Application of the Concept of Reference Timber Joist Ceiling

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Summary

The sound reduction of timber joist ceilings is determined by many construction details. Major and minor differences lead to a large number and diversity of ceilings. A project with the aim of providing airborne and impact sound insulation data of a large set of constructions is presented. The fundamental idea is to boost a series of measurements by calculatory extensions. A basic ceiling without floating screed has been defined. The improvement of various floating screeds (dry, wet, with/without heating system, different loading capacities, etc.) with respect to the bare test basic ceiling is measured. These improvements are transferred to target basic ceilings. The only difference between test ceilings and target ceilings is in the cladding on the lower side. Errors of this calculation compared to measured values are evaluated from ten cases. The calculation tends to underestimate the sound insulation. To compensate for overestimations, a safety allowance of 1 dB is recommended for $L_{n,w}$, $L_{n,w}+C_{I,50\text{-}2500}$, R_w and R_w+C, in case calculated values are used instead of measured values. For $L_{n,w}$ and $R_{w,}$ the errors are greater if the calculation is done with SNQs instead of with the third octave bands. Simple interpolation causes errors of the same absolute value than the SNQ-calculation, but for $L_{n,w}$, more cases of overestimation. While the results confirm the concept of transferred improvements if the lower side cladding is changed, it is not applicable with major changes of the load distribution board.

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1. Introduction

Many different construction elements in combination make up a timber joist ceiling. Examples of these elements are the joists, the load distribution boards on top, damping of the cavity, substructure and cladding on the lower side and screed on top. Architects have the choice between various implementations of these elements. Consequently, there is a diverse range of layouts. Therefore, it is a challenge to provide values of sound insulation over a range of layouts that is as complete as possible.

It is a common concept to split the problem into a basic ceiling and the screed-system on top. ISO 10140 [1] defines standard basic elements (Part 5, Annex C) and how to measure the sound insulation of the basic ceiling and the improvement by the floor covering (screed). EN 12354 [2] describes the calculation of a combination of ceiling and screed with these values as an input. One part of the task is to measure basic ceilings and screeds. Another is to identify the limits of transferring improvements measured on a defined test basic ceiling to a target basic ceiling that differs more or less from the test element. The three timber joist ceilings given in [1] are examples of constructions that are too different to transfer improvement data from one ceiling to another. This article presents a pair of basic ceilings with a more subtle difference in a single item that still causes unacceptably large deviations of the measured improvements.

A further part of the task is to estimate the additional uncertainty caused by calculating the sound insulation from measured data of components instead of measuring the complete ceiling itself. To do this, measured and calculated values are compared in this article.

The article begins with the introduction into the test series currently underway at the R&D of the Knauf group. There is a core timber joist ceiling that represents the test basic ceiling with the defined test cladding on the lower side and becomes one of many target basic ceilings with one of a number of different target claddings. While the target basic ceilings are only measured once without the screed system, the test basic ceiling is tested again and again with various floating screed systems to determine the improvements provided by the screeds. The total number of results obtained in this way is the number of claddings times the number of screeds. Both airborne and impact sound insulation are the subject of the project. For reasons of brevity here, the focus is on impact sound. This article is not a total or even representative listing of the results of the project. The results will be published by Knauf group companies, and if appropriate, in the public database by lignum [3]. The choice of results given in this article is rather determined by the example of differing core ceilings and the investigation of prediction uncertainty as mentioned above.

2. Description of constructions

2.1. Core basic ceiling

The part of the ceiling that both test and target construction have in common is called the core in this text.

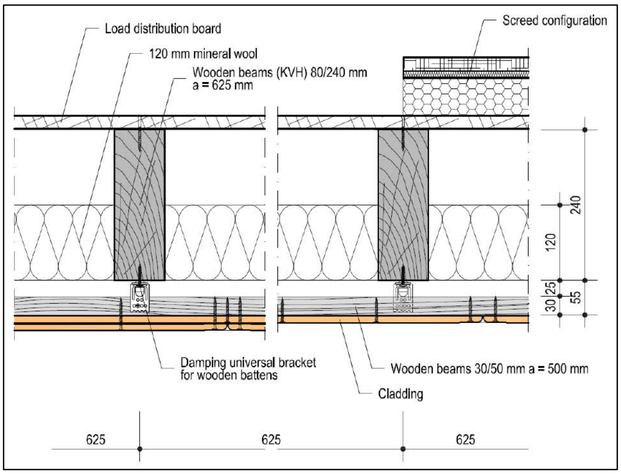

Figure 1: Basic ceiling, cross section perpendicular to the joists. Screed and lower claddings shown are examples.

From bottom to top, it consists of wooden battens, a decoupled suspender with a rubber element and a resonance frequency of less than 25 Hz under typical load conditions (20 % to 100 % of approved maximal load), the timber joists and load distribution boards. Two different core basic ceilings are considered. They differ only in the load distribution board. One referred to as "**Wood**" is 22 mm chipboard (14.0 kg/m², screw centre spacing 350 mm). The other referred to as "**GF**" is 28 mm high density gypsum fibre (46 kg/m², distance of screw nails 150 mm). Wood is a contemporary construction at least in Germany and is the subject of the current project. The large height of the joists of 240 mm aims to reduce vibration levels. The GF core here is used solely to derive estimators of the prediction uncertainty and as a second example of a core. There is 120 mm mineral wool inside the wood core, 240 mm inside the GF core.

2.2. Cladding of the lower side

The current project deals with one or two layers of gypsum board on the lower side screwed to the suspended wooden battens of the core ceiling. Different densities and thicknesses are utilized. The range of total mass per area covers 8.5 kg/m² to 35 kg/m². Hence, the minimal resulting resonance frequency (assuming a mass per area of 50 kg/m² of the core basic ceiling together with screed) goes down to 21 Hz. This is two octave bands below the resonance frequencies of the best floating screeds and shows how greatly the sound insulation of timber ceilings can be regulated by suspended ceilings. The densities of the boards involved are approximately 0.68 t/m³ (standard), 0.83 t/m³ (GKF), 1.0 t/m³ (type Diamant) and 1.4 t/m³ (type Silentboard). Thicknesses are 12.5, 15, 18, 20 and 25 mm.

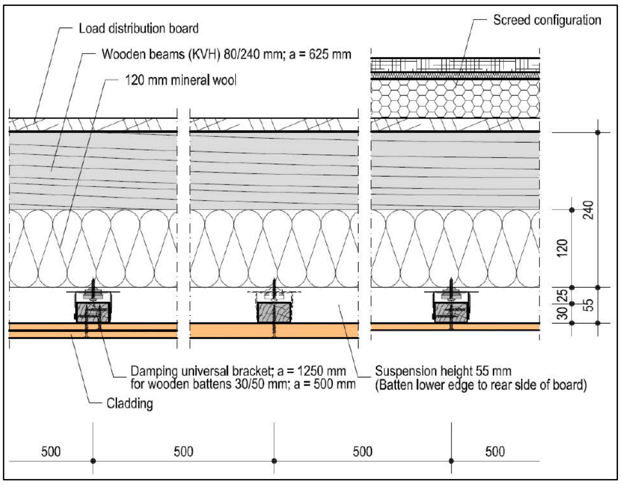

Figure 2: Basic ceiling, cross section parallel to the joists. Screed and lower claddings shown are examples.

At the conclusion, 16 combinations will have been tested without screed. 14 of them are intended as target basic ceilings. Instead of only one test cladding, it was decided to measure two test claddings. These claddings are one ("**1SB**") and two ("**2SB**") layers of 12.5 mm type Silentboard equivalent to 17.5 and 35 kg/m² with a critical frequency slightly higher than standard boards. This choice represents the middle and the high end of the sound insulation range. The arithmetically averaged improvements of both will be used for the calculations. Besides deriving a further directly measured value, the advantages are more robust values of improvements and a better basis for plausibility checks.

2.3. Floating screed constructions

The choice of a screed can be driven by various motivations. Sound protection is just one of these. An underfloor heating system or a layer for installations like conduits, pipes or wires is often needed. A prefabricated screed is slim and requires no drying time. On the other hand, a self levelling flowing screed can be combined with softer impact insulation materials and offers the better sound insulation. The dynamic stiffness of impact insulation materials is restricted to a lower limit by the load of the floor for the intended usage and the screed material and thickness. A wide range of floor screed constructions is therefore included in the project. Up to now, there are two calcium sulphate flowing screeds. One (55 mm) with a heating system on 35 mm EPS (dynamic stiffness classification < 15 MN/m³, measured 12 MN/m³) and one (35 mm, approx. 70 kg/m²) on 25 mm mineral wool (class. < 15 MN/m³, measured 9-13 MN/m³ dynamic stiffness, 2 kg/m²) and an intermediate wood wool slab (13 kg/m²). The latter has a calculated resonance frequency on heavy massive floors of 50-70 Hz. In the following, this screed is referred to as “**FS**”. Most of the prefabricated floor screeds of the project are made of gypsum fibre boards with a density of 1.2 t/m³ and thicknesses of 18 or 23 mm in one or two layers. In case of two layers, they are glued and/or screwed to each other. A popular prefabricated element consists of 10 mm wood fibre as impact sound insulation material glued to such a board. An element like this (23 mm gypsum fibre) on 60 mm EPS is referred to as “**PS**” in the following. In this layout, the EPS layer provides space for ventilation channels or other equipment and has no dynamic stiffness classification. Other layouts of prefabricated screeds utilize mineral wool impact sound insulations that are a compromise of the lowest possible dynamic stiffness and the maximum static load required by the application. The lowest calculated resonance frequencies on heavy massive floors are below 100 Hz (2x23 mm gypsum fibre ≈ 55 kg/m²). It is also intended to include prefabricated screeds with heating systems into the project.

3. Evaluated datasets

By the nature of the project, the target sound insulations with screed are not measured. Still in case of two target basic ceilings, it has been done with the screed called FS. In a former test series with the slightly different basic ceiling GF, no prediction has been applied, but nevertheless the measurements without screed have been done. We get four datasets from this series. Including the measurements with the claddings 1SB and 2SB from both series, there are 10 datasets (see Table 1).

Figure 3 shows the normalized impact sound pressure levels without screed for these datasets. The different basic ceilings’ cores can be distinguished by the colour of the lines. The test lower side claddings with Silentboard are marked by dots. The dots are filled in case of the Silentboard double-layer (2SB) and empty for the single layer (1SB).

Table 1: Claddings and measured SNQ improvements of evaluated datasets.

Core basic ceiling	Screed configuration	Lower side cladding			Measured improvement			
		Abbreviation	Thickness [mm]	m’ [kg/m²]	$-\Delta(L_{n,w})$ [dB]	$-\Delta(L_{n,w}+C_{I,50\text{-}2500})$ [dB]	$\Delta(R_w)$ [dB]	$\Delta(R_w+C)$ [dB]
GF	PS	C1	12.5	8.5	12.2	4.2	4.8	3.5
		C2	18	14.6	17.9	6.5	5.7	3.9
		1SB	12.5	17.8	14.1	5.3	3.5	1.8
		C3	12.5 12.5	8.5 12.6	15.9	5.3	4.8	3.9
		C4	12.5 12.5	8.5 17.8	14.7	5.5	4.5	3.9
		2SB	12.5 12.5	17.8 17.8	15.3	5.5	3.0	2.1
		average SB			14.7	5.4	3.2	2.0
		average all			15.0	5.4	4.4	3.2
Wood	FS	C2	18	14.8	15.4	11.3	12.3	6.7
		1SB	12.5	18.1	13.2	11.2	8.5	3.8
		C5	25	20.1	13.7	11.5	11.4	6.9
		2SB	12.5 12.5	17.7 17.8	12.4	12.0	6.5	4.5
		average SB			12.8	11.6	7.5	4.2
		average all			13.7	11.5	9.7	5.5

Apparently, both basic ceilings have different characteristics. Hardly surprising is the better performance of the more heavy core basic ceiling GF below 200 Hz. It follows a crossover range and above 500 Hz the version with chipboard performs better under excitation with the tapping machine. The lower critical frequency of the thicker boards leads to corresponding peaks. Besides these peaks, the basic ceilings rank according to the mass per area of the lower side cladding.

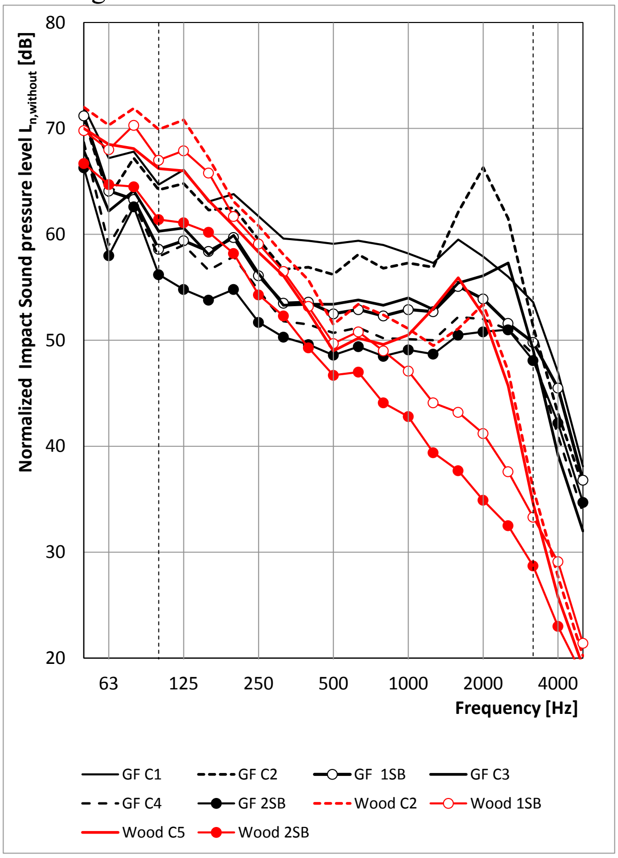

Figure 3: L_n of the basic ceilings of the evaluated datasets.

4. Prediction models

In the following, X denotes either 1/3-octave band or single number quantities of impact or airborne sound insulation.

X	L_n	normalized impact sound pressure level
	R	sound reduction index
	$L_{n,w}$	
	$L_{n,w}+C_{I,50\text{-}2500}$	
	R_w	
	R_w+C	

Here, the improvement Δ is defined as for airborne sound insulation in ISO 10140 [1] Part 1 Annex G.

$$\Delta X = X_{with} - X_{without} \qquad (1)$$

For impact sound pressure levels, this means a different sign than in the definition of ISO. Note the extra signs in Table 1 and Figure 6 to obtain the usual appearance.

Thus, the prediction model can be expressed in a unified manner:

$$X_{target,with,calc} = X_{target,without,meas} + \Delta X_{test,meas} \qquad (2)$$

Here, the indices have these meanings:

with, without	presence of screed construction
target	construction to be predicted
test	basic ceiling used to measure the improvement of the screed
calc	value predicted by calculation
meas	measured value

Prediction of SNQs can be done in two ways: Either by directly using SNQs in formula (2) or by first applying formula (2) to each 1/3 octave band followed by determination of the SNQ according to ISO 717. It is not considered to add the improvements ΔX to an intermediate reference floor, like for example, $L_{n,r,0}$ given in ISO 717-2 table 4 [4], as improvements and basic values are measured in the same transmission suite and even the basic ceiling core is one and the same.

For this project, the improvements of the claddings 1SB and 2SB are averaged

$$\Delta X_{test,meas} = 0.5\left(\Delta X_{1SB,meas} + \Delta X_{2SB,meas}\right) \qquad (3)$$

Other choices of the test basic ceiling evaluated in [5] are C1, 1SB, 2SB and the average of all available datasets.

An interesting question is how a rough interpolating estimation performs by comparison. As a mathematical representation of such a interpolation, linear regression over the mass per area log(m') of the lower side cladding is evaluated in [5]. The regression was fitted to the datasets 1SB and 2SB (see e.g. Figure 4 and Figure 5).

5. Uncertainty of the prediction

The prediction error Err is considered as the deviation of the predicted value from the measured value.

$$Err_X = X_{calc} - X_{meas}, \text{ impact}$$
$$Err_X = X_{meas} - X_{calc}, \text{ airborne} \qquad (3)$$

The distinction of cases yields a positive error, whenever the sound protection is underestimated. The purpose of a safety allowance is to compensate negative error values.

The error of the single number quantities is given in Table 2. The average error is smaller for impact (-0.3 dB to 1.4 dB) than for airborne excitation (1.5 dB to 2.4 dB). One could consider an offset compensation by a constant value in formula (2) to give an average error of 0 dB. This idea is not taken further, as there is no physical explanation, the database is small and the positive offset has the effect of a safety margin. The root mean square (RMS) is included as a measure of the spread. The spread of $L_{n,w}$ is greater for the SNQ calculation than for the third-octave calculation. Out of all four SNQs under consideration, $L_{n,w}+C_{I,50\text{-}2500}$ is outstanding for errors being minor, having little spread and not being greater with SNQ calculation. This may be explained by the SNQ being dominated only by a view of third octave bands and it may be different with special combinations of screed and basic ceiling.

Table 2: Prediction errors. Extremes in bold print. In red: Negative values, i.e. overestimation of sound insulation.

Core basic ceiling	Screed configuration	Lower side cladding	Error of prediction Err [dB]: 1/3 octave band calculation: $L_{n,w}$ [dB]	$L_{n,w}+C_{I,50\text{-}2500}$ [dB]	R_w [dB]	R_w+C [dB]	SNQ calc.: $L_{n,w}$ [dB]	$L_{n,w}+C_{I,50\text{-}2500}$ [dB]
GF	PS	C1	**-0.8**	**-1.2**	1.5	**2.2**	**-2.5**	**-1.2**
		C2	0.6	**0.4**	**1.7**	**1.4**	**3.2**	**1.1**
		C3	0.9	-0.2	**1.3**	1.8	1.2	-0.1
		C4	**1.3**	0.1	1.5	2.1	0.0	0.1
		avrg	*0.5*	*-0.2*	*1.5*	*1.9*	*0.5*	*0.0*
		RMS	*0.9*	*0.6*	*1.5*	*1.9*	*2.1*	*0.8*
		1SB	0.2	0.0	0.3	0.1	-0.6	-0.1
		2SB	-0.2	0.1	-0.2	-0.2	0.6	0.1
Wood	FS	C2	**2.4**	**-0.4**	**2.8**	**2.4**	**2.6**	**-0.3**
		C5	**0.4**	**-0.1**	**1.2**	**2.4**	**0.9**	**-0.1**
		avrg	*1.4*	*-0.3*	*2.0*	*2.4*	*1.8*	*-0.2*
		RMS	*1.2*	*0.2*	*1.5*	*1.7*	*1.4*	*0.2*
		1SB	0.4	-0.6	0.8	-0.4	0.4	-0.4
		2SB	-0.4	0.4	-0.9	0.3	-0.4	-0.4

For the sake of brevity, the errors of the SNQ calculation are not included in Table 2 for the airborne quantities R_w and R_w+C. Compared to the third-octave calculation, they are larger for R_w (up to 5 dB) and quite the same for R_w+C. In both cases, the worst overestimation remains the same.

Considering third-octave-calculation, only the three worst cases of overestimation are close to -1 dB (-0.8 dB $L_{n,w}$, -1.2 dB $L_{n,w}+C_{I,50\text{-}2500}$ first line and -0.9 dB R_w last line). Consequently, it is recommended to apply a safety allowance of 1 dB when calculated values are used in the same way as measured values. This holds for the named four SNQs, third-octave-calculation, both basic ceilings (Wood and GF) and is to be used in addition to allowances for other uncertainties, e.g. of measurement.

Interpolation works surprisingly well, especially for $L_{n,w}+C_{I,50\text{-}2500}$ (see Figure 4). Still, Figure 5 shows that for $L_{n,w}$ overestimations up to 3 dB occur. Note that a much better regression could be fitted if all datasets were evaluated. This is just a simulation of what would happen, if only the datasets 1SB and 2SB were available. Similar results arise from the combination wood+FS and for the airborne SNQs. For complete evaluation of the interpolation method see [5].

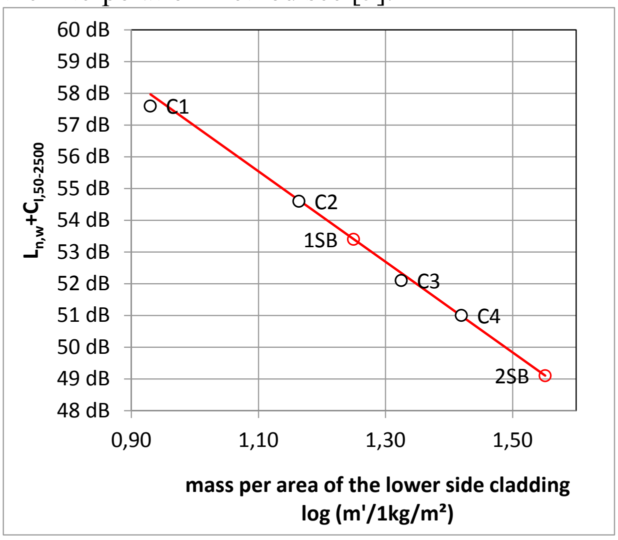

Figure 4: Interpolation of $L_{n,w}+C_{I,50\text{-}2500}$.

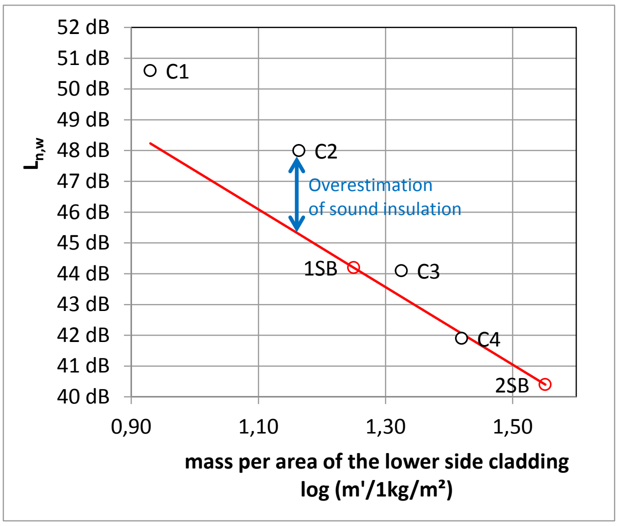

Figure 5: Interpolation of $L_{n,w}$. The straight line from measurement 1SB to measurement 2SB predicts a $L_{n,w}$ up to 3 dB below the measured value.

6. Incompatibility of the basic ceilings

The small errors of Table 2 show that the prediction model works well, as long as improvements are transferred to basic ceilings that differ only in the cladding on the lower side. The improvements are within a small corridor as can be seen in Figure 6. This applies to both variants: The one with the light thin chipboard load distribution board and the one with the heavy, thick gypsum fibre boards. But Figure 6 also shows that the transfer between the different core basic ceilings will cause unacceptable errors. The improvement is clearly different, and the difference exceeds the spread within the same basic ceiling. Supported by a single comparative measurement, the difference of cavity damping (120/240 mm) is judged to be irrelevant in this context.
As long as no better data is available, the errors of the GF basic ceiling are still considered as estimators of the errors of the wood basic ceiling and vice versa.

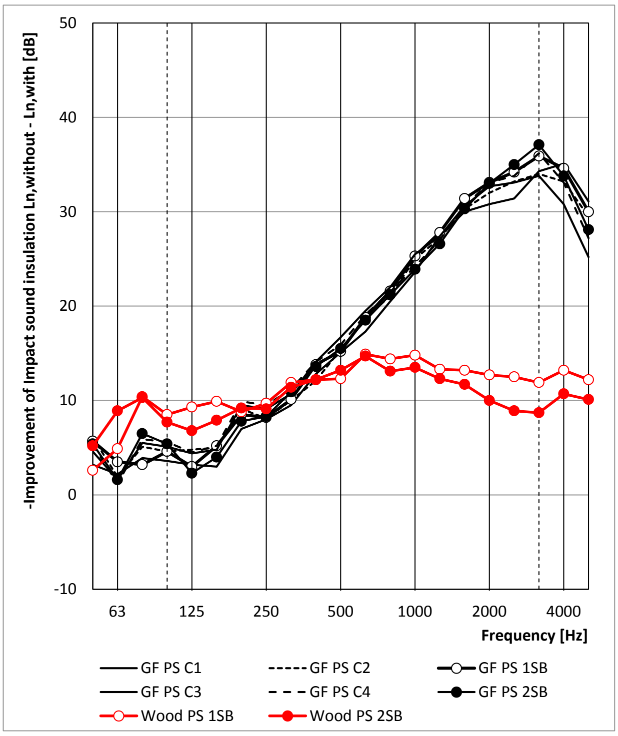

Figure 6: Improvement of screed PS on basic ceiling GF and Wood (Impact sound insulation).

7. Outlook

The evaluation of the calculation errors supports the concept of this project. It is a question of vital interest which differences of ceiling constructions can be bridged by transferring improvements and which constructions require consideration as a separate basic ceiling with the need to repeat the tests of the screeds.

The organization "Lignum – Holzwirtschaft Schweiz" provides an online database of timber ceiling constructions and their impact and airborne sound insulation [3]. Its suitability to publish the results of this project is currently being considered.
ISO 10140 provides three reference lightweight floors of questionable practical relevance. It is desirable that further basic ceilings satisfying the need of contemporary architecture are included. This project may be a starting point.

8. Acknowledgements

The project and this article were enabled by the colleagues who selected constructions of practical relevance and those who built the specimen. Special thanks is addressed to Volker Müller for logistics, measurements and documentation. The project is supervised by experts from Knauf companies in Belgium, Czech Republic, Switzerland, Italy, Austria, Russia and Germany.

References

[1] ISO 10140:2010 Acoustics – Laboratory measurement of sound insulation of building elements.

[2] EN12354 Building Acoustics — Estimation of acoustic performance of buildings from the performance of elements. Part 1 and Part 2: 2000

[3] http://bauteilkatalog.lignum.ch

[4] ISO 717-2: 2013-03 Acoustics – Rating of sound insulation in buildings and of building elements – Part 2: Impact sound insulation

[5] J. Seidel: Vorhaltemaße für die Holzbalkendecken-matrix; report draft, nr. SAR 13 022, Research and Development Knauf Group, Research Area Drywall Systems& Application Testing, Sound Insulation and Acoustics Knauf Gips KG, Am Bahnhof 7, 97346 Iphofen, Germany; 2015