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NOISE CONTROL FOR A BETTER ENVIRONMENT

Design of a new generation of floors, with visible wood, using LVL, measurements and predictions

Jean-Luc Kouyoumji[1]
FCBA, Research Division,
Allées de Boutaut, BP227
33028 Bordeaux, France

Laureline Roy[2]
Metsawood France,
La Grande Arche - Paroi Nord
1, Parvis de la Défense
92044 Paris La Defense, France

ABSTRACT

Adequate levels of noise control in multi-family buildings are mandatory requirements of building codes, in Europe. Also, quality construction labels, since 2018, include low frequency behaviour, starting from 50 Hz. In many jurisdictions, these requirements are as strictly enforced as those for structural sufficiency and fire safety. Much effort has been spent on evaluation of sound transmission (R_w) and impact sound level (L_{nw}) of floor and wall assemblies and on studies of flanking transmission in multi-family dwellings. However, architects are challenging acoustic design with visible wood in construction: visible wood as a sealing or visible wood as a wall. This article focuses mainly on the development of LVL floors and walls assemblies made of laminate veneer lumber elements capable to perform well acoustically, in residential, multi-residential and non-residential buildings. Design, prediction and test results are presented.

Keywords: Modelling, Impact, Transmission Loss, Low Frequency, Wood
I-INCE Classification of Subject Number: 33, 43

1. INTRODUCTION

This article focusses on results obtained during a R&D project defining the composition of a partition floor for multi-dwelling wooden housing. The floor must be cost effective and of high acoustic insulation grade, toward airborne and impact noise. The innovative floor is composed by a load-bearing kerto-Ripa T inverted box-beam, filled with gravel.

[1] jean-luc.kouyoumji@fcba.fr
[2] laureline.roy@metsagroup.com

The industrial partner, Metsawood, stared with the design of a new type of floor that is known to be of high acoustic performance. Initial work, that inspired, was presented at the WoodRise Congress in September 2017, by Bart Ingelaere from CSTC Belgium.

The mission of the Timber Construction Division of FCBA is therefore initially to undertake a study, as complete as possible with:

- Acoustic tests
- Fitting of an acoustic calculation tool adapted for the building system,
- Acoustic extrapolation calculations, to complete the testing campaign for acoustic global values.

To adequately qualify the acoustic performance of the biggest range of build-ups, partners agreed on a new methodology based on measured and partially calculated floors. For that methodology the building systems are measured in the acoustic laboratory of FCBA, and calculation are performed on SEA-Wood calculation model developed by InterAC (France) mixed with an empirical approach, to better fit to laboratory measurements. Thus measurement are extended to other build-ups using an extrapolation methodology.

Extrapolation of measurement with calculation, opens-up a good opportunity to better qualify a bigger range of products, this is especially useful for lightweight constructions, where building configurations are very abundant.

2. LABORATORY MEASUREMENT CAMPAIGN

2.1 Aim of the measurement

The measurements of insulation characteristics of wooden floor for airborne noise, impact noise and heavy impact noise (method with the “Japanese ball”) were performed, at FCBA Acoustic facility in Bordeaux. All tests are covered by COFRAC accreditation.

1.2 Floor configuration description

Innovative wooden floor are composed as:

- Load-bearing wooden structure Kerto-Ripa T upside down 325 mm
- Insulation, mineral wool, thickness 100 mm
- Filled with gravel 35mm (60 kg/m²)
- CTBH 22 mm floor put on elastic interface glued on Kerto-Ripa Ribbs
- Elastic interface : Sylomer plot (45 x 100 mm) glued every 400 mm on Kerto-Ripa Ribbs
- Decking, Floor Topping: floating screed, plaster board 20 mm thickness
- Decking 2, Cement floor topping, liquid screed of 50 mm thickness
- Ceiling, Metallic structure: 35 mm studs, plaster board 12,5 mm thickness

Tests were conducted according to standards NF EN ISO 10140-1(2013), NF EN ISO 10140-2(2013), NF EN ISO 10140-4(2013), NF EN ISO 10140-5(2013) and evaluation of the global index according to standards NF EN ISO 717/1(2013) for airborne insulation and NF EN ISO 717/2(2013) for impact insulation.

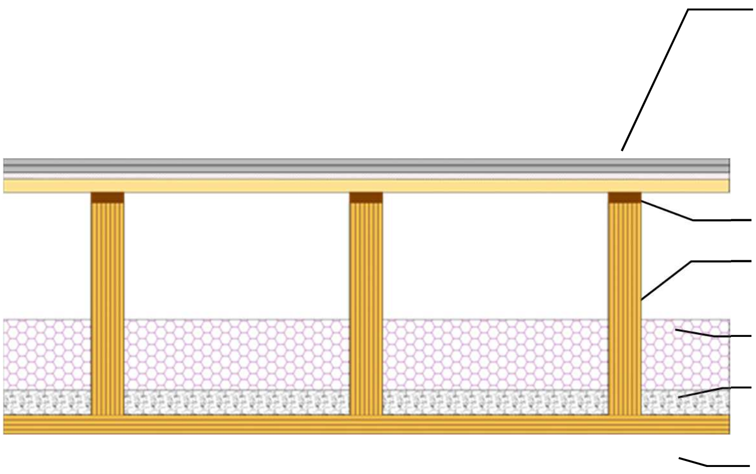


Figure 1 : Building system description

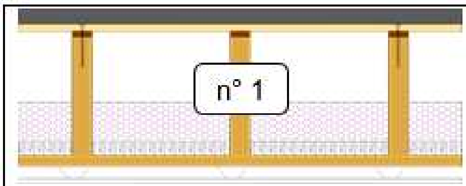
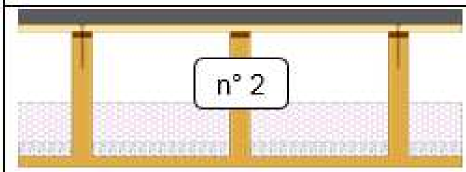
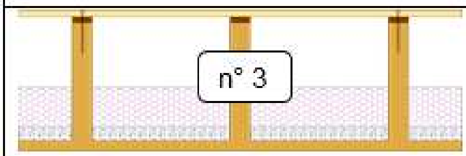
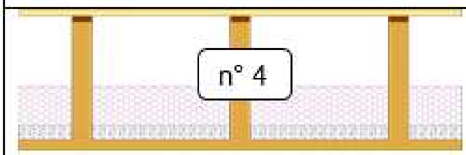
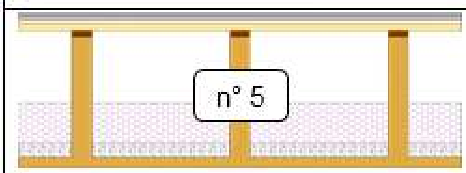
	Load-bearing wooden structure Kerto-Ripa T upside down 325 mm Cement floor topping, liquid screed of 50 mm thickness CTBH 22mm floor screwed to the Kerto-Ripa Ribs through an elastic interface Insulation: mineral wool, thickness 100 mm Filled with gravel 35mm (60kg/m²) Plaster board 12,5 mm thickness on metallic studs
	Load-bearing wooden structure Kerto-Ripa T upside down 325 mm Cement floor topping, liquid screed of 50 mm thickness CTBH 22mm floor screwed to the Kerto-Ripa Ribs through an elastic interface Insulation: mineral wool, thickness 100 mm Filled with gravel 35mm (60kg/m²)
	Load-bearing wooden structure Kerto-Ripa T upside down 325 mm CTBH 22mm floor screwed to the Kerto-Ripa Ribs through an elastic interface Insulation: mineral wool, thickness 100 mm Filled with gravel 35mm (60kg/m²)
	Load-bearing wooden structure Kerto-Ripa T upside down 325 mm CTBH 22mm floor put on the Kerto-Ripa Ribs above an elastic interface (so, without screws) Insulation: mineral wool, thickness 100 mm Filled with gravel 35mm (60kg/m²)
	Load-bearing wooden structure Kerto-Ripa T upside down 325 mm Floor topping: floating screed, plaster board 20mm thickness+10mm resilient CTBH 22mm floor put on the Kerto-Ripa Ribs above an elastic interface (so, without screws) Insulation: mineral wool, thickness 100 mm Filled with gravel 35mm (60kg/m²)

Figure 2 : Tested configurations

In this article, we only present the work on impact noise measurements. All configurations were also measured for airborne noise, and heavy load impact ball.

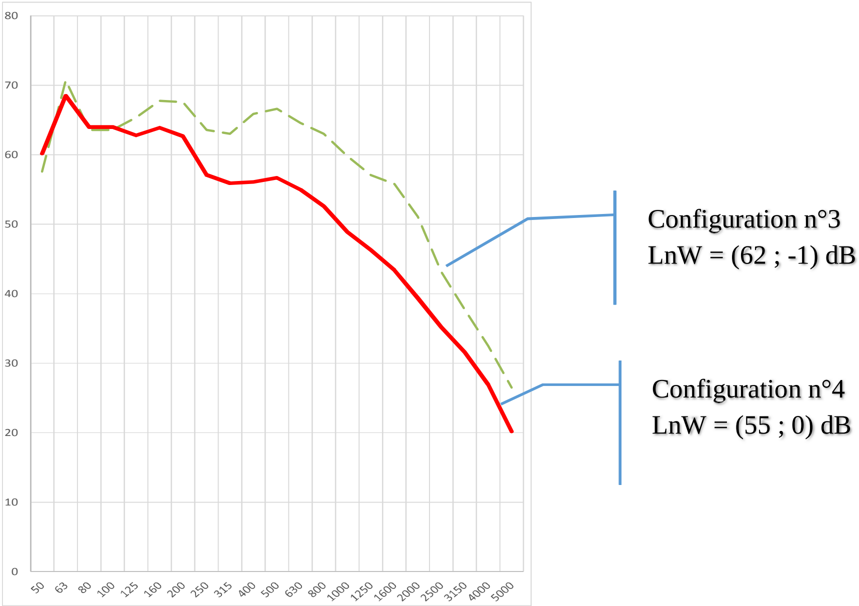


Figure 3 : Impact noise characterization, effect of point connection

[_] CTBH 22 mm on resilient layer on top of Kerto-Ripa with 35 mm gravel (red)

[--] CTBH 22 mm screwed (17 points) in resilient layer on Kerto-Ripa with 35 mm gravel (green)

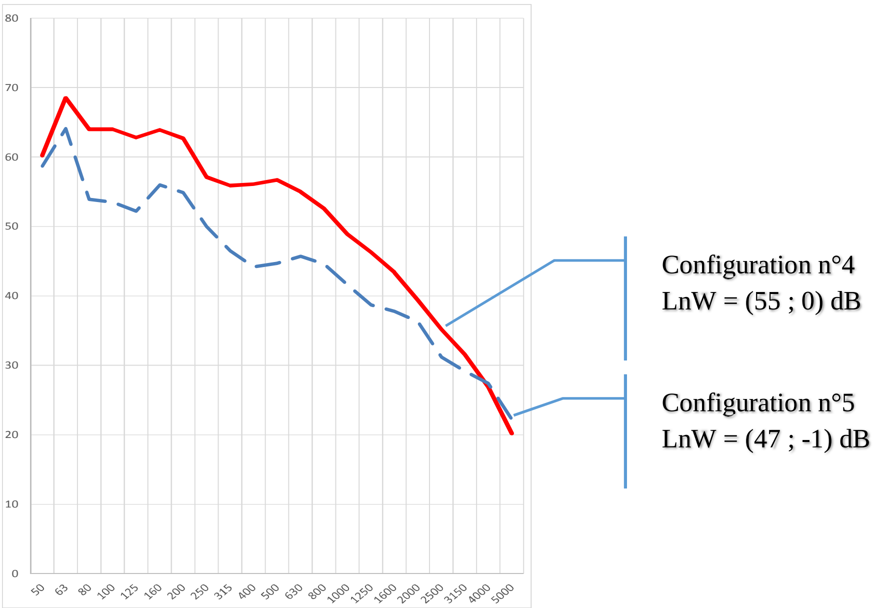


Figure 4 : Impact noise characterization, effect of floating decking

[_] CTBH 22 mm on resilient layer on top of Kerto-Ripa with 35 mm gravel (red)

[--] Floating decking on CTBH 22, on resilient layer on top of Kerto-Ripa with 35 mm gravel (blue)

3. STATISTICAL ENERGY ANALYSIS USED FOR ACOUSTIC MODELING

Statistical Energy Analysis theory involves subdividing the structure into subsystems and decomposing the frequency spectrum into third-octaves or octaves. In this way, the exchange of energy flow in the substructures can be analyzed. The parameters that set power flow vibrational transmission between subsystems are damping and coupling loss factors and can be identified experimentally by reversing the direct SEA problem as exposed in next paragraphs.

3.1. SEA theory for lightweight building prediction

Using Direct SEA, the modeling starts by decomposing the system into a set of components (the subsystems). For each of them the dynamical behavior is then predicted by SEA. Each subsystem is classically defined by:

- a modal density, N, that represents the distribution of statistical local resonances of the subsystem in the analyzed frequency band,
- a damping loss factor, η or DLF, which represents the fraction of power lost within the subsystem in steady-state,

The exchange of vibrational power between two coupled subsystems i and j is described by a pair of coupling loss factors ($\eta_{ij}$and η_{ji}or CLF) related by a reciprocity relationship:

$$\eta_{ij}N_i = \eta_{ji}N_j \qquad (1)$$

The total vibrational energy of a subsystem can be obtained from its spaced and frequency averaged velocity v² (the measurable engineering quantity and its total mass m) by the relationship:

$$E = mv^{2} \qquad (2)$$

E represents the total energy stored in resonant modes in a given frequency band of analysis centered on a radian frequency ω and acoustic pressure is related to velocity in cavities by

$$p = \rho c \cdot v \qquad (3)$$

In this band, SEA states that the exchange of power between coupled subsystems can be expressed as

$$P_{ij} = \omega\left[\eta_{ij}N_i\varepsilon_i - \eta_{ji}N_j\varepsilon_j\right] = \omega N_i N_j \beta_i^j\left[\varepsilon_i - \varepsilon_j\right] \qquad (4)$$

where $\beta_i^j$is the mean modal coupling loss factor between one pair of local modes of subsystems i and j and ε_i the mean modal energy. From this, $\eta_{ij} = \beta_{ij}N_j$

Knowing all modal densities, DLF and CLF, the energy state of the fully coupled system excited by external forces can be predicted from the following set of energy balanced equations traducing the energy conservation in each subsystem:

$$\frac{P_i}{\omega} = \eta_i E_i + \sum_{j}^{\text{All j coupled to i}} \left\{\eta_{ij}E_i - \eta_{ij}E_j\right\} \qquad (5)$$

where P_i is the power delivered in subsystem i by its applied external forces.

This theory: "Direct SEA" is used to predict energy flow between subsystems. The energy is converted into pressure level for cavities or rooms and into vibration level for flexural plates.

Below, we show how DLF and CLF can be determined by testing the structure using "Reverse SEA".

3.2. CLF and DLF determining using Reverse SEA

When the structure is decomposed into substructures, measuring damping and coupling loss factors corresponding to the physical studied structure is achievable by an inverse energy method. The related theory is called "Reverse SEA". The methodology is well known but is not part of current engineering practices except in some specific industry. Testing may be quite time consuming when dedicated software implementing Reverse SEA method is not used. In our testing approach, SEA-Exp developed by InterAC Toulouse is used for both acquiring the data and post-processing results.

To determine [η] (SEA loss matrix made of DLF and CLF), the transfer energy matrix and the vector of injected power are measured. Finally, we can use measured coupling to better predict junctions between panels.

3.3. Acoustic calculation module creation for the building system

In this task, we « adapt » a calculation module based on SEA, modeling. The theoretical calculation module proposed is hybrid, including measurements to perform better predictions.

The calculation module has validity limited. It estimates the sound transmission class R_W and/or L_{nW} for similar structures to the measured ones. For example, it is possible to estimate the acoustic sound transmission loss of a floor having two plasterboards from computing using the measurement of a floor having one plasterboard. So step by step, it is possible to propose values calculated for most configurations of the range.

The calculation results are presented with three modulations of the reliability:

- C+ = good reliability, the global values are given with +/- 1 dB
- C = average reliability, the global values are given with within +/- 3 dB,
- C° = low reliability, the global values are given with +/- 4 dB

Once the module is available and accordingly fitted, it is possible to calculate any structure configurations deriving from the tested structures. It is also be possible to get back later to perform new calculations if needed. The module is fitted only with specified and tested products. This it can be used only by the owner of products, here Metsawood.

The module needs vibroacoustic measured characteristics accurately (dynamic stiffness, mass, and possibly amortization). Thus, the estimates is valid for commercial products clearly identified. And, in case of modification of the compositions, it will either degrade the reliability of the calculation or will need a new characterization.

We modeled the test corresponding to the laboratory measurement of impact noise. Panels are modeled using flexural vibrating plates. Coupling is generated automatically by the code. Between the two leaves of the floor, we used a measured Coupling Loss Factor. Actual geometries of rooms, panels and cavities are introduced in the model. The material database of the software is implemented with the different beams, panels and fibrous characteristics.

The created Model is composed of a floor in point connection on top of the inverted Kerto Ripa, Kerto Q and Kerto S The ceiling is line connected to the beams.

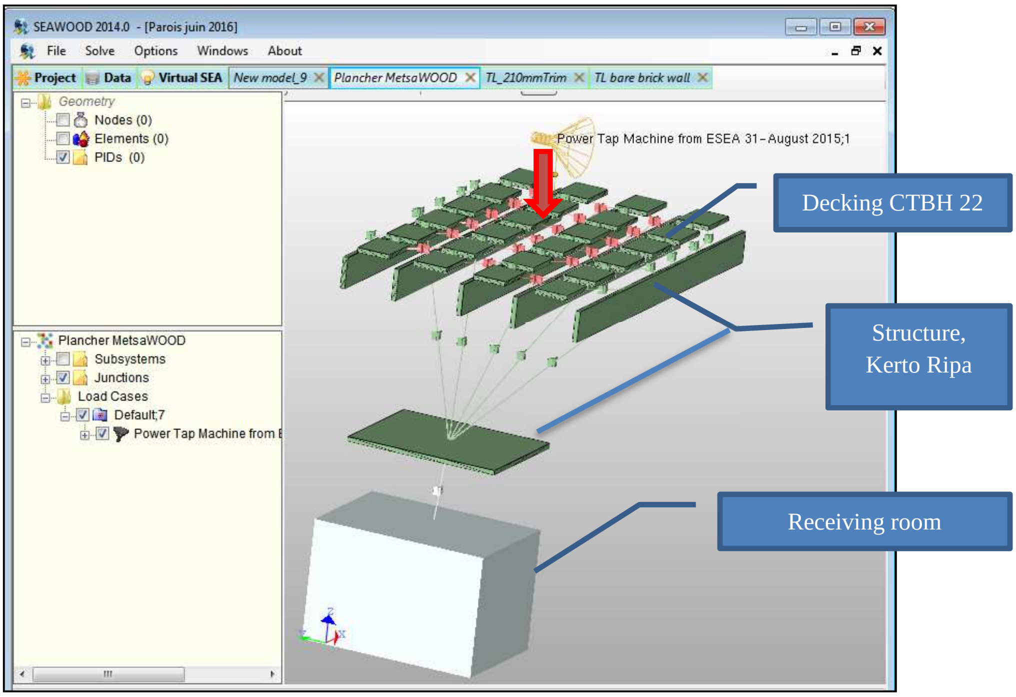


Figure 5 : Model for impact noise characterization

Power is injected in the structure via a tapping machine model.

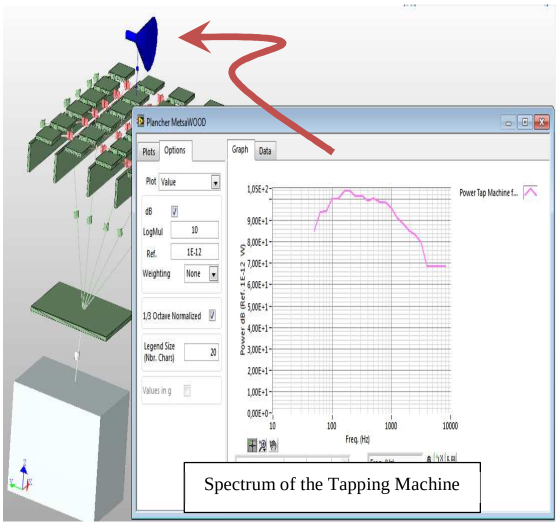


Figure 6 : Injected tapping machine power spectrum

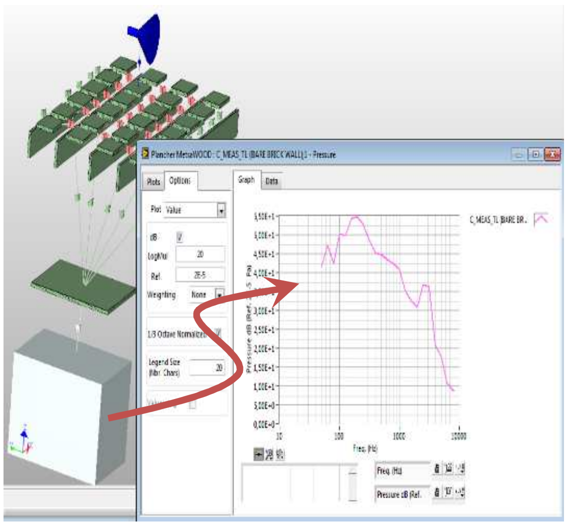


Figure 7 : Calculated noise spectrum in receiving room due to taping machine excitation

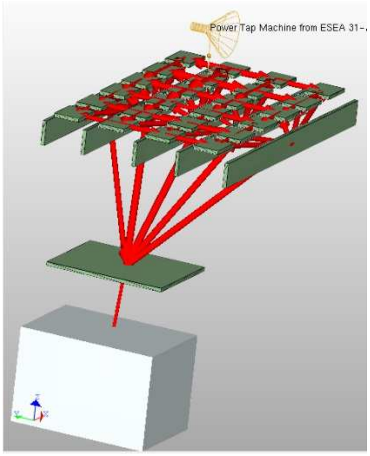


Figure 8 : Energy flow between subsystems of the floor

3.4. Prediction of impact noise level

A first step of validation is necessary to get the better agreement between measured and predicted L_n. Then, the measurement is used as a reference to derive the prediction from SEA-wood calculation and the lab measurement. Finally, we change the composition of the floor, in SEA-wood model, and determine the new impact noise level, Ln. In Figure 9, 10 and 11, we show measurements compared to the calculation of a derived floor using measured impact noise set as a reference for the calculation. First extrapolation was based on measurement n°4. With the addition of the suspended ceiling composed of one plasterboard on metallic studs.

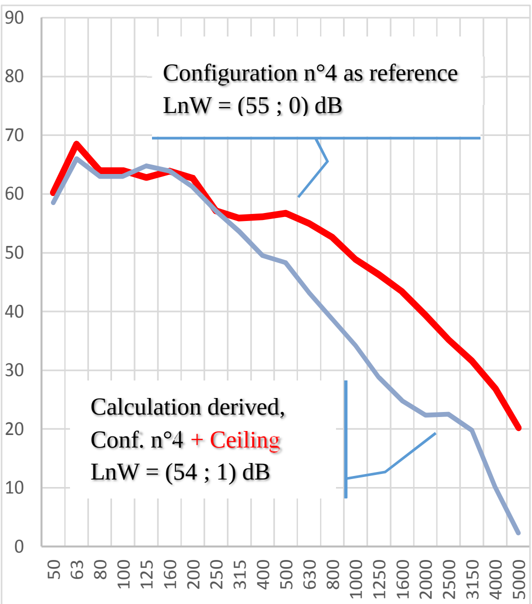


Figure 9 : First calculation, measured floor (n°619_4) [red line]
Extrapolation calculated with the addition of the ceiling, 1 plasterboard [blue line]

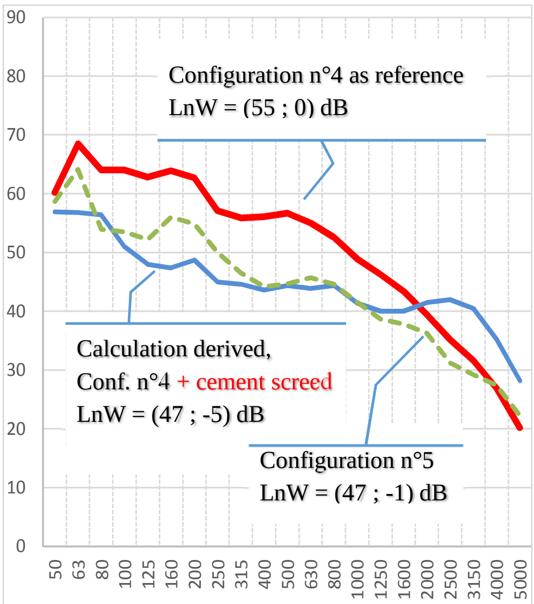


Figure 10 : Second calculation, measured floor (n°4) [red line]
Measured floor with a floating decking 20mm Plaster on resilient layer (n°5) [green line]
Extrapolation calculated with 50 mm of cement screed [blue line]

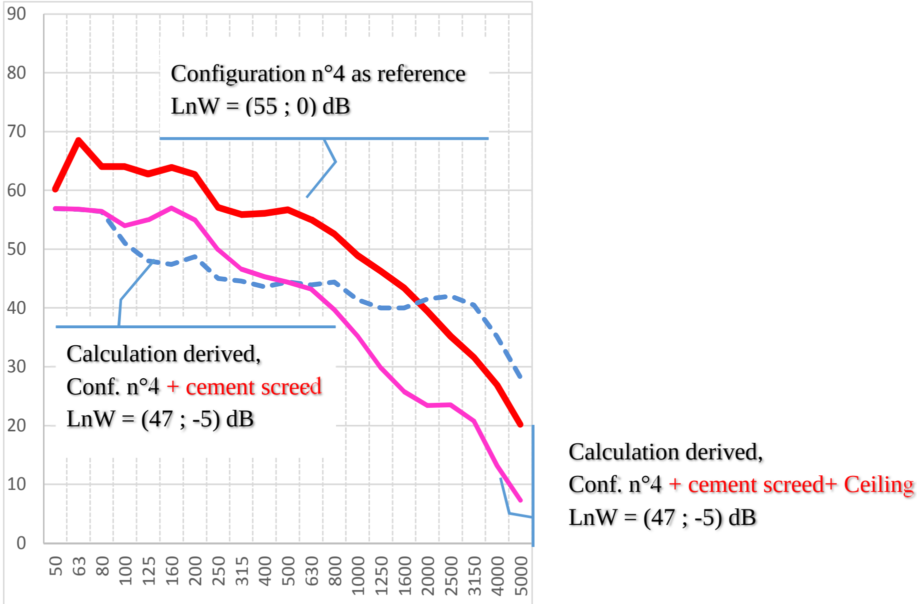
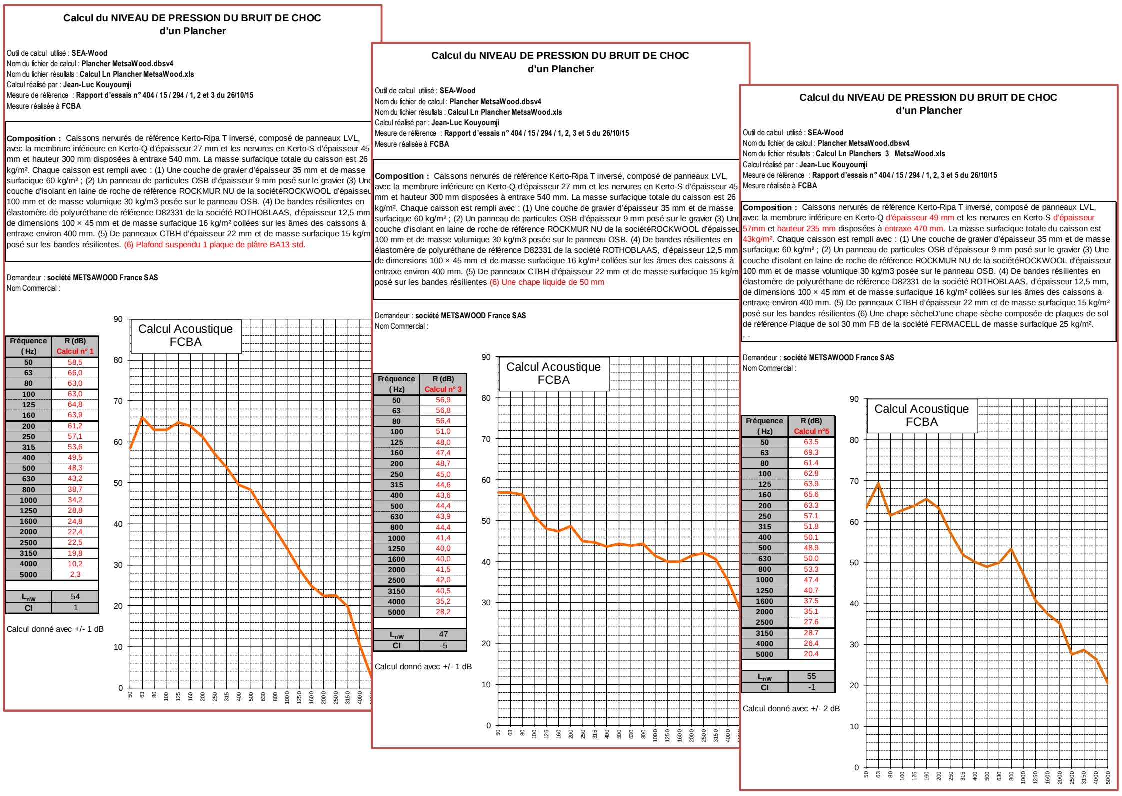


Figure 11 : Third calculation, measured floor (n°619_4) [red line]
Extrapolation calculated with 50 mm of cement screed [blue line]
Extrapolation calculated with 50 mm of cement screed and a suspended ceiling [pink line]



Calcul du NIVEAU DE PRESSION DU BRUIT DE CHOC d'un Plancher

Outil de calcul utilisé : **SEA-Wood**
Nom du fichier de calcul : **Plancher MetsaWood.dbsv4**
Nom du fichier résultats : **Calcul Ln Plancher MetsaWood.xls**
Calcul réalisé par : **Jean-Luc Kouyoumji**
Mesure de référence : **Rapport d'essais n° 404 / 15 / 294 / 1, 2 et 3 du 26/10/15**
Mesure réalisée à **FCBA**

Composition : Caissons nervurés de référence Kerto-Ripa T inversé, composé de panneaux LVL, avec la membrure inférieure en Kerto-Q d'épaisseur 27 mm et les nervures en Kerto-S d'épaisseur 45 mm et hauteur 300 mm disposées à entraxe 540 mm. La masse surfacique totale du caisson est 26 kg/m². Chaque caisson est rempli avec : (1) Une couche de gravier d'épaisseur 35 mm et de masse surfacique 60 kg/m² ; (2) Un panneau de particules OSB d'épaisseur 9 mm posé sur le gravier (3) Une couche d'isolant en laine de roche de référence ROCKMUR NU de la sociétéROCKWOOL d'épaisseur 100 mm et de masse volumique 30 kg/m3 posée sur le panneau OSB. (4) De bandes résilientes en élastomère de polyuréthane de référence D82331 de la société ROTHOBLAAS, d'épaisseur 12,5 mm, de dimensions 100 × 45 mm et de masse surfacique 16 kg/m² collées sur les âmes des caissons à entraxe environ 400 mm. (5) De panneaux CTBH d'épaisseur 22 mm et de masse surfacique 15 kg/m² posé sur les bandes résilientes. (6) Plafond suspendu 1 plaque de plâtre BA13 std.

Demandeur : **société METSAWOOD France SAS**
Nom Commercial :

Fréquence (Hz)	R (dB) Calcul n° 1
50	58,5
63	66,0
80	63,0
100	63,0
125	64,8
160	63,9
200	61,2
250	57,1
315	53,6
400	49,5
500	48,3
630	43,2
800	38,7
1000	34,2
1250	28,8
1600	24,8
2000	22,4
2500	22,5
3150	19,8
4000	10,2
5000	2,3
L_{nW}	54
CI	1

Calcul donné avec +/- 1 dB

Calcul du NIVEAU DE PRESSION DU BRUIT DE CHOC d'un Plancher

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Nom du fichier de calcul : **Plancher MetsaWood.dbsv4**
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Composition : Caissons nervurés de référence Kerto-Ripa T inversé, composé de panneaux LVL, avec la membrure inférieure en Kerto-Q d'épaisseur 27 mm et les nervures en Kerto-S d'épaisseur 45 mm et hauteur 300 mm disposées à entraxe 540 mm. La masse surfacique totale du caisson est 26 kg/m². Chaque caisson est rempli avec : (1) Une couche de gravier d'épaisseur 35 mm et de masse surfacique 60 kg/m² ; (2) Un panneau de particules OSB d'épaisseur 9 mm posé sur le gravier (3) Une couche d'isolant en laine de roche de référence ROCKMUR NU de la sociétéROCKWOOL d'épaisseur 100 mm et de masse volumique 30 kg/m3 posée sur le panneau OSB. (4) De bandes résilientes en élastomère de polyuréthane de référence D82331 de la société ROTHOBLAAS, d'épaisseur 12,5 mm, de dimensions 100 × 45 mm et de masse surfacique 16 kg/m² collées sur les âmes des caissons à entraxe environ 400 mm. (5) De panneaux CTBH d'épaisseur 22 mm et de masse surfacique 15 kg/m² posé sur les bandes résilientes (6) Une chape liquide de 50 mm

Demandeur : **société METSAWOOD France SAS**
Nom Commercial :

Fréquence (Hz)	R (dB) Calcul n° 3
50	56,9
63	56,8
80	56,4
100	51,0
125	48,0
160	47,4
200	48,7
250	45,0
315	44,6
400	43,6
500	44,4
630	43,9
800	44,4
1000	41,4
1250	40,0
1600	40,0
2000	41,5
2500	42,0
3150	40,5
4000	35,2
5000	28,2
L_{nW}	47
CI	-5

Calcul donné avec +/- 1 dB

Calcul du NIVEAU DE PRESSION DU BRUIT DE CHOC d'un Plancher

Outil de calcul utilisé : **SEA-Wood**
Nom du fichier de calcul : **Plancher MetsaWood.dbsv4**
Nom du fichier résultats : **Calcul Ln Planchers_3_ MetsaWood.xls**
Calcul réalisé par : **Jean-Luc Kouyoumji**
Mesure de référence : **Rapport d'essais n° 404 / 15 / 294 / 1, 2, 3 et 5 du 26/10/15**
Mesure réalisée à **FCBA**

Composition : Caissons nervurés de référence Kerto-Ripa T inversé, composé de panneaux LVL, avec la membrure inférieure en Kerto-Q d'épaisseur 49 mm et les nervures en Kerto-S d'épaisseur 57mm et hauteur 235 mm disposées à entraxe 470 mm. La masse surfacique totale du caisson est 43kg/m². Chaque caisson est rempli avec : (1) Une couche de gravier d'épaisseur 35 mm et de masse surfacique 60 kg/m² ; (2) Un panneau de particules OSB d'épaisseur 9 mm posé sur le gravier (3) Une couche d'isolant en laine de roche de référence ROCKMUR NU de la sociétéROCKWOOL d'épaisseur 100 mm et de masse volumique 30 kg/m3 posée sur le panneau OSB. (4) De bandes résilientes en élastomère de polyuréthane de référence D82331 de la société ROTHOBLAAS, d'épaisseur 12,5 mm, de dimensions 100 × 45 mm et de masse surfacique 16 kg/m² collées sur les âmes des caissons à entraxe environ 400 mm. (5) De panneaux CTBH d'épaisseur 22 mm et de masse surfacique 15 kg/m² posé sur les bandes résilientes (6) Une chape sècheD'une chape sèche composée de plaques de sol de référence Plaque de sol 30 mm FB de la société FERMACELL de masse surfacique 25 kg/m².

Demandeur : **société METSAWOOD France SAS**
Nom Commercial :

Fréquence (Hz)	R (dB) Calcul n°5
50	63.5
63	69.3
80	61.4
100	62.8
125	63.9
160	65.6
200	63.3
250	57.1
315	51.8
400	50.1
500	48.9
630	50.0
800	53.3
1000	47.4
1250	40.7
1600	37.5
2000	35.1
2500	27.6
3150	28.7
4000	26.4
5000	20.4
L_{nW}	55
CI	-1

Calcul donné avec +/- 2 dB

Figure 5 –Presentation Form of different predicted structures using SEA-Wood and measurement as a reference.

All calculation results are presented nearly the same way like a tested structure. With FCBA quality control department the calculation presentation was agreed, all acoustic calculation must follow a strict management:

- Title, with impact calculation or sound transmission loss calculation,
- Software used for acoustic calculation
- Name of the calculation file

- Name of the results file
- Name of the expert
- Name of the measurements used as a reference
- Place where the measurements were performed
- Precise description of the floor or wall calculated
- Identification of the structural variation calculated (in red)
- Curve values frequency / level
- Indices L_{nW}, R_w, R_a, $R_{a,tr}$
- On the curve presentation we add “Calcul Acoustique FCBA”

4. CONCLUSIONS

In this paper, we showed the methodology proposed for calculation of building systems using dual approach: SEA modeling and empirical. Tests are used as reference for calculation. We showed how impact prediction can be comparable to tested ones. We showed also how convenient this methodology fits to builders need. Companies get a more wide-ranging qualifications of their building systems offer.

5. ACKNOWLEDGEMENTS

We would like to acknowledge the financial support of Metsawood France and the active participation of Metsawood engineers.

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