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A new building acoustical concept for lightweight timber frame constructions

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ABSTRACT

In this paper, a new building concept for multi-family lightweight timber frame housing is proposed. This concept combines party walls, floors and façade elements ensuring comfort levels equal or better than currently encountered in typical Belgian heavy constructions. Low frequency behaviour and prefabrication potential were the key points in the design process of the new wall and floor types. Nevertheless, structural aspects, fire safety issues and thermal capacity have been taken into account as well. Solutions were found by maximally exploiting the mass-spring-mass mechanism. Finally, a holistic approach was followed to develop a building concept in which the walls, floors and façade elements are connected in an optimized way.

Keywords: Sound, Insulation, Transmission I-INCE Classification of Subjects Number(s): 51.3, 51.4, 51.5

1. INTRODUCTION

The use of wood in construction is growing. This evolution is pushed by the Kyoto protocol. Timber construction presents numerous strong points for sustainability: it allows for CO_2 storage, it is a renewable raw material, it provokes only small construction waste on site and it requires little energy to produce. There are other several more pragmatic reasons why lightweight timber frame constructions (abbreviated as LWTF further in the text) are increasing their market share to the detriment of heavy constructions: prefabrication, speed of assembly, new architectural tendencies (fashion trends), and not in the least the possibility of enlarging the thermal insulation layers in the façade walls without increasing the traditional thickness of the façades.

Many construction models available now in Europe focus only on the existing requirements, but their acoustic quality very often dissatisfies inhabitants. So an ‘acoustically good’ LWTF construction is not just a construction that complies with the acoustic requirements. It should be a construction that offers at least the same “experienced” acoustic quality as that of acoustically well-designed heavy constructions.

Airborne low frequency sound insulation, sufficient impact sound insulation and the realization of satisfying comfort against vibrations in particular appear to be the major challenges for LWTF constructions. People often complain about buzz or, the almost thunderous sound of someone walking on the floor above. They also complain about the possibility of hearing from where to where someone is walking. Some research shows that the evaluation should go below 50 Hz to explain all of this and to obtain a real description of the acoustic comfort.

But there is also positive news: if the construction allows for similar comfort in the low frequency bands as with heavy constructions, then it will generally offer a much better comfort in the middle and high frequency bands than with heavy weight constructions, due to the more steep increase in sound insulation with this technology.

In previous papers, we focused on the aspect of flanking transmission in LWTF. It has been shown that flanking transmission is -in correctly designed- constructions a smaller problem than for heavy weight constructions [1]. Consequently, in this paper we can focus on the optimization of the composing building elements: the party walls, the floor construction and the façades.

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2. FLOOR DESIGN

In a first step, we want to examine and improve the impact sound insulation with LWTF constructions. If we want to obtain similar or better results with LWTF floors as with traditional heavy constructions with a floating floor, then we have to know what these traditional constructions offer as a performance. Making an average of the test results of 20 well executed floating floors, we obtain a value of $L'_{nT,w}$ (C_I; $C_{I,50\text{-}2500}$) = 48(1;1) dB. For heavy constructions, the actual Belgian standard considers this as enhanced acoustic comfort and the experience shows that more than 90 % of the inhabitants are satisfied with this impact sound insulation. We have learned from traditional complaints about impact sound in LWTF constructions, that we need to focus on the impact sound level performance of the LWTF floor in the low frequency bands. As a reference, we chose the single number quantity of $L'_{nT,w} + C_{I,50\text{-}2500}$ and fixed a limit value equal to 48 dB, to judge whether a LWTF floor is to be considered as equivalent or better in impact sound insulation compared to a good heavy floating floor construction.

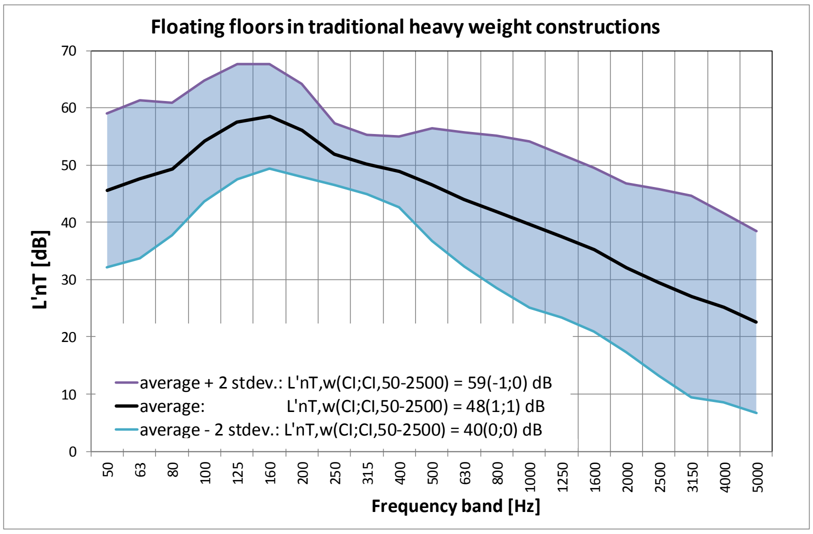


Figure 1 – Average spectrum of the standardised impact sound pressure level L'_{nT} measured in-situ on 20 well-executed traditional floating floors in Belgium. 95% of the measured values are situated inside the shaded zone

It is always easier for industry to adapt slightly existing building methods than to switch to radically innovative systems. So we have first examined the performance of almost all existing dry floating floors (different interlayers, different floor toppings, line-wise and point-wise support of topping, …) and floor/ceiling systems. The results of this research were rather disappointing: we didn't even approach the set target limit. Results of this measurement campaign are discussed more in detail in [2]. Some test results for different resilient interlayers under the same topping are given as an example to show the disappointing performance in figure 2.

So we proved to industry that a very different, innovative approach was necessary. In literature we have found systems approaching or going beyond the proposed target limit, using totally independent mounted ceilings (spanning from wall to wall) [3] or LWTF floors combined with concrete and even sand [4]. The disadvantage of independent ceilings is the resulting limited width of rooms. The floors with concrete/sand combinations have an important floor thickness and are very heavy, resulting in expensive wood sections and again a limited maximum span and room width. A reasonable floor height is necessary to be competitive with heavy weight floors which are in average only around 30 cm thick (floating floor included). As a result, the construction industry did not want to apply these systems.

To design a new type of floor, a considerable number of constructions were tested using the same basic floor construction in a real-scale timber frame mock-up and in collaboration with a large LWTF manufacturer in Belgium. The designs had to offer the possibility of off-site manufacturing and needed to be cost-effective. Not all tested constructions are presented here, but we select just three designs that finally led to the final design that is now being used by the manufacturer and that is now being proposed to the construction industry in Belgium. One series of experiments used two sandwich elements filled with 35 mm of sand to add mass (see Figure 3). First the upper sandwich element was put on top of a layer of rock wool of 20 mm (140 kg/m³), itself continuously applied on top of the lower sandwich element leading to a performance of $L'_{n,w} + C_{I,50\text{-}2500}$ = 53 dB. This result was considerably better than what could be obtained with conventional dry floating floor solutions. The next design tried to improve this performance by adding laths (see Figure 3) between the rock wool and the upper sandwich element in order to increase the involved effective surface masses in the mass-spring (rock wool)-mass system. This further improved the performance with 3 dB, but showed a mass-spring-mass resonance at 63 Hz due to the relatively stiff rock wool spring.

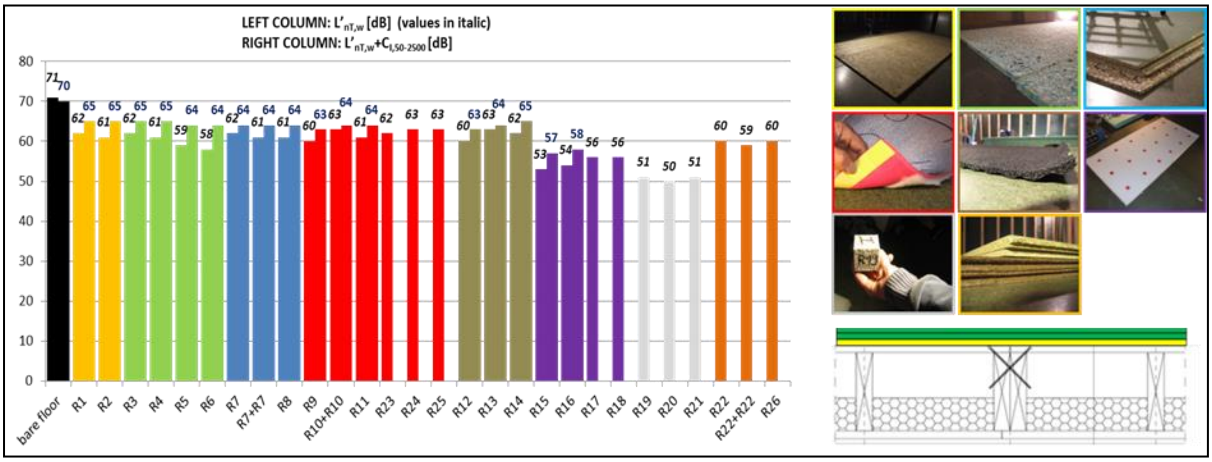


Figure 2 – Results for different type of resilient layers combined loaded with a double layer particle boards (12 mm + 18 mm as simulated parquet). The grey results approach the target limit, but are far too resilient with respect to vibrational comfort ("trampoline effect").

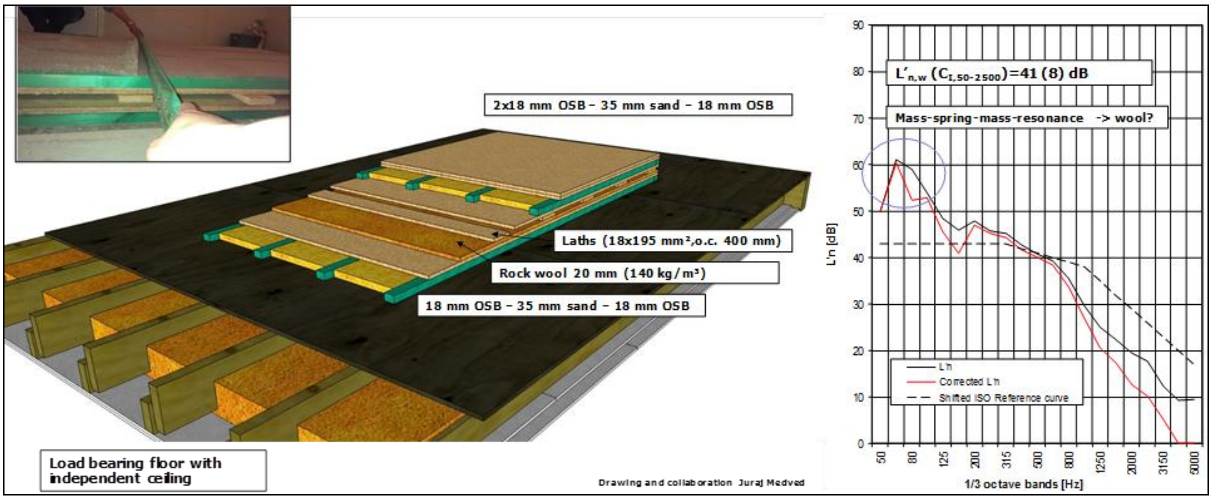
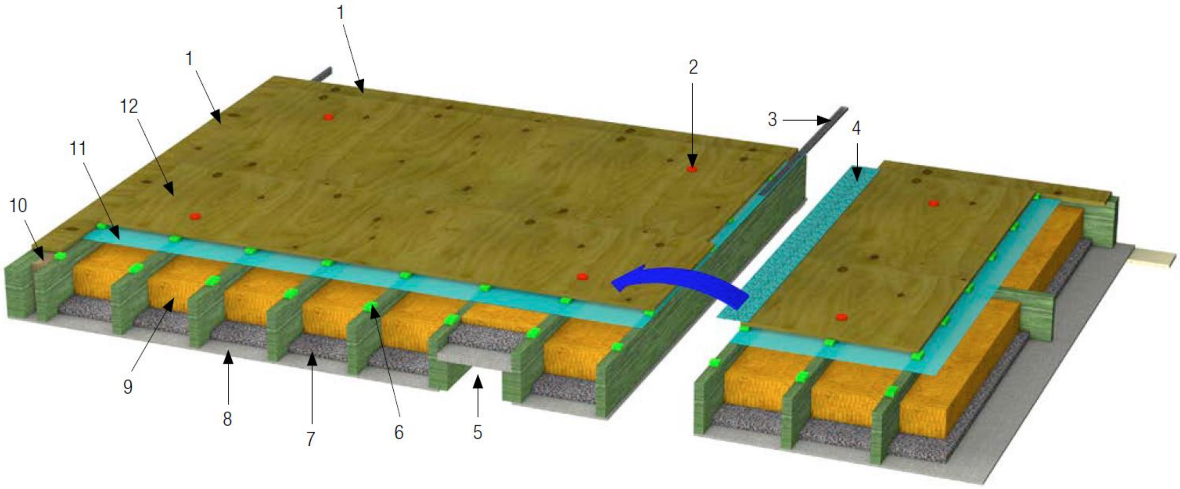


Figure 3 – Measured impact sound pressure level of two sand-filled elements put on top of a load bearing floor with independent ceiling. The upper element rests on OSB laths, put on a 20 mm rock wool mat applied on top of the lower sand-filled element. Also shown is the L'_n spectrum corrected for airborne tapping noise transmission according to ISO 10140-3:2010/FDAmd 3:2014..

The next step was obvious: a wider air gap was necessary to eliminate this peak and as such to obtain a better low frequency performance. An extra gap of 14 cm between both sandwich elements led to a $L'_{n,w} + C_{I,50\text{-}2500}$ value of 44 dB but then the total floor height became unrealistically large. Hence, different solutions were applied that tried to exploit the important cavity between the floor joists by the use of line-wise or point-wise (resilient) connections between the joists and the topping. In the final configuration, the lower mass of the designed mass-spring-mass system consists of the ceiling plates, the joists and a 35 mm gravel layer between the joists. The upper mass is a 60 mm screed cast on a formwork panel. The spring is now a parallel connection between the airborne spring through the mineral wool and the structural spring created by elastomer pads on the joists. After some optimization (from elastomer strips to pads, different elastomer stiffnesses, different gravel heights, different ceiling linings…) the final system that was withheld is shown in Figure 4. The floor has a performance measured in the laboratory of $L_{n,w} + C_{I,50\text{-}2500}$ = 48 dB and $R_w + C_{50\text{-}3150} \geq$ 64 dB and is less than 40 cm thick. (With a gravel layer of 60 mm, a $L_{n,w} + C_{I,50\text{-}2500}$ value of 46 was obtained.) Due to the use of gravel and screed, the construction equally offers a better thermal inertia. Wind forces and other structural concerns have been examined and solved (see Figure 9). The horizontal forces are now taken up by the lower boards that are a structural part of the floor composition.



1. Strip cut in a 12 mm thick particle board that facilitates the fixation of the vertical walls into the structure of the floor
2. Screws going through the joists in order to ensure the fixation of the particle boards during transport. These screws must be removed before executing the screed
3. Steel assembly piece (40 mm wide, 10 mm thick and 1,350 mm long) situated in a groove provided for this purpose in the joist. This piece continues up to the floor element that is located on the other side of the party wall and then is once again anchored in the joist. This assembly piece ensures the diaphragm effect with the floor of the neighbouring apartment, without interrupting the acoustical double wall of the party wall. The top face of this element is situated 12 mm (i.e. the thickness of the particle board, see no. 1) below the two parts of this double wall. The space thus created must be filled with mineral wool to ensure the continuity of the fire protection
4. Adhesive strip serving to waterproof the space between the two floor elements
5. Technical space intended for the apartment on the floor below
6. Resilient acoustical blocks 4 cm wide, 7 cm long and 2 cm thick, placed every 40 cm so as to form a grid pattern
7. Bulk stony material with a density > 1700 kg/m³ (a mixture of sand and gravel, for example)
8. 12 mm thick fibre-cement sheet
9. Flexible open-celled thermal insulation material (glass wool, for example) that also ensures the acoustical absorption, but which does not have to meet any particular fire-protection requirements
10. Mineral wool with specific fire-protection properties
11. Plastic film protecting against precipitation during installation on the work site
12. Moisture-resistant particle board 18 mm thick with an adhesively-bonded tongue-and-groove joint. This is simply placed on the acoustical blocks (see no. 6) and is no longer rigidly fixed either to the bearing floor after the implementation of the screed or to the vertical walls

Figure 4 – Schematic drawing of the innovative LWTF floor.

3. PARTY WALL DESIGN

The path we followed to develop a party wall that overcomes the low frequency problems of traditional timber frame party walls has been extensively described in [5] and [3]. The key point here is to move all the boards from the central cavity towards the extreme parts of the party wall in order to avoid the individual leaf resonances and to expel the central cavity mass-spring-mass frequency below 50 Hz. For fire safety reasons, the studs have to be deep enough or have to be protected by extra strips in the central cavity. When a technical lining is added at both sides, a small dip due to the lining cavity mass-spring-mass resonance can be seen at around 200 Hz, without reducing the overall performance considerably (see Figure 5). In laboratory, this effect becomes much more important due to the lack of edge losses that dampen this resonance (see Figure 6). This may also be an explanation why laboratory results are generally slightly worse than in-situ performances for LWTF constructions.

In-situ measured values for $R'_w + C_{50\text{-}3150}$ vary from 58 dB (Hechtel-Eksel) to 63 dB (Houthalen), while in laboratory, $R_w + C_{50\text{-}3150}$ values were between 58 and 61 dB (all with empty lining cavities). The final selected party wall has stud sections of 45x140 mm (400 mm o.c. and mineral wool in between) with a structural 15 mm fibre reinforced gypsum board attached. The technical lining is a 15 mm fire retarding gypsum board on 45x45 mm wooden studs (400 mm o.c.) (see Figure 9). Based on in-situ measurements, an R'_w value of at least 69 dB and an $R'_w + C_{50\text{-}3150}$ of at least 63 dB may be expected.

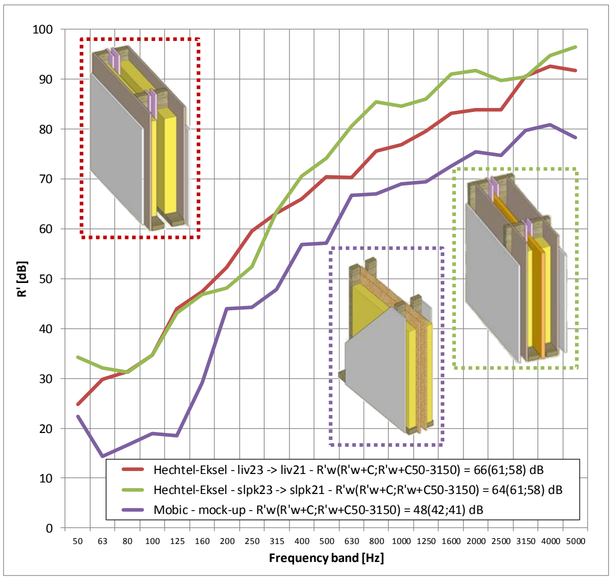


Figure 5. In-situ airborne sound insulation of double-stud party walls with panels inside the central cavity (Mobic mock-up) and with panels moved outside the central cavity (Hechtel-Eksel liv23 -> liv21). The green curve (Hechtel-Eksel slpk23 -> slpk21) shows the performance of the previous construction where at both sides a technical lining using timber battens has been added.

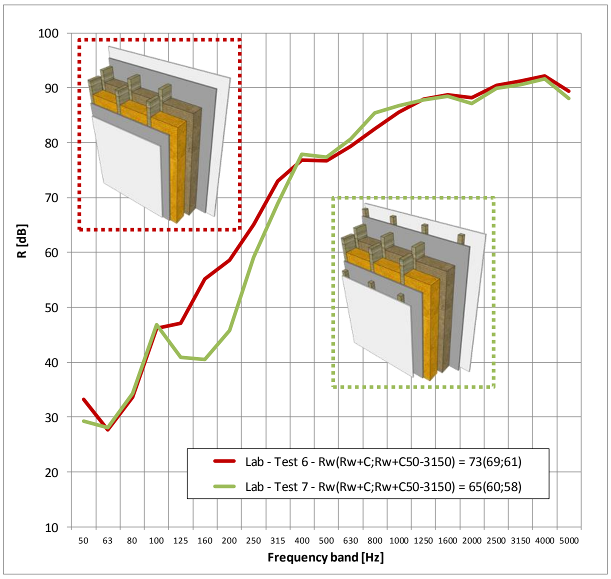


Figure 6. Laboratory airborne sound insulation of double-stud party walls with and without technical linings.

In order to obtain such a high in-situ values, it is obvious to avoid any flanking sound transmission by the façade panes. This is realised by extending the structural break formed by the party wall cavity over the façade wall and using a flexible open-porous sound absorbing material, at least in the façade inter-stud fields near the party wall. Indirect sound transmission through ventilation grids in the façade walls needs to be considered as well. At the ground floor and under the roofs, specific precautions need to be taken (see reference [3]).

4. FACADE DESIGN

In common LWTF constructions, façade panes are mostly single stud walls, with boards screwed at both sides and with an external cladding attached (eventually with a ventilated cavity behind). In order to optimize the airborne sound insulation properties of these façade elements, we started with elements without external cladding. In a first analysis, elements with internal technical linings are studied through a series of laboratory measurements. We observed that, also in this case, the basic principle of concentrating masses at the outsides of the elements and hence avoiding small non-filled cavities is extremely beneficial. In Figure 7, removing the panel behind the resilient bars improves the sound insulation performance dramatically: element 18 is much lighter than element 17 but performs 13 dB better in R_w and 6 dB better in $R_w + C_{50\text{-}3150}$ (less is more). Adding extra mass-loading panels further increases the performance in the whole frequency range. When a sound absorbing material is present in the technical lining cavity, the increase in performance by removing the middle panel is only substantial at low frequencies (50-100 Hz). The increase has however not been observed with similar façade elements where horizontal battens are used instead of resilient channels, most probably due to a dominant structural transmission in this case.

In a second laboratory measurement series, façade elements with both external and internal linings were studied. More than 30 measurements were done, studying several design parameters. Here, it was also interesting to look at the effect of adding mineral wool in the internal technical lining cavity. As can be seen in Figure 8, adding mineral wool makes only sense for resiliently attached linings, since with wooden lining studs, the structural transmission path appears to be dominant (compare tests 8-9 and 10bis-10). Even better than adding mineral wool in the internal lining cavity, would be removing the panel between the internal lining and the structural timber frame (compare tests 10-12). Once this is done, the broad-band performance is further increased when filling the internal and eventually also the external lining cavity (compare tests 12, 16 and 22). As an optimal cost-effective system, façade element 12 has been selected to be implemented in the new global LWTF concept. Extra work is still going on to optimize the hygro-thermal behaviour of the façade.

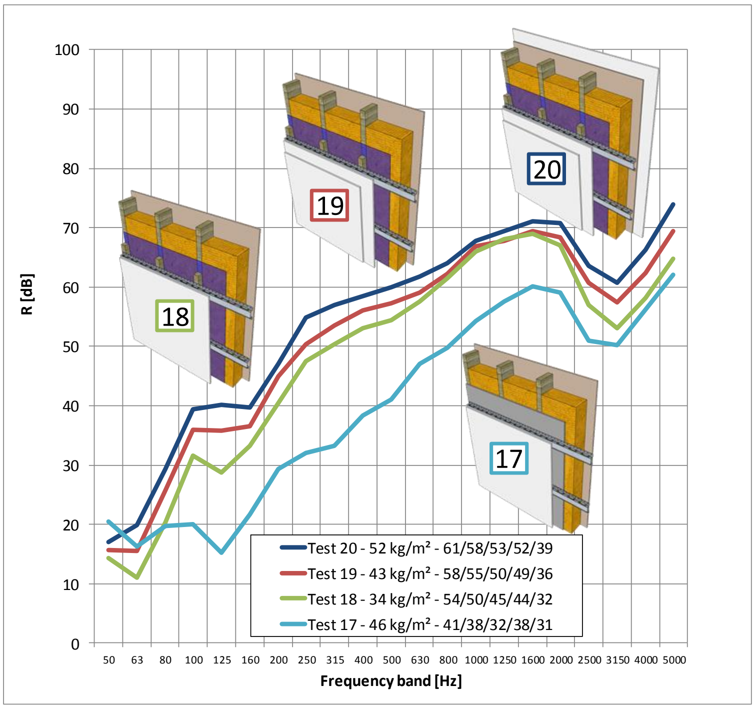


Figure 7. Laboratory airborne sound insulation of façade elements with inside linings on resilient channels. All elements have on the outside a 10 mm wood fibre cement board (brown) screwed to 140x45 mm² studs (o.c. 400 mm and filled with 140 mm glass wool). The grey board is a 12.5 mm fibre reinforced gypsum board. All white panels are applied to add extra mass and are 12.5 mm standard gypsum boards. The purple colour is a PE foil, serving as an airtightness membrane. Single number quantities in the legend are respectively R_w / R_w+C / R_w+C_{tr} / R_w+$C_{50-3150}$ / R_w+$C_{tr,50-3150}$.

5. TOTAL LWTF CONCEPT

Based on the cost-effective optimization of LWTF floors, party walls and façades as described above, a new LWTF building concept for multi-family housing has been developed in cooperation with a large off-site LWTF producer in Belgium, taking into account all engineering aspects, like fire safety, stability, hygro-thermal aspects, air tightness, HVAC, plumbing, …. The concept is proposed in Figure 9 and is proposed to the construction sector in Belgium.

6. CONCLUSIONS

In this paper, it was shown how the design of LWTF floor, party wall and façade elements has been acoustically optimized and how a cost-effective solution was found combining these elements into a new LWTF building concept ensuring comfort levels equal or better than currently encountered in typical acoustically well-designed Belgian heavy constructions.

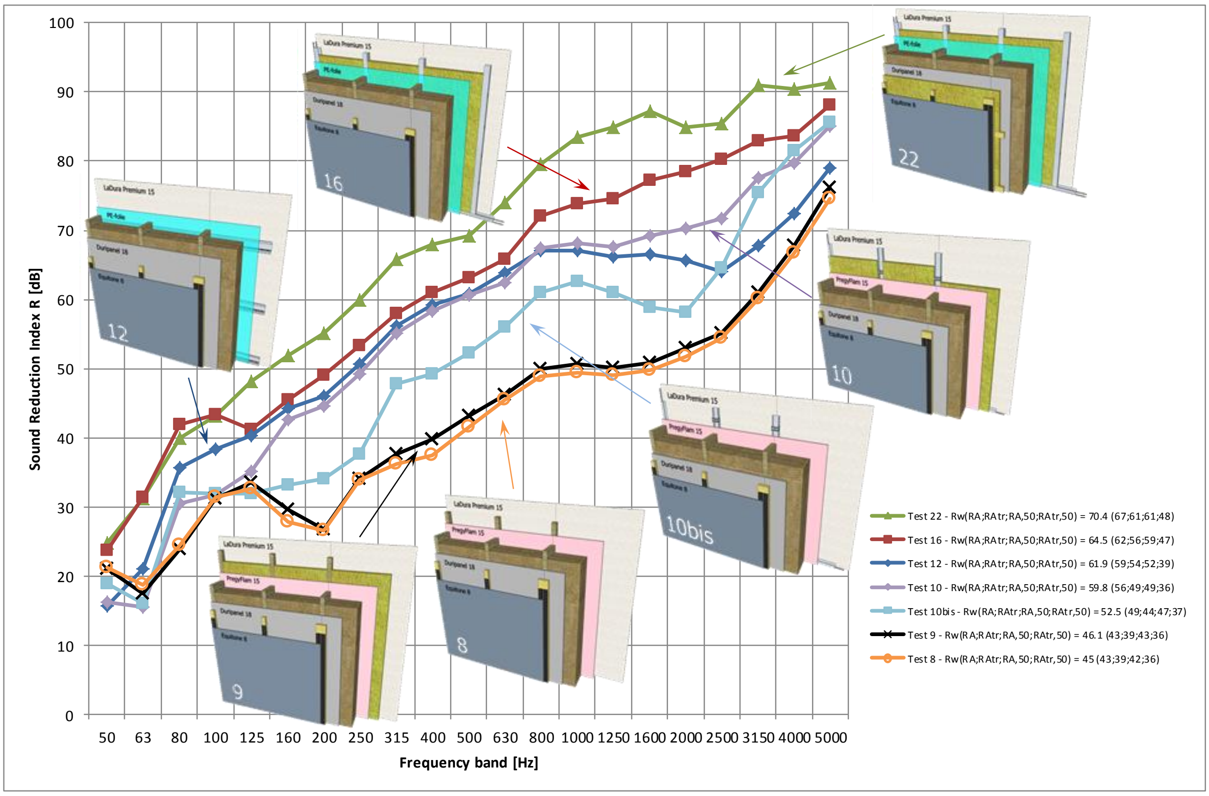


Figure 8. Some results of laboratory airborne sound insulation measurements on LWTF façade elements. The structural frame is made of 190x45 mm² studs, 600 mm o.c. and completely filled with mineral wool (30 kg/m³). The external lining (front side) is made of 10 mm fibre cement façade panels on 30 mm thick timber battens. The external racking board is an 18 mm wood fibre cement board. The internal board screwed to the structural frame (if any) is a 15 mm fire retardant gypsum board. In tests 12, 16 and 22, this board is replaced by a PE foil. The inside lining panel is a 15 mm fibre reinforced gypsum board. The inside lining support system consists of vertical wooden battens (tests 8-9), vertical metal studs on resiliently fixed braces (tests 10-10bis), horizontal resilient metal channels (test 12) or an independent metal stud frame (tests 16-22). The single number quantities in the legend are R_w, $R_w + C$, $R_w + C_{tr}$, $R_w + C_{50\text{-}3150}$ and $R_w + C_{tr,50\text{-}3150}$ respectively.

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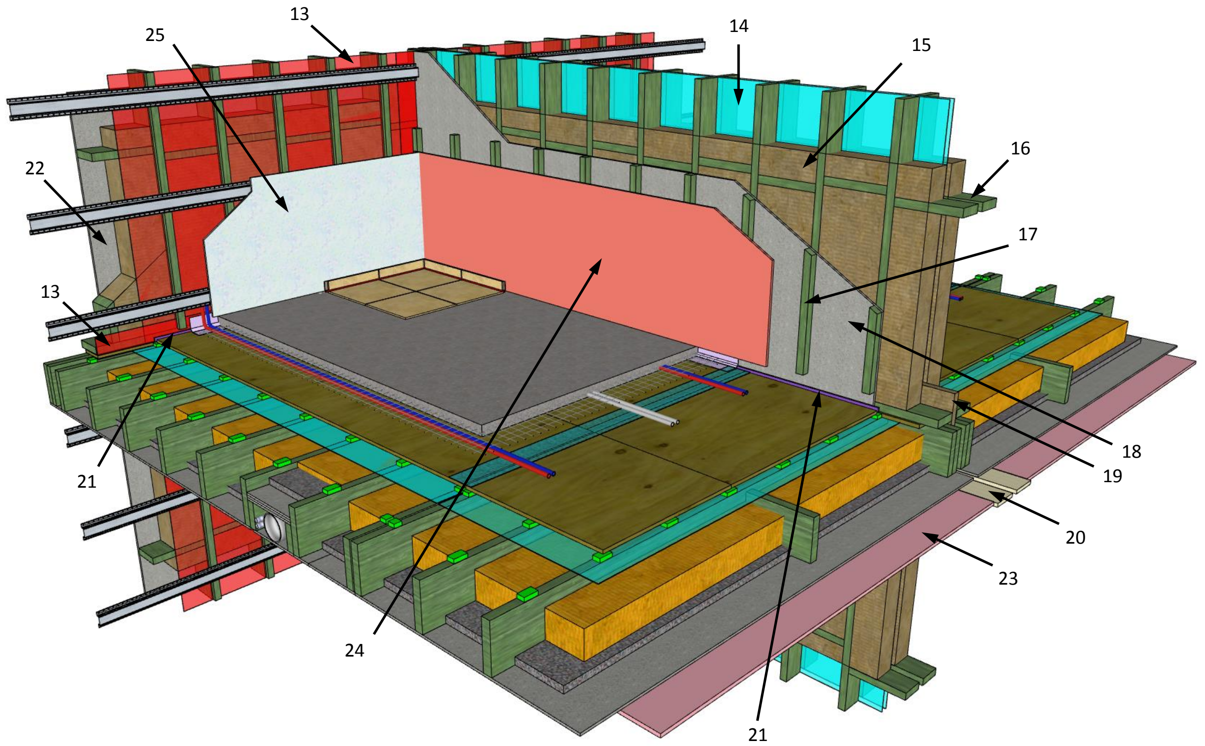

13. Airtight membrane
14. Plastic film protecting the wall against moisture during installation on the work site
15. 140 mm wide mineral wool panels with specific fire-protection properties
16. Wooden crosspieces in order to prevent the uprights of the wooden structure from buckling in case of fire after the disappearance of the panels (see no. 18)
17. Upright of the wooden structure of 45 x 45 mm² serving to hold up the technical lining
18. 15 mm thick fibre-reinforced gypsum board
19. Piece of rock wool placed perpendicular to the floor in order to close up the 4 cm interspace between the walls of the party wall and at the same time to prevent a chimney effect in case of fire
20. 12 mm thick fibre-cement sheet that participates in the fire safety
21. Rubber strip serving as an elastic separator between the formwork panel for the screed (see no. 12) and the vertical wall
22. 18 mm wood fibre cement board
23. 18 mm thick fire-retarding gypsum board
24. 15 mm thick fire-retarding gypsum board
25. 15 mm thick fibre-reinforced gypsum board

Figure 9. Newly proposed LWTF building concept.

REFERENCES

1. L. De Geetere, B. Ingelaere, M. Rychtárikova: Flanking sound transmission measurements on a timber frame mock-up. Project AH+, part 4. Proc. Inter-Noise 2013, Innsbruck

2 B. Ingelaere, D. Wuyts: Impact sound measurements on wooden floors. Project AH+, part 6. Proc. Inter-Noise 2013, Innsbruck

3 COST Action FP0702: Net-Acoustics for Timber Based Lightweight Buildings and Elements, Chapter 4: Acoustic Design of Lightweight Timber Frame Constructions. Available from: http://www.wtcb.be/homepage/index.cfm?cat=research&sub=scientific_publications

4 B. Zeitler, I. Sabourin, S. Schoenwald, E. Wenzke: On reducing low frequency impact sound transmission in wood framed construction. Proc. Inter-Noise 2012, New York

5 B. Ingelaere, M. Van Damme: Building guidelines for lightweight constructions. Project AH+, part 5. Proc. Inter-Noise 2013, Innsbruck