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# Sound Insulation between Buildings: The Impact Noise Transmission through Different Floor Configurations

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***Abstract*****—**The present paper examines the impact noise transmission through some floor building assemblies. The Acoubat software numerical simulation has been used to simulate the impact noise transmission through different floor configurations used in Algerian construction mode. The results are compared with the available measurements. We have developed two experimental methods, i) field method, and ii) laboratory method using Brüel and Kjær equipments. The results show that the different cases of floor configurations need some improvement to ensure the acoustic comfort in the receiving apartment. The recommended value of the impact sound level in the receiving room should not exceed 58 dB. The important results obtained in this paper can be used as platform to improve the Algerian building acoustic regulation aimed at the construction of the multi-storey residential building.

***Keywords*****—**Impact noise, building acoustic, floor insulation, resilient material.

## I. INTRODUCTION

IN the last years, the building regulation codes are focused on buildings structure stability against earthquakes and other natural disasters. The sustainable development which was recently introduced in the building sector leads to the construction of multi-storey building with minimum energy consumption and sufficient thermal comfort for the occupants. However, it is still necessary to consider the acoustic comfort for it is very crucial to study the sound transmission through a building element such as walls, floors and windows.

Andreia Pereira et al. [1] studied experimentally the noise reduction provided by floor coverings; using reduced sized slab following the procedure described in the ISO/CD 16251-1 document [2]. Many resilient coverings, floating floors and floating slabs are evaluated and the results are compared with those obtained using the standards EN ISO 140-8 [3] and ISO 717-2 [4]. The results show that the impact sound reduction provided by resilient coverings are close to those obtained using the methodology described in ISO 140-8 [3].

Birgit Rasmussen et al. [5] have investigated a comparison study of the legal requirements for sound insulation between dwellings in 24 European countries. They obtained significant differences in descriptors and the levels used by the European countries.

Alessandro Schiavi et al. [6] investigated an experimental measurement of impact sound insulation of floor coverings with resilient layers according to the ISO 10140 standards series. They found that the accurate characterization of acoustical performances of resilient layers depends on several conditions, such as the state (clean or dirty) of the surfaces, and the fixation of the layer on the reference floor. They reported that these conditions are not stated by the standard ISO 10140.

Ha-Seog Kim et al. [7] studied the manufacture of mineral damping materials using mineral binders and applied to reduce the effects of floor impact noises. Different configurations have been used depending on physical properties such as density, dynamic stiffness, and remnant strain. Their results show that the installation of damping materials between a concrete slab and a form concrete layer reduced very significantly the impact noises. Nevertheless, the damping materials currently used are mainly manufactured from organic materials with lower density and lower dynamic stiffness such as polystyrene (EPS). These products generate a floating structure due to heterogeneous material layers and cause problems such as resonance and amplification of some frequencies.

The low frequency vibro-acoustic characteristics of a massive floating floor with different resilient layer are investigated with experimental measurements and numerical simulations method by Tongjun Cho et al. [8].

In Algeria, the main construction type is a multi-storey building, lacking sufficient acoustic insulation to dampen the noise transmission through the floors. The Algerian building acoustic regulations specifies the sound insulation calculation method for airborne noises in the "DTR 3.1.1" code.

The executive decree N° 93-184 of July 27th, 1993 [9] regulating noise emission states the following in its 2nd and third articles:

- **Article 2.** The maximum allowed noise levels in residential areas, roads and private or public places are 70 dB during the daytime (from 6 am to 10 pm) and 45 dB at night (from 10 pm to 6 am).
- **Article 3.** The maximum allowed noise levels in the immediate vicinity of hospitals, teaching, rest and relaxation areas as well as within their walls are 45 dB during the daytime (from 6 am to 10 pm) and 40 dB at night time (from 10 pm to 6 am).

In this paper, we examine both numerical simulation and experiments method to investigate the impact noise through

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floor assemblies. The main task is to develop a detailed method for acoustic evaluation behavior of the floor in multi-storey residential buildings. To our knowledge, there is no published work about the acoustical performance of the floor in residential multi-storey buildings in Algeria.

The paper is divided into six sections. After the Introduction (Section I), mathematical formulations and numerical solution of the impact sound level are given in Sections II and III, respectively. The material and measurement methodology are presented in Section IV. Section V deals with the acoustic results and discussions. Finally, a conclusion is given in Section VI.

## II. Mathematical Formulation

In multi-storey constructions, heavy-weight impact sounds caused by walking of the occupant, running or jumping are important sources of noise transmission through the floors junctions.

The impact sound insulation is calculated according to ISO 140-7 [5]. The evaluation of the sound transmission is divided in two quantities:

Normalized impact sound pressure level:

$$L'_n = L_i + 10\lg\frac{A}{A_0} \tag{1}$$

Standardized impact sound pressure level

$$L'_{nT} = L_i + 10\lg\frac{T}{T_0} \tag{2}$$

where; $L_i$ is the impact sound pressure level measured in the receiving room when the floor under test is excited by the standardized impact source (tapping machine or impact rubber balls), A is the equivalent sound absorption area in the receiving room, $A_0$ is the reference absorption area, $A_0$= 10 $m^2$. T is the reverberation time measured in the receiving room. $T_0$ is the reference reverberation time, $T_0$=0.5 s. A = 0.16V/T, where V is the room volume in $m^3$.

## III. Numerical Solution and Software

The Acoubat software is used to calculate the acoustic behavior of the floor. This software is developed by CSTB center and is based on modeling the impact noise through a floor according to the method described in EN 12543-2 [10]. This standard describes the models used to calculate the impact sound insulation between apartments in multi-storey building based on the measured data characterizing the transmission of sound in the structural elements.

Acoubat software has a products database, where each product is disposed according to its function within the building such as masonry, covering layer, windows, door, ceiling, floor and others different construction materials. Figs. 1 and 2 display the architectural sketch of the apartments used for the numerical modeling.

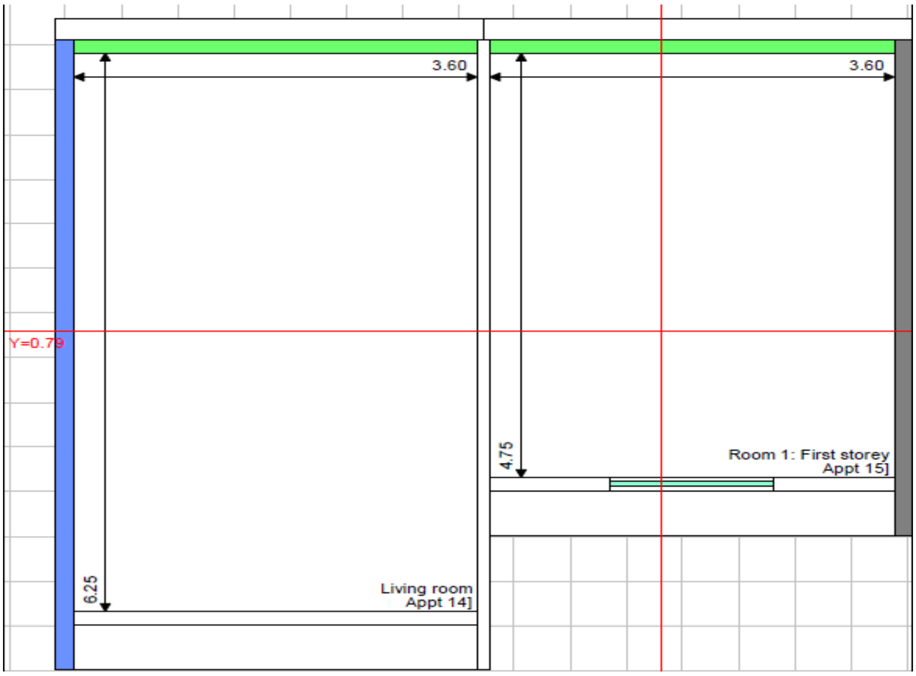


Fig. 1 Architectural sketch of the apartment under experiment

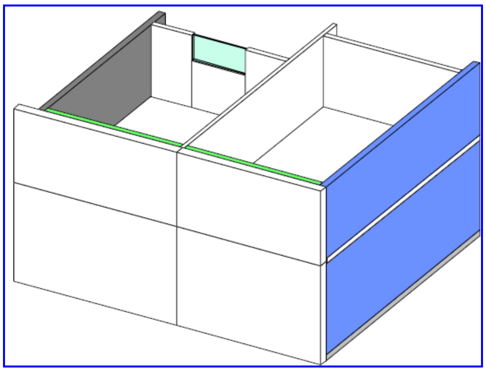


Fig. 2 Acoubat 3D Model of the apartment under experiment

Acoubat is a good tool for estimating different building acoustic descriptors such as airborne noise insulation, impact noise of the floor, noise equipment, and reverberation time of classrooms.

## IV. EXPERIMENTAL WORK

### *A. Field Measurements*

The experimental works are examined by national center of building researchers in deferent cases: projects research and in situ expertise [11]. The measurements are investigated in second storey apartment of residential building situated in Algiers using Brüel and Kjær sound level meter.

The impact sound is the sound level in the receiving room from standardized tapping machine containing five steel hammer of 0.5 kg weight, which is placed in the source room to simulate footsteps of the occupant.

The first measurements are made in five-storey residential building situated in the Algiers region. The floor is composed from different layers: 15 cm of concrete, 2 cm of sand, and 2 cm of tile.

Fig. 3 illustrates the plan configuration of the apartment under investigation [11].

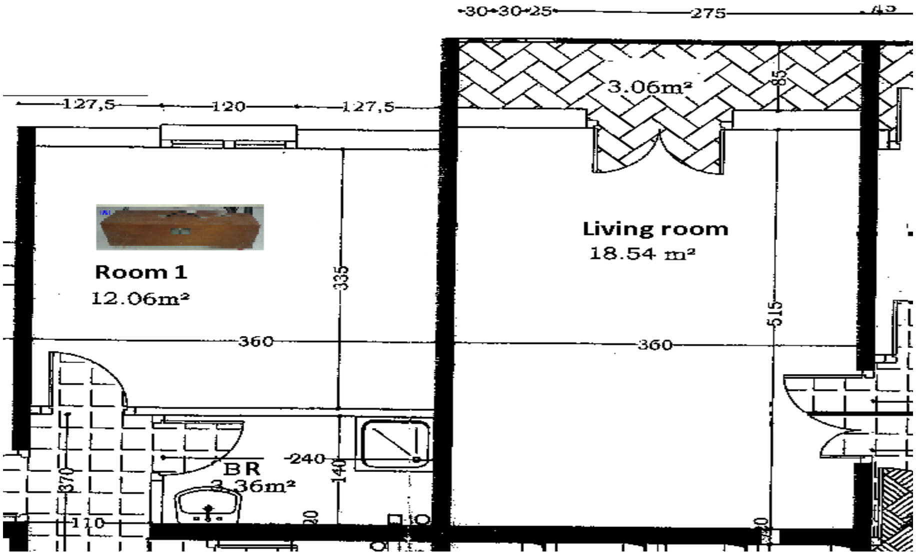


Fig. 3 Detailed plan configuration of the apartments under experiment [11]

The second work under experiment is a two-storey residential building situated in the north of Algiers with a floor made of ribbed reinforced concrete and polystyrene hollow blocks.

Sound pressure levels obtained at different microphone positions must be averaged for all positions of the tapping machine using:

$$L = 10\lg\left(\frac{1}{n}\sum_{j=1}^{n}10^{Lj/10}\right) \qquad (3)$$

where; Lj is the sound pressure levels $L_1$ to $L_n$, n is the number of the different positions of the microphone in the receiving room.

### *B. Laboratory Measurements*

The laboratory measurements are made on building elements such as wall panels, windows, and floor cover mounted in special test assemblies. Fig. 4 illustrates the first step in the construction of a reinforced concrete floor to be used as an acoustic performance cover specimen. The measurements are done under a uniform and strict procedure [2]. The results are used by manufacturers to document the performances of their products.

A laboratory experimental procedure is developed in the national center for building research (CNERIB), it aims at measuring the impact sound level in residential building with the following equipment: the sound level meter analyzer Brüel and Kjær 2270 with BZ 5503 software and impact-tapping machine Brüel and Kjær 3204. The equipment is illustrated in Fig. 5.

Fig. 4 Detailed reinforced floor (1.2 m×0.8 m×0.2 m) in the initial phase

Fig. 5 Building acoustic equipment used for the measurements (a) Sound level meter Brüel and Kjær 2270 with accelerometer, (b) sound source, (c) professional signal amplifier and (d) Tapping machine

## V. RESULTS AND DISCUSSIONS

Measurements in the field are performed in situ on partition of buildings. The results are used to document conformance to building regulation. In the field measurements, sound and vibration propagate not just via the partition under investigation, but also via other partitions, structures, and leaks. This propagation is called flanking transmission.

The impact sound level for the vertical transmission direction according to the model of the Acoubat is $L'_{nT,w} = 67$ dB (see Fig. 6). However, the value in the diagonal transmission is less than the one in the vertical direction, i.e $L'_{nT,w} = 59$ dB. The measurements reported in [11] showed that the global sound level is 66 dB (see Fig. 6). The difference between measurements in situ and numerical simulation with Acoubat software is 1 dB. There exist a good agreement between numerical simulation and experimental measurements.

The noise radiated by the structural element can be evaluated as the sum of the acoustic transmission noises in various ways. Each way can be identified by the element ***i*** for which the noise is incidental in the emission room and the element ***j*** radiating the noise in the received room [4].

The dimensions of the facades play a significant role in the values of the sound insulation. Fig. 7 shows the impact sound levels when the dimensions of the facade are changed. Generally, in the bottom room the noise levels are expressed relative to the equivalent absorption area measured in the receiving room, expressed in $m^2$ or the reverberation time (see (1) and (2)).

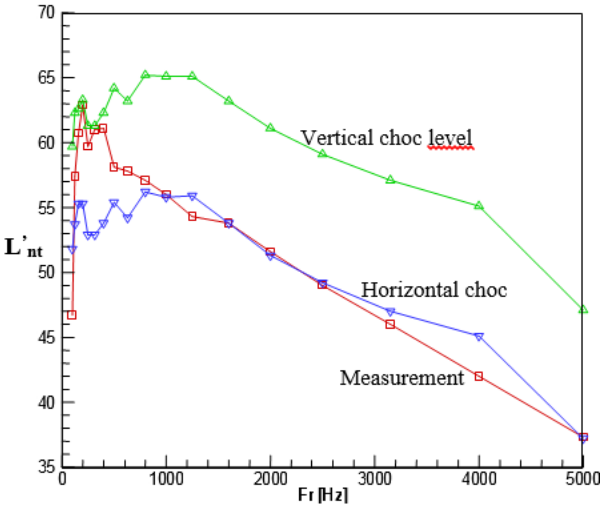


Fig. 6 Impact sound pressure level of the floor in five storey residential building in the horizontal and vertical transmission ways

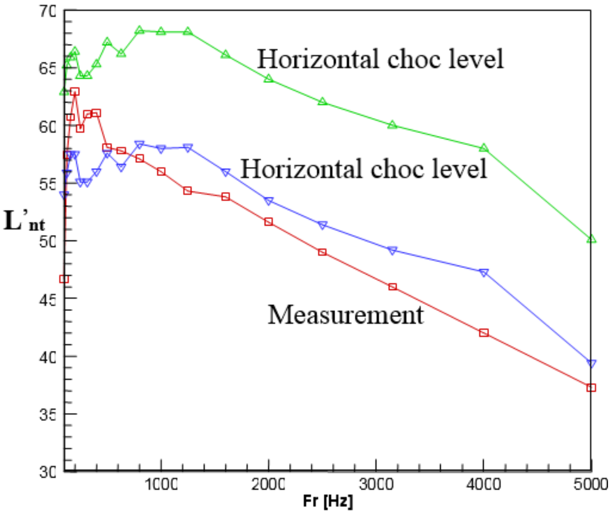


Fig. 7 Impact sound pressure level of the floor in five-storey building in the horizontal and vertical transmission ways when the dimensions of the façade are changed

In the second apartment which is located in a two-storey building, the measurements showed that the total level of the impact noise obtained is 79 dB(A), which is not in agreement with the recommended value, 58 dB(A) (Fig. 8).The impact sound level in vertical transmission direction simulated by Acoubat software is 76 dB(A). However, the value in the diagonal direction is 67 dB(A).

Numerical simulations were carried out in floor made of (bottom to top) 10 cm concrete, then 22 cm hollow bloc and a tile covering of 5 dB (A) acoustic reduction.

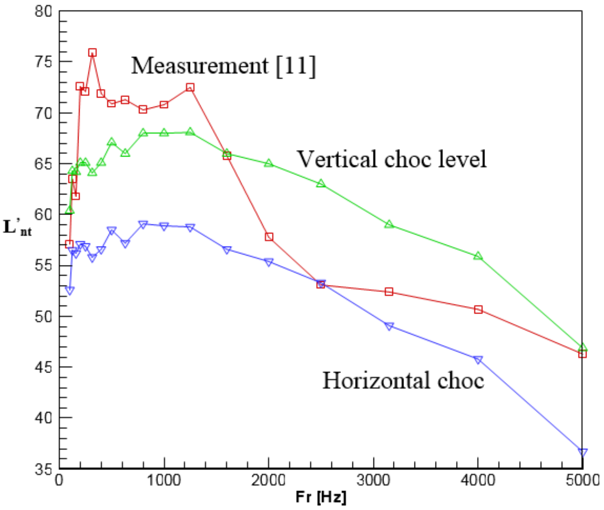


Fig. 8 Impact sound pressure level of the floor in two storey residential building in the horizontal and vertical transmission ways

Figs. 9-12 illustrate the numerical simulation of the impact sound pressure level through some floor with different resilient materials. In the first case: (from bottom to top) 17 cm of concrete, underneath layer of 16 dB acoustic reduction and then a tile covering. In the second case: (from bottom to top) 17 cm of concrete, polystyrene hollow blocs, and then a tile covering. Figs. 11 and 12 show the impact sound noise level in the case of the hollow bloc with polyethylene and mineral wool resilient materials respectively.

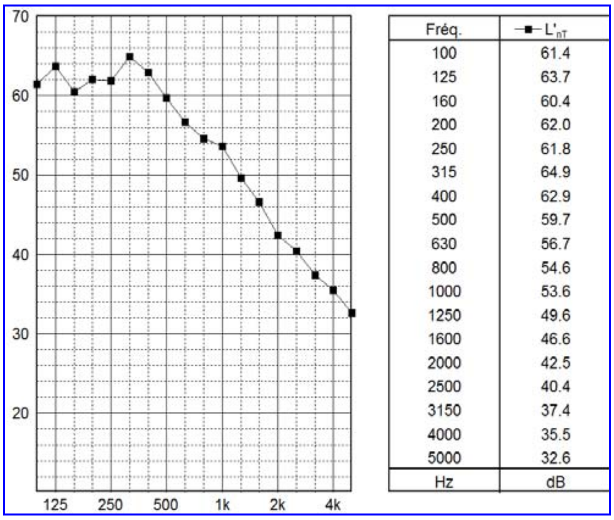
The global value obtained is 57 dB calculated according to ISO 717-2 [4] for two floors. The allowable sound level was found to be 58 dB according to the European regulation. In addition, the maximum of light-weight impact sound and heavy-weight impact sound must be lower than 58 dB and 50 dB, respectively, in other international building codes [12].

Resilience is defined as the capacity of a material to absorb energy when it is deformed elastically and then, upon unloading to have this energy recovered. In other words, it is the maximum energy per volume that can be elastically stored. It is represented by the area under the curve in the elastic region in the stress-strain diagram.

In case of floating floors, resilient materials are placed between concrete or wooden slab and finishing materials. The resilient materials reduce impact sound through a floor by reducing the vibration generated whenever a body hits the floor [12]. The floor impact sound reduction increases with the decrease of dynamic stiffness of resilient material [12].

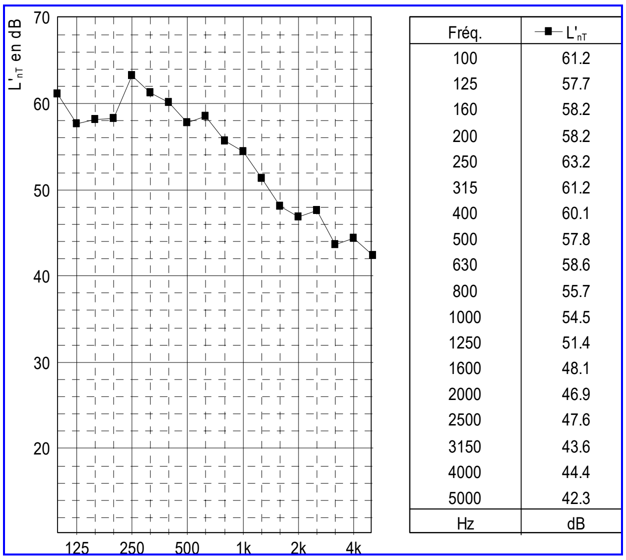
Results obtained in the literature indicate that dynamic stiffness, as a physical property of resilient materials, decrease as the thickness of the resilient materials increase.

Widely used resilient materials are made of EPS (Expanded Polystyrene), waste urethane series, EVA (Ethylene Vinyl Acetate), EPE (Expanded Polyethylene), EPP (Expanded Polypropylene), glass fiber and rock wool, waste tires, compressed polyester [12].



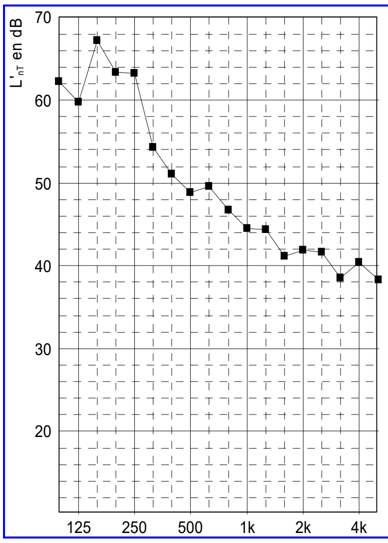
| Fréq. | $L'_{nT}$ |
|---|---|
| 100 | 61.4 |
| 125 | 63.7 |
| 160 | 60.4 |
| 200 | 62.0 |
| 250 | 61.8 |
| 315 | 64.9 |
| 400 | 62.9 |
| 500 | 59.7 |
| 630 | 56.7 |
| 800 | 54.6 |
| 1000 | 53.6 |
| 1250 | 49.6 |
| 1600 | 46.6 |
| 2000 | 42.5 |
| 2500 | 40.4 |
| 3150 | 37.4 |
| 4000 | 35.5 |
| 5000 | 32.6 |
| Hz | dB |

Fig. 9 Impact sound pressure level of the floor: First case (from bottom to top): 17 cm of concrete, underneath layer of 16 dB acoustic reduction and then a tile covering. $L'_{nT,w}$ = 57 dB



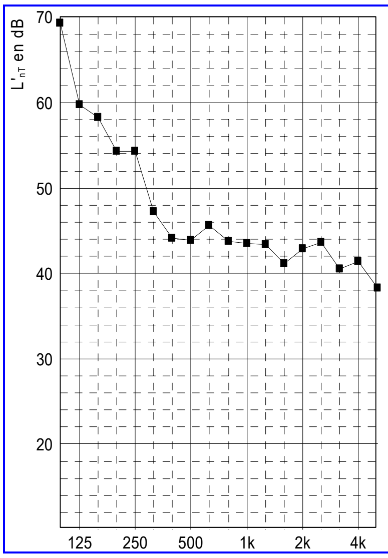
| Fréq. | $L'_{nT}$ |
|---|---|
| 100 | 61.2 |
| 125 | 57.7 |
| 160 | 58.2 |
| 200 | 58.2 |
| 250 | 63.2 |
| 315 | 61.2 |
| 400 | 60.1 |
| 500 | 57.8 |
| 630 | 58.6 |
| 800 | 55.7 |
| 1000 | 54.5 |
| 1250 | 51.4 |
| 1600 | 48.1 |
| 2000 | 46.9 |
| 2500 | 47.6 |
| 3150 | 43.6 |
| 4000 | 44.4 |
| 5000 | 42.3 |
| Hz | dB |

Fig. 10 Impact sound pressure level of the floor polystyrene hollow bloc, underneath layer of 16 dB acoustic reduction and then a tile covering $L'_{nT,w}$ = 57 dB



| Fréq. | L'$_{nT}$ |
|---|---|
| 100 | 62.3 |
| 125 | 59.7 |
| 160 | 67.3 |
| 200 | 63.3 |
| 250 | 63.3 |
| 315 | 54.3 |
| 400 | 51.1 |
| 500 | 48.8 |
| 630 | 49.6 |
| 800 | 46.7 |
| 1000 | 44.5 |
| 1250 | 44.4 |
| 1600 | 41.2 |
| 2000 | 41.9 |
| 2500 | 41.6 |
| 3150 | 38.6 |
| 4000 | 40.4 |
| 5000 | 38.3 |
| Hz | dB |

Fig. 11 Impact sound pressure level of the floor hollow bloc, mortar underneath layer of polyethylene of 16 dB acoustic reduction. $L'_{nT,w}$=56 dB



| Fréq. | L'$_{nT}$ |
|---|---|
| 100 | 69.3 |
| 125 | 59.7 |
| 160 | 58.3 |
| 200 | 54.3 |
| 250 | 54.3 |
| 315 | 47.3 |
| 400 | 44.1 |
| 500 | 43.8 |
| 630 | 45.6 |
| 800 | 43.7 |
| 1000 | 43.5 |
| 1250 | 43.4 |
| 1600 | 41.2 |
| 2000 | 42.9 |
| 2500 | 43.6 |
| 3150 | 40.6 |
| 4000 | 41.4 |
| 5000 | 38.3 |
| Hz | dB |

Fig. 12 Impact sound pressure level of the floor hollow bloc, mortar underneath layer of mineral wool of 20 dB acoustic reduction. $L'_{nT,w}$=54 dB

Figs. 13 and 14 show the impact signal of the tapping machine measured with sound level meter analyzer Brüel and Kjær 2270 and accelerometer Brüel and Kjær 5408 placed on the upper and lower surface of the concrete floor. The value of the impact sound level obtained is 101.2 dB on the upper surface and it is 87.5 dB measured in the lower surface.

In the reinforced concrete apartment buildings, the floor impact sound from the floor above can be easily transferred to the floor below [12]. Due thin floors, neighboring occupants can hear conversations from the neighboring flats.

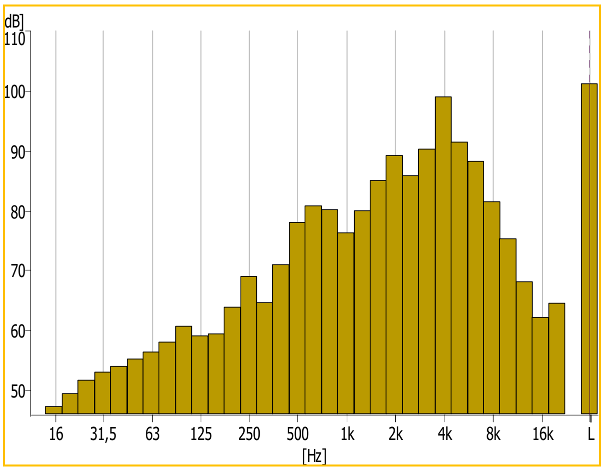


Fig. 13 Impact sound pressure level on the upper surface

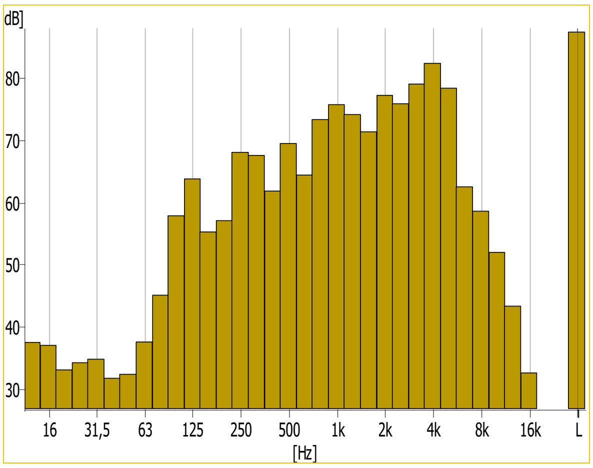


Fig. 14 Impact sound pressure level on the lower surface

## VI. CONCLUSION

This work deals with the numerical simulation and acoustic characterization of different floor assemblies in Algerian construction mode. The conclusion is summarized as:

- The results of our simulations display that the values of the simulated model with ACOUBAT software are close to the experimental results for frequencies below than 1000 Hz, but there exist a discrepancy for frequencies higher than 1000 Hz.
- The impact sound level of the first apartment for the vertical transmission direction according to the model of the Acoubat is $L'_{nT,w}$= 67 dB. However, the value in the diagonal transmission is less than the one which is in the vertical direction, i.e $L'_{nT,w}$ = 59 dB. The measurements showed that $L'_{nT,w}$ = 66 dB.
- For the second apartment which is located in two-storey building, the total level of the impact noise is $L'_{nT,w}$ =79 dB, which is not with agreement with recommended value, i.e. $L'_{nT,w}$=58 dB.

The numerical simulation shows that the addition of resilient underneath tile reduces the impact noise level from 67 dB to 57 dB. When the polyethylene and mineral wool are used, the results showed that the total level of the impact noise can be achieved $L'_{nT,w}$=56 dB and $L'_{nT,w}$ =54 dB, respectively.

A project of an experimental procedure for acoustic performance measurements of soil covers is ongoing. This method is based on impact noise measurements with the Brüel and Kjær accelerometer probe and will be communicated in a future paper.

## ACKNOWLEDGMENT

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