Experimental investigations on acoustical retrofitting of timber floors

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Abstract
Improving existent timber floors in buildings is not an easy task since many technical and space-related restraints usually apply. Often only adaptation above or under the load-bearing joists are possible, sometimes both. In a few experimental studies, solutions are sought within these restrictions, focusing on impact sound insulation. The measurements allowed to gain insight in different transmission mechanisms. The results reveal the possibilities but also the limitations of several improvement techniques.

Keywords: timber floors, impact sound insulation, acoustical retrofitting, experimental investigation.

PACS no. *43.55.-n, 43.55.+p, *43.55.Rg

1 Introduction

The airborne and impact sound insulation between floors in nineteenth-century and other historical housing with timber floors, are often very weak. If these floor constructions become partitions between different housing units at the moment of conversion, the sound insulation will probably not comply with the current nor future sound insulation requirements. Fortunately, the sound insulation of timber floors can be improved considerably by adding suspended ceilings and/or floating floor systems. Depending on technical and other (property, budget, legal, social…) restrictions, some solutions may not be applicable. Designers then have the difficult task to select the best available solution that complies with all these restrictions. This paper aims to help in this process by providing an overview of the performance of several traditional Belgian and some innovative solutions.

2 Airborne and impact sound insulation of timber floors

If we want to improve the apparent airborne sound insulation between two superimposed rooms, we have to consider that, in old traditional Belgian dwellings, timber floors are usually constructed between continuous heavy masonry walls. Due to the weight contrast between walls and floors, the flanking sound transmission through the continuous walls (Ff-path) is a contribution that cannot be neglected since it limits the maximal airborne sound insulation to be achieved in practice (Figure 1). This is clearly illustrated in [1].

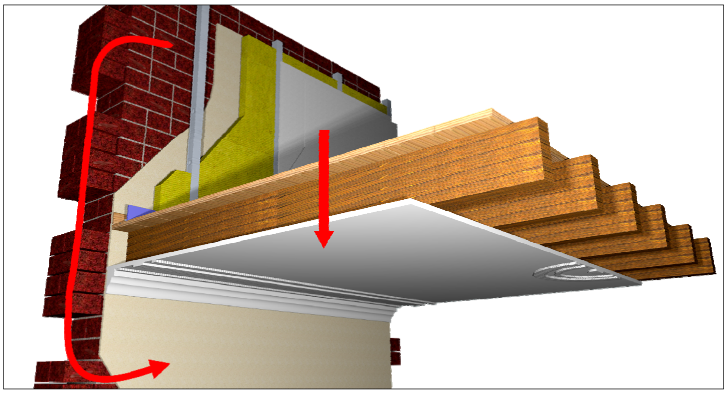

Figure 1 – F-f flanking sound transmission path and direct path for airborne sound transmission

For the same constructional reasons, impact sound transmission through timber floors is usually dominated by the direct impact sound transmission. From a user's perspective, impact noises through timber floors usually cause more annoyance than airborne noises. This means that impact noise requirements will generally be more demanding than airborne noise requirements on the acoustical design of timber floors. In that respect, we can limit our analysis to the direct impact sound insulation performance of timber floors. We hence suppose that – for a given acoustical comfort class – floor solutions that comply with the impact sound requirements, will also comply with the airborne sound requirements in that class. If not, this is probably due to the flanking sound transmission through the continuous walls. In that case, the high airborne sound insulation requirements will usually require extra wall linings (see e.g. Figure 1).

3 Impact sound insulation requirements and comfort classes

Belgian sound insulation requirements for dwellings are specified in the Belgian standard NBN S 01-400-1:2008 [2]. With regard to impact sound insulation, they are expressed in the $L'_{nT,w}$ descriptor, historically based on acoustical comfort surveys in traditional heavyweight dwellings in Belgium. However, due to the increase in market share for lightweight timber frame constructions, adapted requirements become essential. Indeed, recent research pointed out that – unlike heavy constructions - typical timber frame constructions are prone to significant resonances in the typical low frequency range between 50-100 Hz [3]. To ensure equal acoustic comfort experience in both heavy and lightweight construction, descriptors that take into account the frequency range starting from 50 Hz need to be used [4]. An obvious choice is the $L'_{nT,w} + C_{I,50\text{-}2500}$ descriptor. However, due to poor reproducibility while evaluating this descriptor in the field, the Belgian proposal for a further revision of the NBN S 01-400-1 will be to express the in-situ requirements in $L'_{nT,w} + C_I$ and a parallel laboratory requirement for separating constructions expressed in $L_{n,w} + C_{I,50\text{-}2500}$.

Based on the existing Belgian requirements for minimal acoustic protection (MAP) and enhanced acoustic comfort (EAC) and anticipating the future requirements, Table 1 may be used to express requirements in-situ or in laboratory that correspond more or less to 5 comfort classes. The table must not be read as a collection of 6 requirements that need to be fulfilled for each intended comfort class, but rather as a collection of requirements from which a regulation editor can chose.

Table 1 – Proposal for impact sound requirements expressed in dB for 5 comfort classes. The conversion from field to laboratory requirements is done supposing a receiving room volume of 30 m³. For larger receiving rooms, 10lg(V/30m³) can be added to the laboratory requirements (weakening the requirement).

		field requirements			laboratory requirements		
class	description	$L'_{nT,w} \leq$	$L'_{nT,100} \leq$	$L'_{nT,50} \leq$	$L_{n,w} \leq$	$L_{n,100} \leq$	$L_{n,50} \leq$
1	NAC inside dwelling	64	64	66	64	64	66
2	EAC inside dwelling	58 [1]	58	60 [3]	58	58	60
3	MAP	54 [1]	54 [2]	56 [3]	54	54	56 [4]
4	EAC	50 [1]	50 [2]	52 [3]	50	50	52 [4]
5	HAC	46	46	48[3]	46	46	48

Table notes:

$L'_{nT,100} = L'_{nT,w} + C_I$ / $L'_{nT,50} = L'_{nT,w} + C_{I,50}$ / $L_{n,100} = L_{n,w} + C_I$ / $L_{n,50} = L_{n,w} + C_{I,50}$

NAC = Normal Acoustic Comfort

EAC = Enhanced Acoustic Comfort

MAP = Minimal Acoustic Protection

HAC = High Acoustic Comfort (considered to be a superior acoustic comfort class)

[1] corresponds respectively to the requirements in NBN S 01-400-1[2] for EAC regarding impact sound insulation inside dwellings and MAP and EAC between dwellings

[2] corresponds respectively to the field requirements in the draft revision of NBN S 01-400-1 for MAP and EAC regarding impact sound insulation between dwellings

[3] corresponds respectively to classes E_{50}, D_{50}, C_{50} and B_{50} in the 3rd working draft of ISO/WD 19488[5]

[4] corresponds respectively to the laboratory requirements in the draft revision of NBN S 01-400-1 for MAP and EAC regarding impact sound insulation between dwellings

4 Impact sound insulation performance of retrofitting solutions

4.1 Reference floor types

During several experimental studies from 1997 up to now, 150 different timber frame constructions have been measured in the E-lab, the acoustic laboratory of the Belgian Building Research Institute (BBRI). During each campaign, a reference timber floor is chosen to which several improvements are made. Basically, 2 groups of reference floors may be distinguished, depending on the point of departure: wooden joists with subfloor sheeting, with or without rigidly connected ceiling (see Figure 2). The reference floors without ceiling will represent existing timber floors in historical (medieval) buildings, while the ones with ceiling may represent typical floors found in nineteenth-century mansions with ceiling plasterwork on wooden strips. For each floor, the measured difference with its corresponding reference floor is then applied on the average reference floor for that group, in order to qualify its average performance on the group of reference floors. This is done to assure a fair comparison of solutions over different measurement campaigns, since small differences occur between nominally equal reference floors from different measurement campaigns.

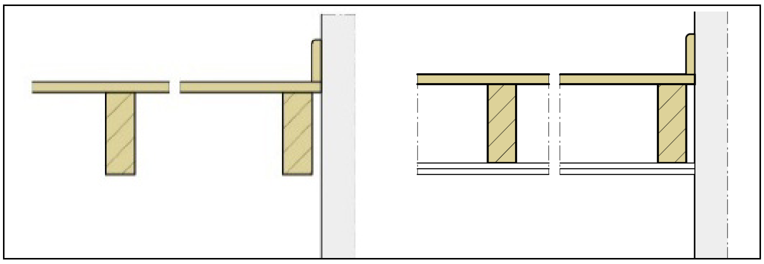

Figure 2 – Typology for both groups of reference floor types studied
Left: reference floor with open ceiling, average $L_{n,w}(C_I;C_{I,50-2500})$ = 92(-4;-4) dB
Right: reference floor with closed ceiling, average $L_{n,w}(C_I;C_{I,50-2500})$ = 79(-1;-1) dB

4.2 Solutions for reference floors with open ceilings

In this section, solutions will be discussed that can be applied on reference floors with open ceilings, depending on the retrofitting possibilities in different situations. The findings are based on laboratory measurements on 104 timber floors. In almost all cases, no floor finishing is present. Some solutions may not be possible due to the limited load-bearing capacity of the existent floor. In these cases, reinforcing the joists by e.g. adding scabbed joists or attaching steel strips may provide a solution.

4.2.1 Only upside interventions possible

The ceilings of existent wooden joists in historical buildings are often left visible when retrofitted because of their authentic character. To improve the acoustic properties of such floors, one is restricted to actions on the upper side. Therefore the achievable improvements are very small. Heavy toppings from anhydrite or mortar based screeds do not improve impact sound insulation, neither if mechanically fixed to the subfloor, unless a floating screed on top of this screed is installed [1]. In this case, class 1 can be obtained only in large receiving spaces (≥ 50m^3). For these spaces, class 1 may also be obtained by applying dovetailed sheeting filled with micro-concrete on a resilient layer [1]. Typical dry floating floors do not allow to obtain class 1, even when extra damping layers are inserted.

4.2.2 Only downside interventions possible

It is obvious that applying a ceiling lining together with a sound absorbing material between or under the joists is a very effective way for increasing the airborne sound insulation of timber floors. Different solutions may be classified according to the degree of structural connection between base floor and ceiling (Figure 3). In the case of ceilings on a structurally independent grid of metal channels, it is observed that the obtained impact noise level spectrum may be obtained by subtracting the airborne sound insulation spectrum of the ceiling lining from the impact noise level spectrum of the reference floor, except for the low frequency region, where cavity resonances may further increase the transmitted impact noise.

Ceilings on rigid hangers or resilient channels barely obtain class 1. For systems on resilient hangers, no substantial influence is found regarding the number of hangers or the thickness of the cavity absorber. Resilient hangers usually do not increase performance compared to rigid hangers. However, the use of these resilient hangers in combination with double particular gypsum boards with superior sound insulation properties or with a damping layer between both boards, approaches class 2 (not for $L_{n,50}$).

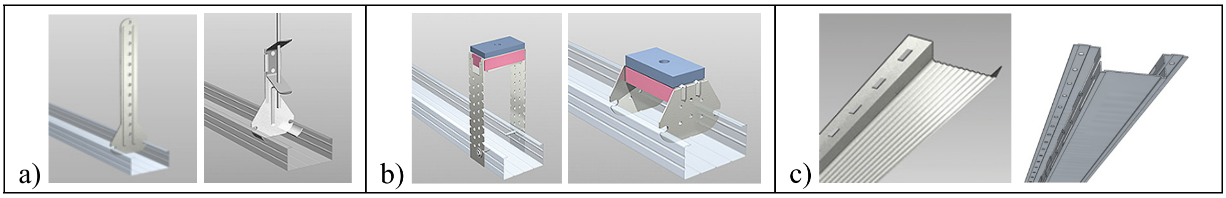

Figure 3 – Examples of connection system for ceiling linings.
a) Rigid hangers, b) Resilient hangers, c) Resilient channels

When applying an indepent ceiling (using a steel or timber frame), a whole range of performances are possible. Class 1 can be obtained using traditional gypsum boards with at least 100 mm of cavity absorber. Two heavier boards (e.g. fire rated or fibre reinforced gypsum boards) are needed to reach class 2. In this case 100 mm mineral wool can be replaced by 25 mm of gravel between the frame or by using two 15 mm boards instead of 12.5 mm boards. Increasing the mineral wool thickness to 200 mm further approaches the Normal Acoustic Protection class (NAP, class 3). The combination of 25 mm gravel and 100 mm leads to Enhanced Acoustic Comfort (EAC, class 4). Adding another 100 mm of mineral wool approaches a class 5 ranking for the frequency range from 100 Hz ($L_{n,w}(C_I;C_{I,50\text{-}2500})$ = 46(1;6) dB).

4.2.3 Both sides interventions possible

In some cases, the above mentioned solutions on both sides of the existent floor may be combined to obtain a higher comfort class. Table 2 gives an overview of the comfort classes that may be obtained for several combinations by using the color scheme used in Table 1. If not mentioned explicitely in the table, an absorbent with a thickness of at least 100 mm has to be inserted in the cavity between or under the joists of the existent floor. It is interesting to note that all comfort classes are possible, even with dry floor systems. An example of a wet floor system that achieves a class 5 (HAC) rating using a floating screed on resilient pads and 35 mm gravel between the joists is given in Figure 5.

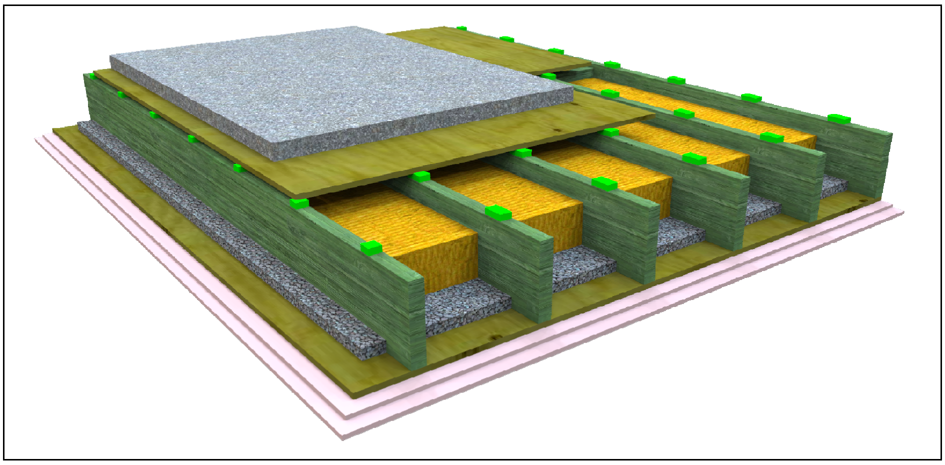

Figure 4 – Example of an innovative floor system complying with comfort class 5 (High Acoustic Comfort)

4.3 Solutions for reference floors with closed ceilings

In this section, solutions will be discussed that can be applied on existent floors with closed ceilings, depending on the retrofitting possibilities in different situations. The findings are based on laboratory measurements on 45 timber floors. In almost all cases, no floor finishing is present.

4.3.1 Only upside interventions possible

In section 4.2.1 we found that none of the possible upside adaptations of the open reference floor obtained comfort class 1 for standard bed room sizes due to the fact there was no ceiling structure connected to the joist. For closed reference ceilings however, this becomes possible. If the subfloor cannot be removed, then a dovetailed sheeting with 50 mm micro-concrete can be added on a resilient layer to obtain class 1. This class can also be obtained using specific dry floating floor systems when applied on a subfloor after filling the cavity between the joists with an absorbent (minimal thickness 100 mm). An example of such a floating floor system is 18 mm OSB on 9 mm softboard strips, 600 mm o.c. on 18 mm softboard (unfortunately no low frequency data available). However, putting a dry floating floor system directly on the joists or on resilient strips or pads on the joist does not allow to achieve class 1. Installing a dry floor system on a subfloor that is supported by resilient strips on the joists complies also with class 1 only if the cavity is filled with an aborbent and an extra mass layer is added between the joists.

Another way to realise a structural decoupling between ceiling and floor is to add a second layer of joists between the existent joists. These are then resiliently supported by steel braces or by blocking trusses between the joists (Figure 5).

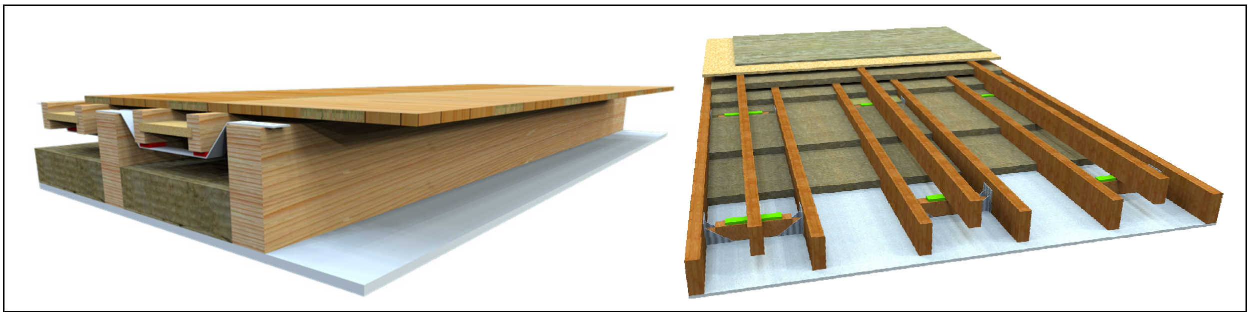

Figure 5 – Examples of decoupling floor and ceiling parts with only a small increase in floor height. *Left:* joists supported by steel braces - *Right:* joists supported by blocking trusses between the joists enabling a larger span between the upper layer joists

In the former case, class 1 can be obtained using two floor boards on an inverse U joist and class 2 can be reached by two floor boards on joists on particularly designed braces. These concepts are patent-pending. In the latter case, class 1 is obtained using a single floor board and 200 mm absorbent while class 2 (class 1 for $L_{n,50}$) needs an extra floor board.

4.3.2 Only downside interventions possible

In this case, only suspended ceilings on rigid and resilient hangers have been studied, without removing the fixed ceiling of the existent reference floor (since the systems with removing the fixed ceiling can be found in 4.2.2). With rigid hangers, it was found that class 1 could only be obtained using two heavy ceiling boards and 80 mm of absorbent. With resilient hangers and specific acoustic gypsum boards, 1 board and and 80 mm of absorbent is sufficient to reach class 1 but 2 boards are not sufficient to achieve class 2.

Table 2 – Obtained comfort classes for different combinations of added ceiling system and added floor system for reference floors with open ceilings

added floor system		added ceiling system: fixed ceiling	ceiling on rigid hangers	ceiling on resilient channels	ceiling on resilient hangers	independent ceiling
dry floors	fixed floor	x				
dry floors	dry floating floor		1 ceiling board (*) 2 heavy ceiling boards 1 ceiling board + extra laminate floor covering (*) 1 ceiling board + extra resilient floor covering (*)	2 ceiling boards * 2 ceiling boards + extra floor mass *	2 ceiling boards or 1 acoustic board * 2 acoustic ceiling boards * 2 ceiling acoustic ceiling boards + extra floor mass	1 ceiling board (*) 2 heavy ceiling boards 2 heavy ceiling boards + extra floor mass *
dry floors	dry floating floor on laths on joists	60 mm gravel + 180 mm absorbent in cavity 60 mm gravel + 180 mm absorbent in cavity + extra floor mass *				
dry floors	dry floor on resilient strips on joists	60 mm gravel + 180 mm absorbent in cavity			3 heavy floor boards with damping layer + 2 heavy ceiling boards with damping layer (*)	2 heavy ceiling boards + extra board under subfloor as above + extra dry floating floor * as above + extra floor mass
dry floors	dry floor on resilient pads on joists	60 mm gravel + 180 mm absorbent in cavity				
dry floors	dry floor on resilient wooden battens					2 ceiling boards (*)
dry floors	dry floor on extra resiliently supported joist layer between base joists	1 heavy ceiling board + joists on braces * 1 heavy ceiling board + joists on braces + 2 floor boards 2 heavy ceiling boards + joists on braces + 2 floor boards 2 heavy ceiling boards + joists on special braces + 2 floor boards * 2 heavy ceiling boards + high joists on blocking trusses + 2 floor boards *				
wet floors	dovetailed sheeting with micro-concrete on resilient strips on joists					1 ceiling board (*)
wet floors	floating dovetailed sheeting with micro-concrete					2 ceiling boards + extra board on subfloor no absorbent in cavity (*) 1 ceiling board + extra board on subfloor 100 mm absorbent in cavity (*)
wet floors	floating screed on laths on joists	60 mm gravel + 180 mm absorbent in cavity 60 mm gravel + 180 mm absorbent in cavity + higly resilient strips				
wet floors	screed on resilient strips on joists	60 mm gravel + 180 mm absorbent in cavity				
wet floors	screed on resilient pads on joists	3 heavy ceiling boards 60 mm gravel + 180 mm absorbent in cavity 30 mm gravel + 180 mm absorbent in cavity + 3 heavy ceiling boards * 35 mm gravel + 180 mm absorbent in cavity + 3 heavy ceiling boards + 20 mm pads * 60 mm gravel + 180 mm absorbent in cavity + 3 heavy ceiling boards		60 mm gravel + 180 mm absorbent in cavity + 2 heavy ceiling boards *		

Table notes:

x : no class is obtained

* : the obtained class for $L_{n,50}$, is one class lower than the class corresponding to the colour used

(*) : no data for $L_{n,50}$ available

4.3.3 Both sides interventions possible

In this case, only dry floor systems have been tested in combination with fixed ceilings, ceilings on rigid and resilient hangers and independent ceilings. For all systems, the existent fixed ceiling is not removed. (The solutions for the case where the fixed ceiling is removed can be found in section 4.2.3.) Table 3 gives an overview of the comfort classes that may be obtained for these combinations by using the color scheme used in Table 1. If not mentioned explicitely in the table, all ceilings contain at least 80 mm of absorbent. It may be noted that no solutions offering comfort class 5 are reported. However, if this would be required, one may remove the fixed ceiling and choose a system under 4.2.3.

Table 3 – Obtained comfort classes for different combinations of added ceiling system and added floor system for reference floors with closed ceilings

added dry floor system	added ceiling system: fixed ceiling	added ceiling system: ceiling on rigid hangers	added ceiling system: ceiling on resilient hangers	added ceiling system: independent ceiling
dry floating floor		1 ceiling board 1 ceiling board + extra floor mass layer * 2 ceiling boards * 2 ceiling boards + extra floor mass layer * 2 heavy ceiling boards *	1 acoustic ceiling board 1 acoustic ceiling board + extra floor mass layer * 2 acoustic ceiling boards 2 acoustic ceiling boards + extra floor mass layer *	
dry floor on resilient strips on joists			2 ceiling acoustic ceiling boards + extra board under subfloor * as above + floating floor *	2 ceiling acoustic ceiling boards + extra board under subfloor as above + floating floor * as above + extra floor mass layer
dry floor on extra resiliently supported joist layer between base joists	2 ceiling boards + joists on blocking trusses + 200 mm absorbent + 2 floor boards *			

Table notes:

* : the obtained class for $L_{n,50}$, is one class lower than the class corresponding to the colour used

(*) : no data for $L_{n,50}$ available

5 Conclusions

In this paper, a classification system for labeling the impact sound insulation performance of (refurbished) timber floors is proposed. 150 floor solutions that are used in Belgium have been measured at BBRI and classified according to this system. For the designer, this classification is a very useful tool for a quick evaluation of the possible performance of different retrofitting solutions. For two types of reference floors (with and without fixed ceiling), adaptations above and below the existent floor are discussed, as well as possible interesting combinations. It was shown that very high comfort classes are possible, even with dry floor systems. Some innovative retrofitting solutions have also been proposed.

Acknowledgements

This work was conducted within the framework of the research projects “AH+, Acoustical optimization of timber frame constructions” and “DO-IT HOUTBOUW, Sustainable innovation in the field of technology and living comfort for timber applications in construction” sponsored by the Flemish government agency for Innovation by Science and Technology (IWT), which is gratefully acknowledged.

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