory measurement of airborne and impact noise flanking transmissions from neighboring rooms. Two methods can be used according to this standard:

- The use of shielding for directing the sound wave in the right direction; however, this is a cumbersome method that is not efficient enough at frequencies of about 100 Hz and below, as well as for massive structures;
- The flanking path under consideration may be characterized by the difference in vibration levels from which the joint's invariant (vibration reduction coefficient) is calculated.

Table 4. A summary of typical noises heard in the buildings and residential condominiums.

Type on Noise	Refs.
Noise in public zones	[16,29,74]
Influence of noise by daily activities, from neighbors	[21,29,75,76]
Noise of airborne from radios of neighbors (squat frequencies) Noise of airborne from neighbors in common (TV, speaking, and audio)	[21,22,27,75]
Noise of airborne from neighbors dropping/moving items	[21,22,25,29]
Outside noise Transportation noise	[29,77–79]
Shaking encouraged from equipment in other suites	[29,80–82]
Influence of noise from neighbors by walking Noise inside a unit	[21,22,25,27,29,31]
Influence of noise in common from neighbors Shaking prompted from the mobile/echo/cells of neighbors	[29,83–85]

3.4. Impact Noise

In the study of impact noise according to DIN 52210 and ASTM E1007-19 [86], only frequencies from 100 to 3150 Hz are decisive. A "tapping" machine is installed on the tested overlap, equipped with five identical hammers weighing 500 g each. With the help of the shaft, these hammers rise and, in a certain rhythm, freely fall one by one on the overlap. In the room under the testing overlap, measured noise level. Reportedly, Zhang and Poon, in the course of the study [51] modified ASTM E1007-19 [86], in particular, they used a metal ball to create impact noise instead of a "tapping machine". The study aimed to evaluate the effects of reducing the noise of each plate in contrast to the test results of the background experiment. In the frequency range of 100 Hz to 3150 Hz, the noise levels caused by the impact of the metal ball samples were assessed. At intervals of 0.2 s, noise data were reported, and the total duration of the signal pickup was 3 s for the highest noise level. For getting the average noise level, each test was repeated 3 times. Figure 3 illustrates the diagram used to test sound insulation. Low-frequency airborne and impact insulation are essential in light buildings because of the low level of sound insulation in the low-frequency range. Existing measurement methods show poor reproducibility in the low-frequency range.

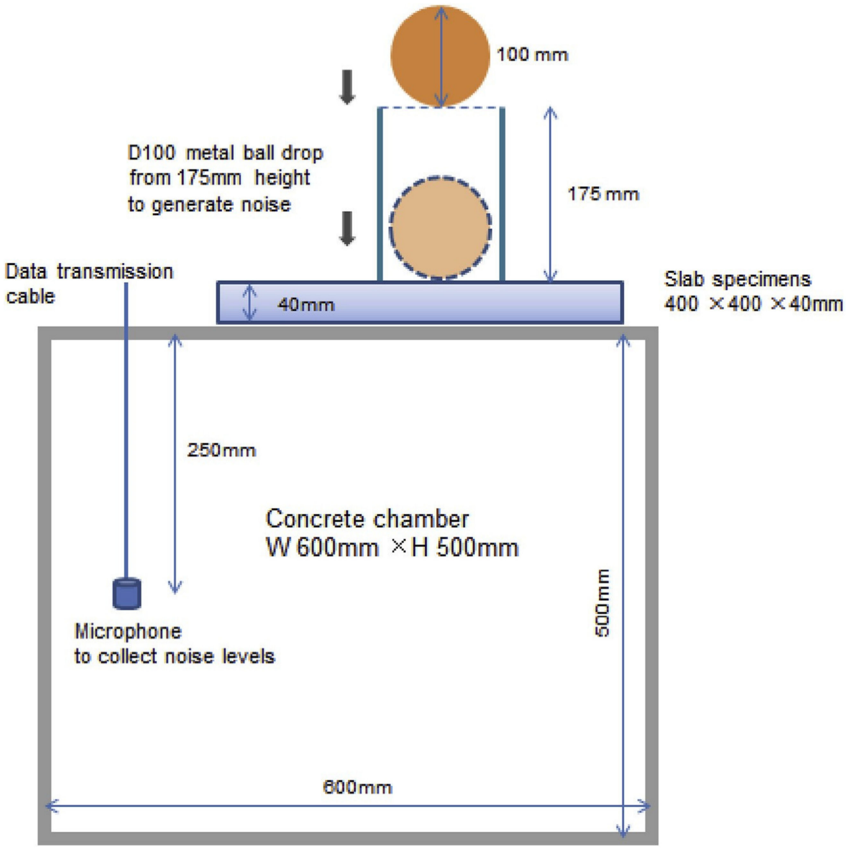

Figure 3. Schematic of sound insulation test setup [87]. Reprinted with permission from Elsevier [87].

3.5. Resistance of Acoustic Insulation

Porous concrete can absorb sound but has low sound insulation. Thus, plastering or painting porous concrete could help in reducing sound absorption and upsurges its sound insulation features [20]. The sound absorption coefficient for normal concrete is almost 0.02, signifying that around 98% of the sound dynamism is a surface reflection. The denser/heavier the concrete, the higher the sound insulation rate can be detected [8]. Current research findings illustrate that porous concrete has more excellent acoustic insulation than ordinary concrete due to its cell-microstructure build-up [88,89]. However, the volumes of reflected frequency and the degree of sound insulation resistance essentially rely on the real stiffness of concrete mass. Concerning the concept of the resistance of solid wall sound, it was articulated that the sound reflection frequency theoretically relies on the thickness and wall rigidly and its surface density [90]. Therefore, the porous concrete wall can be reported to reflect the sound lower than the rigid concrete wall, which can reflect it [91]. The sound frequency diffused by the cellular wall of concrete is 3 percent higher than the ordinary concrete wall. In contrast with cellular concrete, dense concrete has 10 times lower fascinating sound levels [92,93]. The existence of air bubbles, scale, distribution, and degree of pores and their consistency may affect the sound insulation of cellular concrete [92–94]. Figure 4 shows a clear model for the construction of RC walls with extremely high acoustic insulation.

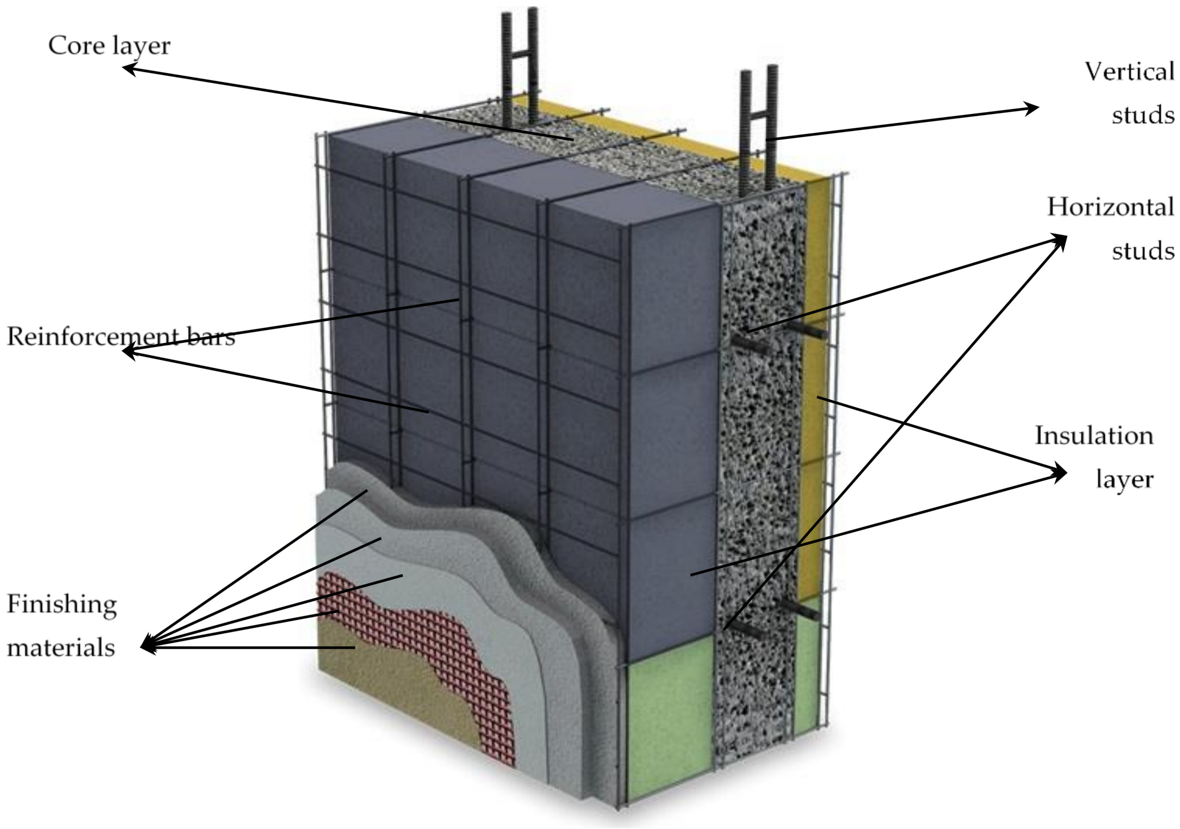

Figure 4. Model for the construction of RC walls with extremely high acoustic insulation [94]. Reprinted with permission from Ecosism [94].

4. Sound Absorption Properties of Construction Materials

Suspended absorbers are much more effective than those mounted directly on the walls. In the case of absorbers fixed to the enclosing surfaces, only sound absorption improves, but the sound level is not reduced [55]. Porous scavengers only act effectively when they have open pores. Materials with a closed porous structure, such as expanded polystyrene, are not suitable for sound absorbers [95,96]. The size, quantity, and distribution (uniform or non-uniform) properties of the pores, as well as the cross-section and connection between the pores, are decisive for the sound absorption coefficient [14] (Figure 5). The sound insulation of a structure with one rigid layer relies on the material's density and bending stiffness, the frequency of the sound, and weaknesses (for example, opens seams) [55]. Flexural rigidity depends on the type of material (for example, concrete is more rigid to bending than wood) and layer thickness. The dispersion of the energy of acoustic oscillations in porous materials with the release of heat (sound absorption of materials) has several reasons [39]. First, because of the air viscosity, which is mostly contained in the pores quite, the oscillation of air particles in the internal volume of the absorber is accompanied by friction. Secondly, there is air friction against the pore walls, which also have a significant total surface area. Therefore, at medium and high frequencies, particularly effective sound absorption occurs. At low frequencies, it is harder to achieve. Furthermore, the characteristics of some materials are given in Table 5.

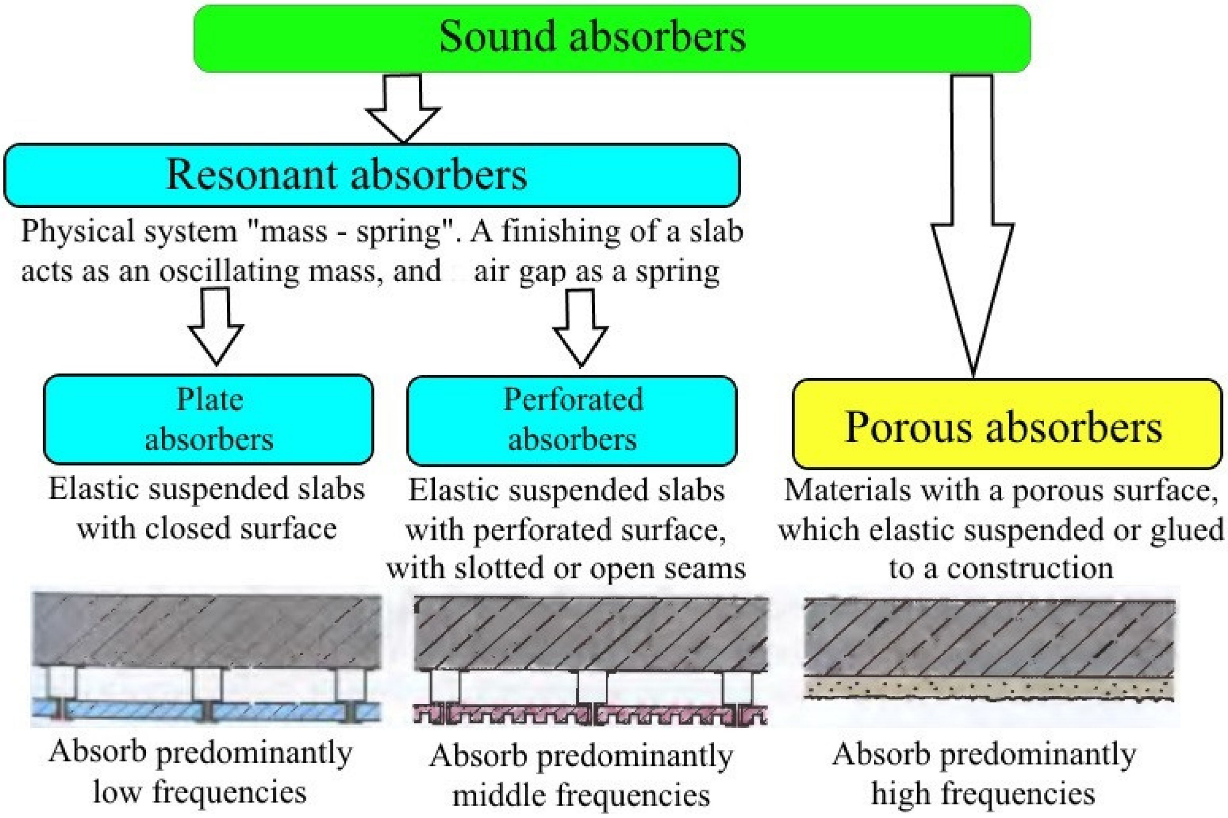

Figure 5. Basic sound absorbers.

Table 5. Coefficient for sound absorption of certain building materials.

Material or Structure	Sound Absorption Coefficient at Sound Frequency 1/3 Freq. Band, Hz						Refs
	125	250	500	1000	2000	4000	
Unpainted brick wall	0.031	0.032	0.041	0.054	0.063	0.061	[3,13,57,64,67,97]
Painted brick wall	0.012	0.011	0.024	0.019	0.020	0.023	
Plastered brick wall	0.019	0.021	0.020	0.030	0.042	0.041	
Unpainted concrete	0.010	0.009	0.021	0.024	0.043	0.042	
Painted concrete	0.012	0.014	0.011	0.011	0.020	0.020	
Marble	0.011	0.011	0.012	0.012	0.022	0.023	
Granite	0.010	0.013	0.015	0.012	0.020	0.021	
Chipboard close to the wall	0.010	0.091	0.089	0.087	0.092	0.143	
Chipboard from the wall by 50 mm	0.322	0.131	0.054	0.054	0.067	0.133	
Duralumin panels from the wall by 50 mm	0.12	0.37	0.12	0.08	-	-	
Linoleum	0.02	0.02	0.03	0.03	0.04	0.04	
5 mm rubber on the floor	0.04	0.04	0.08	0.08	0.08	0.1	
Styrofoam 100 kg/m^2	0.02	0.02	0.03	0.04	0.22	0.24	
Acoustic foam rubber 70 mm	0.15	0.30	0.65	0.80	0.70	0.60	

5. Sound-Absorbing Concrete

5.1. Sound-Absorbing Concrete Structure

The use of porous media is one of the effective solutions to noise reduction issues, and several studies have already been performed to clarify the noise control mechanism in porous media. Porous media's main sound absorbing mechanism is that sound wave energy can switch its form to thermal energy through internal pores friction [40]. Therefore, the following considerations for the proper design of sound-absorbing materials must be monitored adequately: voidness coefficient, pore size, porosity opening size, and pore layer thickness [98]. Maa [55] proposed a model of sound-absorbing concrete in the form of a multi-layer perforated panel, where air cavities are supposed to be consistent in shape with the same diameter (Figure 6). The model was refined by Kim et al. [2,40,53], it is supposed in particular, as can be observed in Figure 6, that the concrete aggregates are of the same size and distributed evenly in a computer model.

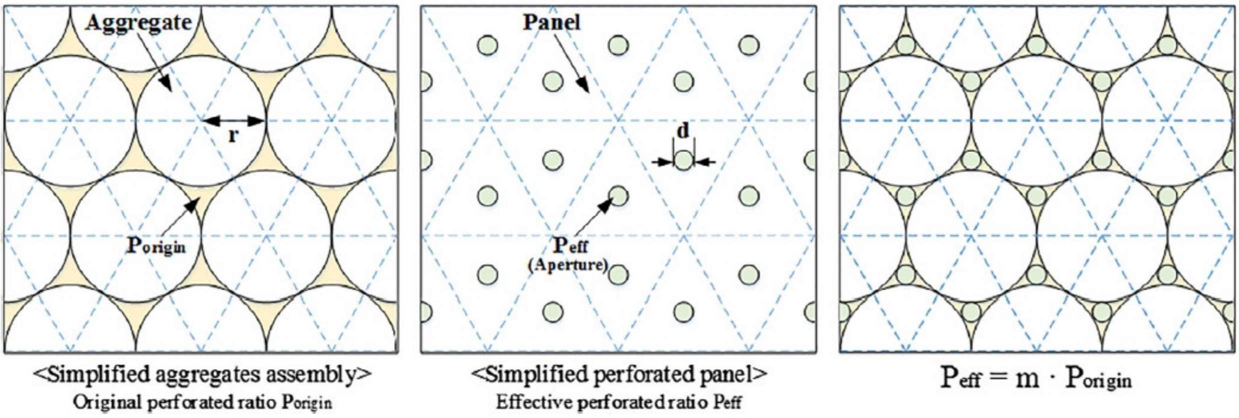

Figure 6. Model of sound-absorbing concrete in the form of a multi-layer perforated panel [40]. Reprinted with permission from Elsevier [40].

The theoretical model of Maa [56] shows clearly that the coefficient of acoustic absorbance relies on several parameters, including the radius and aggregate size, panel thickness, and the void ratio according to different foam agents. Kim et al. [40,53] has shown the efficiency of aluminum powder and cellulose fibers in achieving higher porosity and sound absorption capacity, respectively. In a comparison between the Maa model and experiments, the model revealed that the acoustic characteristics of the developing concrete could be predicted fairly accurately. Certain crucial recommendations for developing the proportions of a mixture of sound-absorbing high-strength concrete are given in [53,97,99,100]. For example, Kim et al. [53] and Gerharz [99] recommended that the aggregate for porous concrete should be 4 to 8 mm. The water to cement ratio should be less than 0.30 and have an efficient sound absorption capacity with no significant compression strength loss. Neithalath et al. [97] found that cellulose fibers in cement composites are sound absorbent to form an increased number of fibers connecting the porous channels in the matrix. Calcined zeolite has reported a better acoustic absorption than glass wool due to its macropores and large specific areas [100]. A broad range of alternate concretes has been studied for their acoustic features. Including porous [101] and gas-concrete [91], concrete, and concrete containing crumb rubber [8] and plant materials [102], including hemp [103]. All of those materials benefit from a porous structure that absorbs sound into the material's pores, which discharges the sound wave by heat conversion [104,105].

5.2. Coefficient of Sound Absorption of Various Concrete Admixtures

The sound absorption coefficient is commonly found by the two-microphone impedance tube for the transmission function technique. In contrast, the unpremeditated center-point loading process is applied to measure the concrete specimens' modulus of elasticity [2,106]. Reportedly, several studies were concentrated on an exploratory assessment of the acoustic absorption of cellular concrete using experimental tests and an assessment of the noise decreasing of sound-absorbing cellular concrete elements via field investigation tests [57]. However, it was revealed that the sound-absorbing of RC elements is highly dependent on the thickness of the members that showed a good impact on the performance of its noise absorption, in particular, for squat frequencies, thus exhibiting that the thinner sound-absorbing element has lower sound absorption influences at low frequencies detection [107].

Another study was conducted by [108] to characterize the sound-absorbing performances of a set of porous concrete panels varying in concrete mix design (A–D), thickness, and mounting method. The measurements have been conducted in the 1:5 scale reverberation room of the Politecnico di Torino in accordance with the ISO 354-1:2003 standard. The study concluded that the mix design with the smallest round lightweight aggregate dimensions (0.5–1 mm) gave the most effective sound absorption coefficient.

5.2.1. Cellular Concrete

It is investigated the distribution of low-frequency intense percussion sounds under 100 Hz in apartments [56,107,109]. The results obtained proved the inability of the light partitions to suppress the vibration of the floors. To stop the sound wave as much as possible (both airborne and impact), mass is needed; that is, high-density materials, such as bricks, are best suited for internal partitions, for example, lightweight concrete is inferior to, for example, brick in soundproofing airborne noise [50]. However, it is worth noting that structural noise of low frequency (in the absence of vibration of the structure) cellular concrete holds better than brick. The cellular concrete wall has sound-absorbing and sound-proofing properties. That is, the material does not miss or produce extraneous noise. Walls made of foam concrete (aerated concrete) reduce noise transmission and absorb low-frequency sounds well. Pores filled with air (gas) are reliable protection against the penetration of extraneous noise.

Luna-Galliano et al. [110] investigated the curves of the sound absorption coefficient of geopolymers with silica fume as a pore-forming agent. With different proportions of the original components, the curves of sound absorption coefficient were similar, including those with two peaks at 400 and 2500 Hz. It is noted that the more micro-silica in the mixture, the higher the width of the curve (which indicates the stability of the sound absorption coefficient), which can correlate with the highest open porosity. The sound absorption coefficient of geopolymer foam concrete activated by hydroxide was slightly higher than when activated by silicate. Both geopolymers' foamed concrete had the same open porosity (slightly higher open porosity was observed in hydroxy-activated geopolymer), which may explain the similarity of their sound absorption coefficients [110]. A geopolymer cured at 70 °C observed the highest sound absorption coefficient values, as the material had maximum open porosity. NRC ranged from 0.08 to 0.23 for all geopolymers and increased with the increasing porosity. Arenas et al. [22] investigated road noise barriers from geopolymer porous concrete based on fly ash with concrete scrap as aggregates. Construction and demolition waste in geopolymeric porous concrete has been shown to have better mechanical and acoustic properties than granite rubbles in geopolymeric concrete. An activating solution (in particular, sodium silicate or sodium hydroxide) has a substantial influence mainly on the mechanical properties but not on the acoustic properties.

Mastali et al. [43] investigated the mechanical and acoustic properties of fiber-reinforced alkali-activated slag foam concrete incorporating light structural aggregates. At a density of 1500 kg/m^3 [111], the compressive stress was 12 MPa, and the sound absorption coefficient was 0.99. The study's goal [112] was to create a sound-absorbent material of porous sound using blasting furnace slag and fly ash as a binder component and coal powder and sodium silicate as a pore-forming agent and an alkaline activator, respectively. In this case, in a furnace at a temperature of above 1000 °C, the samples have been fired. Samples prepared by this method had an NRC and compressive strength of 0.5 and 6.50 MPa, respectively. Table 6 shows a summary of the sound absorption coefficient of different concrete admixtures.

Table 6. Sound absorption coefficient of difference concretes.

Mix ID	The Percentage of Major Components	Density Kg/m^3	Compressive Strength (MPa)	α_{max}	NRC	Refs.
1	FA-60-84,5, slag—0-24,5, NaOH 12 M—15.5	585–1370	12–23	0.7–1.0 at 50–140	0.5	[43]
2	FA-65, SF-20, KOH (NaOH)-15	1750–1900	15	0.9	0.23	[33,110]
3	FA-20, concrete scrap—55, Na_2SiO_3—25	1550	6.3	0.98	0.3	[52]
4	blast furnace slag -56, Na_2SiO_3—44. Foam content—35% and fiber—3%	1500	12	0.99	0.3	[57]
5	Fly ash—50, coal powder—30, blast furnace slag—15, Na_2SiO_3—5	1490	5.11	0.68	0.25	[112]
6	FA-73, Na_2SiO_3 solution—16, 8M NaOH—8, glass fiber—3	1130	5	0.85	0.23	[87]
7	OPC-60, cenosphere—40	1500	N/A	0.33	0.15	[113]
8	OPC—20, aggregate sort 0–4mm—50 aggregate sort 4–8mm—30	2273	36.1	0.279	0.21	[20]
9	ID 8 with replacement 50$_{vol}$% aggregate to PET	2047	23.21	0.496	0.28	[1]
10	ID 8 with replacement 50$_{vol}$% aggregate to corn granules	1775	10.21	0.450	0.24	
11	ID 8 with replacement 50$_{vol}$% aggregate to wool granules	1930	16.0	0.456	0.28	
12	ID 8 with replacement 50$_{vol}$% aggregate to polystyrene granules	1810	13.91	0.447	0.23	
13	ID 8 with replacement 50$_{vol}$% aggregate to sunflower stalk shredded	1850	13.50	0.481	0.27	
14	OPC-20, coarse aggregate—50, fine aggregate—23, rubber crumb—7	2350	57	0.37	0.15	[8]
15	OPC—17, rubber crumb 2, fine aggregate—36, coarse aggregate—45	2100	36	0.93	0.2	[114]
16	OPC-20; rubber crumb—30; sand—50	1668	4.6	0.1	0.245	[19]
17	OPC-20, fine bottom ash-80	1248	5.3	0.95	0.2	[33]
18	OPC-20, coarse bottom ash-80	862	2.2	0.95	0.2	
19	OPC-70-80, ground granulated blast furnace slag—16-20, miscantus—4-12	1260–1559	40	0.63	0.45	[66]
20	OPC-66, hemp-33	340–415	N/A	0.99	0.5	[115]
21	OPC -30, silica filler 15, foam agent-1, coarse aggregate—35, fine aggregate—19	N/A	15.2	0.95	0.49	[2]
22	OPC -30, silica filler-15, aluminum powder-1, coarse aggregate—56	N/A	15.5	0.90	0.46	
23	OPC-550, furnace bottom ash—637, Lightweight aggregate—323	1720	N/A	N/A	N/A	[57]
24	Round light aggregates (0.5–1 mm) Pervious concrete density = 682 kg/m^3	N/A	N/A	N/A	0.55	[108]

With increasing fly ash and firing temperature, the compressive strength increased. With an increasing fly ash ratio and reduced blowing agent, the noise reduction coefficient decreases, and it first increases and then decreases with increasing temperature and sintering time. The optimal preparation environments for the porous sound-absorbing material were the share of fly ash 50% (wt.%), coal powder 30% (wt.%), 1130 °C sintering temperature, and 6-h sintering time. The mechanical, thermal, and acoustic properties of alkali-activated cellular concrete were studied in several studies [19,87,116–118]. A honeycomb made from class C fly ash mixed with preformed foam is described in this article. The resulting mix was cast from 1000 to 1400 kg/m^3 at three densities, and all tests were performed at ambient temperature under drying conditions, resulting in a 940–1310 kg/m^3 density. The compressive capacity ranged between 3.0 and 9.0 MPa, whereas the corresponding elastic modulus varied between 850.0 and 1700.0 MPa. Cellular concrete shows an optimal NRC at about 1130 kg/m^3, reducing NRC with a higher or lower density. The NRC of this cellular concrete is significantly higher than that of heavy concrete, 0.03 [42,113], and comparable (and sometimes superior) acoustic gypsum tiles, 0.20 [19]. This higher NRC will reduce the echoes in rooms built using cellular concrete to a level comparable to traditional building materials.

This is consistent with the results of Tiwari et al. [42,113], who checked the acoustic absorption of cement concrete with cenospheres. The NRC of the resulting paste increases with an increase in the content of the cenosphere up to 40% by volume (it becomes twice as much as without the cenospheres). After that, however, the NRC began to fall with a higher cenosphere content. Five different types of concrete were developed in Romania [1] using polystyrene granules, polyethylene terephthalate granules, corn cobs, crushed sunflower stalks, and sheep wool balls. Each of these concretes' sound absorption coefficients were higher than that of ordinary concrete. The results showed that these materials are an ecological solution for waste disposal and protection against noise in cities. Article [33] is devoted to the development of a prototype noise barrier on the highway, mainly consisting of the ash residue from the traditional combustion of pulverized coal on a semi-industrial scale, following a simple and inexpensive manufacturing procedure similar to that used for commercial concrete noise barriers (Table 7). To obtain good sound absorption coefficient, a multilayer product was developed with a porous layer on the surface of the incident noise, and then with the thinnest material in the back layer. The recycled multi-layered product was characterized according to the current European standard for devices that reduce road traffic noise. The results conformed to the specifications specified in the rules.

Table 7. Types of noise barriers.

Types	Descriptions	Refs.
Absorptive type	Sound absorbent materials and potential finishes of absorptive panels	[33]
Earth landscape	Retaining structures and nature landscaped mound	[119]
Reflective type	Nontransparent and transparent	[120]
Mixed type	A combination of all types	

The acoustic characteristics of crumb rubber concrete panels have been tested [8]. In this article, the acoustic properties of rubber-reinforced concrete panels for low frequencies (63, 125, 250, and 500 Hz) and high frequencies (1000, 2000, 4000, and 5000 Hz) are considered, as far as sound absorption and isolation are concerned. Acoustic tests were carried out with different fine aggregate replacement levels with crumb rubber (7.5% and 15%) with four different classes of frost resistance. The results showed that rubber concrete had proven itself in terms of sound absorption, especially with higher proportions (15%) of crumb rubber. It is reported that the effects of freezing or heating on the insulating properties have been shown to have no significant effect [8]. It was found that the insulation performance of all concretes is improved at high frequencies. The findings show that rubber concrete can absorb sound across high-rise city structures through external cladding, but this requires a full-scale study. This strategy gives the remaining issue of used tires an environmentally friendly alternative.

Sound absorption materials generated in a concrete matrix with the embedding of crumb rubber were also examined [114]. The sound absorption coefficient (α) was greater than 0.50 for 9 of 12 samples and achieved maximum values of 0.820 and 0.930 under satisfactory environments. The study in [51] aimed to develop an efficient pretreatment method of the surface of secondary rubber particles to enhance the sound insulation properties of a lightweight rubberized aggregate made of concrete. A lightweight concrete mix was prepared in this research by the lightweight clay expansion as a coarse aggregate and furnace bottom ash (FBA) as a fine aggregate [120]. Results showed that the overall noise reduction was 32.50 dB in the replacement of the entire FBA with recycled rubber aggregates, which a reduction substantially above 15.50 dB was already achieved by a control concrete mix made without rubber [19,121–123]. The surface of recycled rubber aggregates has been adjusted with a simple procedure for the pretreatment of cement slurry. A further noise reduction was reached by 10.90 dB and 14.80 dB when FBA was substituted by 50% and 75% of rubber pre-treated aggregates, respectively. The dynamic elastic modulus of concrete mixes has also been checked, and the surface adhesion of pretreated/untreated rubber aggregates has also been studied [8].

The results demonstrated that the pre-treatment method resulted in a lower adhesion of rubber additives to cement paste, thereby improving the capacity to vibrate absorption and improving the sound insulation properties of concrete. The purpose of the study [19] is to examine key factors affecting the acoustic properties of lightweight concrete with several amounts of recycled rubber aggregates. For this, the absorption and insulation of sound were checked at different frequencies on rubber concrete. Concrete specimens were meant to replace the 0 to 100% coarse aggregate with two recycled tires rubber aggregates, up to 60% of the overall concrete volume [124–128]. Furthermore, concrete panels were cast with various surface finishes (rough and smooth surface) to evaluate the influence of the external texture and the direct contact of rubber [129]. Crumb rubber and fibers partially covered with crumb rubber were examined for acoustic barriers. Fibre consists of steel and plastic fibers mixed with fine recycled rubber particles and collected through granulation until full rubber separation was investigated [19]. The study's findings show that the combination of rubber-coated steel and textile fibers increases sound absorption in contrast to ordinary or rubber-coated concrete. The application of crumb rubber or fibre decreases concrete density and improves transparent porosity. However, concrete with fiber shows an even greater volume of open pores than concrete with crumb rubber admixtures, thereby increasing the sound absorption [19]. In addition, even with lighter concrete, such as the concrete coating increases with crumb rubber and fibre, the results obtained for sound insulating at high frequencies are further enhanced [130]. As a result, high replacement of aggregate (80–100%) can be carried out in concrete for non-bearing structures to increase sound absorption [127,131–133]. Furthermore, Table 8 shows the acoustic absorption property of the different concrete types, as several researchers have reported.

5.2.2. Lightweight Aggregate Concrete

In [134], good acoustic characteristics of wooden and wood concrete floors, evaluated during the experimental campaign, were obtained. In composite mortars, two types of concrete were accepted: normal and light composition, the last of which included filled cork aggregates. In general, natural fibers as a lightweight aggregate for building materials are rapidly developing and are widely used today, for example, hemp, straw, flax, and Miscanthus. Acoustic characteristics and microstructural analysis of lightweight bio-based concrete containing the perennial plant Miscanthus are given in [66]. When adding Miscanthus fibers with a 2–4 mm length, the sound absorption coefficient increases significantly with increasing Miscanthus content from 0.28 to 0.63. Extensive studies of the Gle, Gourdan, and Arnaud groups characterize the acoustic advantages due to the porous nature of cannabis composites as a result of experimental [103] and model [135] studies. Table 8 shows acoustic absorption property of the different types of concretes.

Table 8. Acoustic absorption property of the different types of concretes.

Type of Concretes	Maximum of the Sound Absorption Coefficient	Sound Transmission Loss (STL), Hz	Level of Sound Reflection	Refs.
Normal concrete	0.05–0.10	3000–5500	High	
Aerated concrete	0.15–0.75	250–2500	Low	
Foamed concrete	0.13–0.50	100–2000	Low	
Crumb rubber concrete	0.30–0.70	400–2500	Medium	
Polyurethane concrete	0.08–1.0	150–1400	Low	[1,8,9,15,19,20,33,38,51,52,64,66,70,136]
Coal bottom ash concrete	0.05–0.31	500–3500	Medium	
Coconut fibers concrete	0.42–0.80	1250–3200	Medium	
Recycled aggregate concrete	0.01–1.0	1500–2000	Medium	
Oyster shell waste aggregate	0.43–0.53	1000–1800	Low	
Polymer concrete	0.90–1.0	64–1600	Low	
Glass based concrete	0.20–0.37	250–3150	High	

Initially, Cezero [39] investigated the effect of the binder to Shiv ratio and found that the sound absorption was significantly lower with an increase in the binder amount. The acoustic parameters for the development of hemp concrete, with hydraulic and cementing binders, were investigated, including density particle size distribution, the form of binding system, and water content [103,137]. In a low-frequency range of up to 500 Hz, hemp concrete exhibits a 0.20–0.50 sound absorption coefficient based on the binder type. The fast cement binder has a substantially lower acoustic absorptive capacity than the hydraulic lime binder [103]. Both loose hemp shiv and hemp concrete contain pores of several scales, various descriptions of which are included in the developed models [103,135]. The effect of water content on hemp concretes' acoustic and thermal properties were investigated by Gourlay et al. [115]. Hemp concrete is characterized by a highly porous microstructure and has an open porosity ranging from 60 to 90%, depending on the mixture [105,115]. In [20], the acoustic properties of hemp-lime concrete using hydrated lime and pozzolan binders and hydraulic and cement binders are investigated. The wall sections are visualized to assess the acoustic absorption of hemp-lime concrete walls in real construction and the effect on absorption is evaluated.

Hemp concrete with lime-pozzolanic binders has excellent acoustic properties compared with many hydraulic binders [20]. They decrease when imaging since it affects the porosity of the open surface. Still, the hemp-lime construction can potentially meet the standard and regulatory objectives for rooms requiring acoustic treatment. Obtaining porous concrete with open porosity is possible using only one fraction of aggregate—from 2 to 6 mm from light porous materials: pumice, Shpak, expanded clay, perlite, and a limited amount of binder, in which the cement dough covers only the grains of aggregates, leaving free voids between them [138]. Obtaining open porosity in concrete is achieved using single-fractional sands of a size of 3 to 5 mm. Porous concrete with 15–25% interconnected porosity has good sound absorption characteristics. Constructions with a target void ratio of 25% for porous concrete and 50% of the target void coefficient for porous concrete with recycled aggregates are sufficient for good sound absorption [101]. It was reported that in concrete, the larger the pore opening coefficient, the greater the sound absorption coefficient [53]. The holes formed in concrete slabs and other porous materials are used to improve sound absorption [139]. In addition, other authors argue that crumb rubber as filler increases the porosity of concrete in the same proportion as solid rubber [140]. The absorption coefficient of concrete can be up to 0.7–1.0 in concretes for frequencies of 40–150 Hz and up to 0.2 for frequencies of 1 kHz due to foaming additives. Still, the physicomechanical characteristics limit its possible use in building construction [43]. Biochar from residual biomass as a concrete filler to improve thermal and acoustic properties was studied [141]. The addition of biochar also significantly increased the sound absorption coefficient of concrete in the 200–2000 Hz range since it created pore networks inside the concrete. The data on the acoustic behavior of coconut fiber concrete are given in [141]. Coconut fiber was added in the amounts of 0.25%, 0.5%, 0.75%, and 1% cement. An acoustic test was performed to determine the amount of sound that the fiber can absorb. The data showed that the concrete reinforced with coconut fiber has a high absorption capacity, because of the way the fibers are processed, absorbed more than other fibers. This is due to the fact that washing the fibers increases the content of lignin responsible for the absorbing property of absorption. The data also show that the curing time does not affect the absorbing properties of fiber-reinforced concrete.

The study in [142] studied the sound insulation properties of a facade system consisting of two layers of lightweight concrete. The inner of which is a structural element, and the outer one is heat-insulating. Compared with other bearing walls of similar thickness, made using traditional technologies, two-layer facades exhibit sound insulation and heat transfer characteristics, which can be considered a good compromise between acoustic and thermal insulation properties. The study of the effect of various types of interlayers on the floor as sound insulation from impact noise in box-shaped reinforced concrete (RC) structures is given in [143]. It is revealed that damping materials provide a higher loss coefficient and a dynamic modulus of elasticity than elastic insulators. Another typical example of low-frequency noise occurs when a train moves across a bridge; in this case, both the wheels and the rails will emit rolling noise directly from behind the wheel/rail. In addition, the components of the bridge will also create noise excited by the vibrating energy that is transmitted to them. The excited steel components of the bridge will generate a higher level of vibration and, therefore, emit more noise [4]. It is established that the dominant frequency of steel-concrete composite bridge noise is 20 to 1000 Hz. The noise from the bottom flange of the steel longitudinal truss is less than that of other components in all frequency bands, while the noise from the steel longitudinal truss network is dominant in the high-frequency range above 315 Hz. Noise from the concrete deck prevails in the low-frequency range from 80 Hz to 160 Hz. Even lower frequencies (infrasound) are observed near wind power stations. In particular, in [144] it was revealed that the audible noise recorded near turbines with lattice towers was about 10 dB lower than the noise near wind turbines with tubular towers. At a distance of 250 m from the lattice tower, the turbine noise is indistinguishable from the acoustic background. In [3], the sound pressure caused by acoustic noise and vibration environment was studied in premises with open windows or ventilation ducts. The important role of the Helmholtz resonance (Figure 7) in increasing the sound pressure, which can adversely affect people, was demonstrated. According to calculations, its frequency is usually below 10 Hz for residential premises; therefore, Helmholtz resonances are infrasonic, unlike standing wave resonances, which usually occur at a frequency of more than 30 Hz.

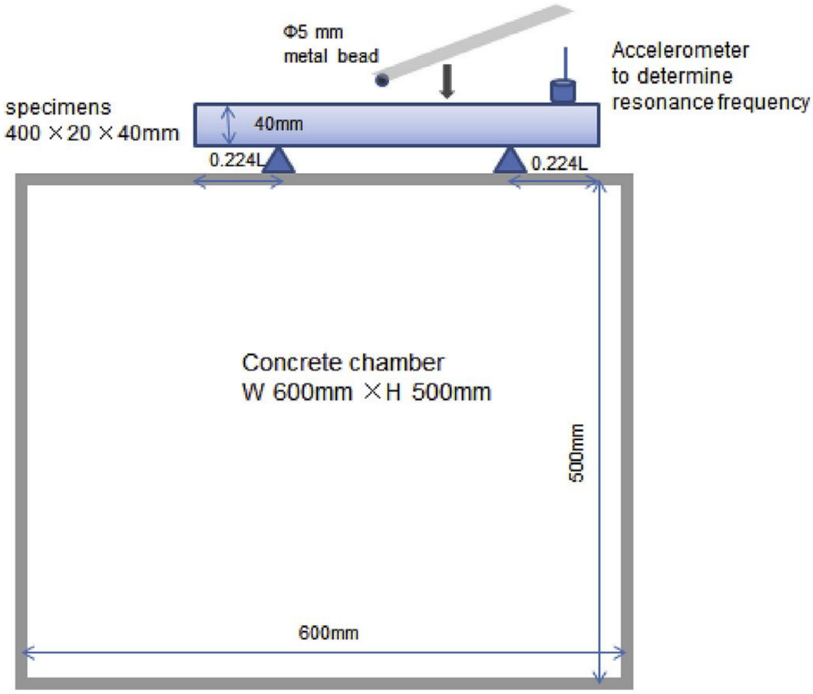

Figure 7. Typical schematic test set-up of resonance frequency [87]. Reprinted with permission from Elsevier [87].

5.3. Strength Characteristics

The compressive strength of cellular concrete is closely related to its density. In particular, the compressive strength and density of conventional foam concrete range from 1 to 10 MPa and from 360 to 1400 kg/m^3, respectively [43]. Still, the strength indicators are improved by adding fly ash to the density range of 650–1224 kg/m^3 with a compressive strength of 2 to 18 MPa [145]. High-strength cement-based foam concrete, which included micro-silica, fly ash, and slag, had a strength of 23.7 MPa at a density of 710 kg/m^3 [146]. For comparison, geopolymer foam concrete has higher strength at the same density [43]. In the range of densities exceeding 1000 kg/m^3, geopolymer foam concrete can be used for semi-structural and structural purposes. As already noted above, the concentration of alkaline activator has practically no effect on the acoustic characteristics of geobeton. However, it affects the strength: a higher Na_2O/SiO_2 ratio increases the rate of dissolution of fly ash, and the formation of a geopolymer structure is improved [52,110,137]. Since the porous structure, by improving the acoustic characteristics of concrete, at the same time reduces the strength properties, it is necessary to strengthen the cement matrix additionally. Mastali et al. [136], due to the introduction of fibers in alkaline-activated slag foam concrete, achieved a compressive strength of 12 MPa with a sound absorption coefficient that reaches up to 0.99 at some frequencies. If you do not increase the porosity and introduce damping additives (for example, crumb rubber), then, without loss of strength, sound-absorbing characteristics will improve, especially at low frequencies [8,19,114]. However, the limit of partial replacement of aggregate for rubber crumb is about 7 to 8%. In the case of replacing rubber crumb by 20%, the compressive strength decreases by about 78% [147].

6. Acoustic Assessment of Effect Sound Conveyance

The initial comprehensive study stated by Bodlund in Europe was in the year 1985 [31]. It has been focused on assessing the sound environments in the residential buildings of Sweden, particularly for the influence of sound insulation. That research suggested a simple technique set for additional investigations in construction acoustics through subjective and objective evaluation of sound. An extensive specimen of around 350 residences of Sweden was targeted, and an acoustic assessment of effect sound conveyance was taken into consideration in several units of residential complexes. The tenants were interrogated to obtain their assessments on the acoustic performance of their units via a satisfying scale limited between 1 (highly unfair) to 7 (highly fair). Approximately 464 totals were composed of 398 entrants. The buildings considered had 22 concrete floors and wood joists in a specimen of connected units and high-rise condominiums. The whole dataset was analyzed and averaged compared to the real urban construction units, consisting of similar structures.

Meanwhile, there was a minimum of 6 dissimilar floor assessments and about 20 discussions per unit. Nevertheless, the regular influence sound index, I_i, of the unit's assessment was verified by comparing with the regular rating result of the unit's residents by means of statistical analysis [148,149]. The classic standard deviation (SD) was described at 3.7 dB for the average influence sound index inside a unit. The investigation revealed that the average result of 4.4 of testified fulfillment parallels 51% of the residence occupants who respect their unit acoustic environments as decent or quite decent [148,149]. Therefore, a more inadequate response is reflected as unacceptable for construction standards in the assessment. The statistical analysis of the collected data attained a prototype of mean $I_i = 86.\ 3 - 5.4$ S, where S indicates the subjective average result with r = 73%; this provides an assessment coefficient of around $R^2 = 0.53$. This result was compared with the other weighted indices, L'n,w and A-weighted stages L'n,A, that are currently applied [25]. Dissimilar records were also requested for correlations of r of 72% and 75%, for R2 = 0.52 and 0.56, respectively [26]. The review study found a thoughtful annoyance problem that was designated as extreme and influences acoustic relaxation in houses. Furthermore, several problems were occurred related to the influence of noise types from the fellow citizen, including a high level of lowest-frequency content. In particular, walking noise was also revealed as the utmost troubling cause of noise (Table 9).

Likewise, the shortage of quite the lowest-frequency content in the influence of sound assessment reduces statistical connotation with the subjective answer of tenants. Consequently, the majority of the investigations propose that assessments should comprise lengthy frequencies (small to 20 Hz) in place of 100 Hz, presenting the lowest boundary in the principles of ISO standards. The highest issues with effect noise and associated lowest-frequency conveyance were also exhibited in lightweight structures. In contrast, concrete constructions have superior, in general, insulation in contradiction of noise conveyance, whether impact or airborne.

Table 9. A summary review for dozens of previous theoretical and experimental studies.

Details of Experiment and Specimen	Variables of the Study	Results of Models	Parameters of Assessment	Results Summary	Refs.
251 participants to study 10 Swedish high-rise condominiums for field assessment 8 lightweight buildings 2 heavyweight structures Findings in acoustic assessment and personal responses were an average of as per trial construction	Independently: $C_{50\text{-}3150} + R'_w$: measured regularized airborne mitigation $L'_{nT,w}$: assessed standardized effect sound Independently: Q1: average nuisance headed forairborne noises from neighbors Q2: average nuisance headed for effect noises from neighbors higher in an 11-set measure	Linear regression: R'_w to Q1 $C_{50\text{-}3150} + L'_{nT,w}$ $L'_{nT,w}$ $C_{I,AkuLite,20\text{-}2500} + L'_{nT,w}$ R'_w $+ C_{50\text{-}3150}$: to Q1	Coefficient: $R^2 = 0.73$, $r = 85\%$ $R^2 = 0.58$, r = 76% $R^2 = 0.32$,$r = 57\%$ $R^2 = 0.26$, $r = 51\%$ $R^2 = 0.85$, $r = 92\%$	Small-frequency spectrum small to 20 Hz is basic for effect sound assessment and relationship to nuisance. nuisance anticipated well with interpreter $C_{50\text{-}3150} + R'_w$, not significant with $L'_{n,w}$, but adequately with recommended interpreter: $C_{I,AkuLite,20\ 2500} + L'_{nT,w}$	[27,28,150,151]
Assemble findings from construction surveys	P: low assessment G: medium assessment F: fair assessment by the tenants	Contact–influence curves and samples not specified. Recommended association: P + G + F = 100%	-	Quantity–response curvatures have a medium gradient of 4% in entire investigated cases	[152]
398 respondents (350 units) in Sweden, 22 concrete, floors, or wood joist were assessed. Findings in acoustic assessment and individual responses were an average of per house unit in the study	Independently: I_j: old-prototype effect sound index L'_{nA}, $L'_{nT,w}$: assessed and A measured regularized effect sound pressure scale. Independently: S: average gratification reply of residents in a condominium unit from 1 (very unreasonable) to 7 (very reasonable)	Statistical analysis: Recommended: $I_S = 86.3–5.53S$ $\underline{I} = 86.3–5.48S$ $L'_{nA} = 85.2–5.09S$ $L'_{nT,w} = 80.6–5.48S$ $S = 4.4$ matches 51% of the householder's sample	Coefficient: $R^2 = 0.52$,$r = 72\%$ $R^2 = 0.53$, $r = 73\%$ $R^2 = 0.76$, r = 87% $R^2 = 0.56$, $r = 75\%$	Significant relationship occurs among effect sound and individual response. Small frequencies from 50 Hz would be measured in the assessment spectrum. Original control curve recommended for ISO code technique adjustment to have good relationship rates.	[31]

Table 9. *Cont.*

Details of Experiment and Specimen	Variables of the Study	Results of Models	Parameters of Assessment	Results Summary	Refs.
600 respondents cross-examined, 300 gathering walls assessed in Canada. Finding in acoustic assessment and individual responses were gathered in 8 clusters in line with STC results.	Independently: STC: assessed airborne sound mitigation index, in the same with R'_w Dependent: Q1: thoughtful neighbors Q2: gratification with house Q3: neighbors' speeches Q4: neighbors' sound eitherside Q5: neighbors' song Q6: neighbors' TV sound Q7: sound isolation gratification Q8: awakening from neighbors' sound	Statistical analysis of STC with: Q1: neighbors' concern Q2: gratification for unit Q3: neighbors' sound in common Q4: neighbors' TV sound Q5: neighbors' singing noises V6: sound isolation rating Q7: sleep wakening Q8: neighbors' song	$p = 0.033$, $R^2 = 0.56$ $p = 0.001$, $R^2 = 0.86$ $p = 0.002$, $R^2 = 0.83$ $p < 0.004$, $R^2 = 0.77$ $p < 0.002$, $R^2 = 0.82$ $p < 0.001$, $R^2 = 0.94$ $p < 0.001$, $R^2 = 0.92$ $p = 0.024$, $R^2 = 0.60$ $p = 0.024$, $R^2 = 0.60$	Recommended result STC = 60 dB should resolve utmost nuisance issues. If STC = 50 dB, formerly nuisance from utmost sound forms reduces considerably; higher than that rate, there is certain significance. Isolation from song noises. If STC = 55 dB, then around 10% of the themes are bothered by a common sound from neighbors.	[21,80]
Assemble findings from construction surveys	Independently: I_j: old effect sound index $L'_{nT,w}$: assessed consistently effect sound pressure scale Independently: S: average gratification response of residents in condominiums unit T: proportion of gratified residents	Statistical analysis: $C_{I,50\text{-}2500} + L'_{nT,w} = I–6.4$ $L'_{nT,w} = 80.6–5.48S$ recommended grouping of formulas: $L'_{nT,w} + C_{I,50\ \text{-}2500} = -0.25–68.3$	Coefficient: $R^2 = 0.92$, $r = 96\%$ $R^2 = 0.56$, $r = 75\%$	Small frequencies less than 100 Hz are significant for exact assessment. Unacceptable self-records if $L'_{n,w}$ 48 dB. Lowest 53 dB recommended for $L'_{nT,w}$,	[148,149]
198 respondents 22 floors of numerous construction forms were assessed, in Sweden; 12 construction information was reserved from Bodlund. Findings in acoustic assessment and individual responses were an average of per house unit in the investigation as in Bodlund	Independently: '$L'_{nw,new,\ i}$: assessed effect sound index joined with recommended novel orientation curves Independently: S: average gratification response of residents in condominiums unit from 1 (very unreasonable) to 7 (very reasonable)	Linear regression: $L'_{nw,new,\ i} = 77.69 = 4.12S$ $L'_{nw,new,\ i} = 76.29 = 4.10S$ $C_{I,50\text{-}2500} + L'_{nT,w} = 74.4–4.71S$ $L'_{nw,new,\ i} = 79.28 = 4.09S$	Coefficient: $R^2 = 0.62$, $r = 79\%$ $R^2 = 0.55$, $r = 74\%$ $R^2 = 0.76$, $r = 87\%$ $R^2 = 0.7$, $r = 85\%$ $R^2 = 0.71$, $r = 84\%$	Significant association between effect noise and individual response. Novel control curvature is recommended for ISO code technique adjustment to attain a significant correlation with particular measures. Low frequencies from 50 Hz essential to be deemed in the assessment spectrum.	[25,26]

Table 9. *Cont.*

Details of Experiment and Specimen	Variables of the Study	Results of Models	Parameters of Assessment	Results Summary	Refs.
159 tenants, 4 heavyweight houses, in Finland, 2 lightweight houses were comprised in a review to associate retorts from numerous buildings	Independently: $C_{50\text{-}3150}$ + L'_{w}, L'_{w} were equivalent for dissimilar building types heavyweight, lightweight Independently: Numerous variables	Whitney–Mann *U*-test	Limits within 95% entire cases	No substantial alterations revealed based on the feedback of tenants from diverse housing construction types.	[22]
800 additional participants to study 13 Swedish high-rise condominiums for site assessment, so 23 in entire, 6 heavyweight, 6 cross-coated wood 11 lightweight buildings. Findings in acoustic assessment and individual answers were an average of per test construction	Independently: $L'_{nT,w}$,: assessed standardized effect sound pressure scale Independently: Q2: average nuisance headed for the effect sounds from neighbors overhead in an 11-set measure	Statistical analysis: $C_{I,50\text{-}2500}$ + $L'_{nT,w}$ $C_{I,50\text{-}2500}$ + $L'_{nT,w}$ $L'_{nT,w}$ $C_{I,AkuLite,20\text{-}2500}$ + $L'_{nT,w}$	Coefficient: R^2 = 0.71, r = 84% R^2 = 0.18, r = 42% R^2 = 0.65, r = 80%	Findings from preceding investigation established, enclosure to less than 20 Hz is vital for effect noise assessment to associate well with self-recorded nuisance. The small-frequency insertion does not influence greatly the findings from heavyweight structures in respect to the lightweight ones.	[27,153]
Through review study by circulation to several numbers of participants to 10 French high-rise isolated constructions	Independently: $L'_{nT,w}$: assesses standardized effect sound pressure scale Dependent: Q2: average nuisance to the effect sounds from neighbors overhead in an 11-set measure	Statistical analysis: C_1 + $L'_{nT,w}$ $C_{I,50\text{-}2500}$ + $L'_{nT,w}$ $L'_{nT,w}$ to V2 $L'_{nT,w}$ L'_{FAmax} to Q2	Coefficient: R^2 = 0.73, r = 85% R^2 = 0.79, r = 89% R^2 = 0.74, r = 86%	$C_{I,50\text{-}2500}$ + $L'_{nT,w}$ associated best to measures Recommendations: L'_{FAmax} = 54 dB (A) $C_{I,50\text{-}2500}$ + $L'_{nT,w}$ = 52 dB and	[29]
600 Norwegian houses Closely 720 participants: 83% as concrete floors structures and 17% in lightweight buildings	Independently: $L'_{nT,w}$,$L'_{n,w}$: assessed regularized and standardized effect sound pressure scale Independently: Q1: nuisance to airborne noises from neighbors Q2: nuisance to effect sounds from neighbors overhead in a 5-set measure	Contact–influence curvatures utilized but reversion models not specified $D'_{nT,w}$ proposals significant relationship with Q1 $C_{I,50\text{-}2500}$ + $L'_{n,w}$ relates quite fine with Q2 $C_{I,50\text{-}2500}$ + $L'_{nT,w}$+ compared to best assurance with Q2	Curvatures within 95% entire cases	Sound is a serious problem for tenants, in particular, small-frequency issues. L'_{nTw} and $L'_{nT,w}$ do not relate with Q2 deprived of modification terms.	[21,80]

7. Conclusions

In the current global development, noise pollution associated with population growth and industrial development is a major problem for people living mainly in cities with stressful environments and many inconveniences. This condition underlines the importance of continued research into new building materials identified as sound-absorbing products, reducing the acoustic power of the sound wave. However, the sound absorption performance of building materials is essential for controlling airborne noise in some building structures. Permeability is also seen as a necessary feature in sound absorption performance, and concrete masonry blocks are regularly used for this purpose. In the meantime, lightweight aggregates seem to help increase the sound absorption of brick blocks. This review study found that each building material has a different NRC and is mainly dependent on its density. However, to avoid a sound wave, any building material requires mass whenever possible; materials with a high density, such as brick, are best suited for partitions, and foam concrete is lightweight and inferior to brick in terms of sound insulation from wave noise. As far as previous research is concerned, noise has been noted as a serious problem and is consistently viewed as an annoyance to humans and indeed manifests itself in natural inconveniences. It is also of interest to engineering tactics that propagate this noise. Previous researchers have rarely taken into account the fundamentals of sound propagation, the preservation of propagation, sound absorption properties, and their parameters. Thus, acoustic performance and soundproofing of structures have gained importance over the past five decades due to the placement of urban apartments and multi-story residential complexes. Because of this dilemma, the proliferation of high-power entertainment systems has placed extraordinary demands on buildings in terms of acoustic performance. However, the construction industry around the world has mainly started using sound-absorbing concrete to reduce the frequency of sounds in open and closed spaces and improve sound insulation

Reportedly, the acoustic properties of concrete are generally related to its density; however, lighter ones, such as aerated concrete, will absorb more sound than high-density concrete. This article provided a broad overview of sound-absorbing acoustic concretes. The measurement methods of the sound insulation performance and sound-absorbing properties of building materials were reviewed. The aim of this literature review is to gain insight into the potential uses of typical sound-absorbing acoustic concrete in today's building industry to improve the productivity, wellness, and health of the residents of cities. Based on this review study, several recommendations for future work have been highlighted:

- Further studies are required to evaluate the acoustic performance of various concrete mixes such as rubber-based crumb concrete, polyurethane concrete, and aerated concrete;
- Evaluate the optimal thickness of various concrete microstructures in terms of their influence on the sound absorption coefficient;
- Search for suitable materials with ideal cenosphere sizes used for asphalt concrete decoration to increase the NRC;
- Further coherent explanation of approaches and results using common acoustical and numerical indicators, adequate presentation of numerical assessment factors, and examination of statistical significance.

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