Vibrations in residential timber floors – A comparison between the current and the revised Eurocode 5

Whokko Schirén
Department of Building Technology,
Linnaeus University
Växjö, Sweden

Trixie Swahn
Department of Building Technology,
Linnaeus University
Växjö, Sweden

Vibrations in residential timber floors – A comparison between the current and the revised Eurocode 5

1. Introduction

Floor structures could, in very general terms, be divided into heavy and light-weight floor structures. Traditional building methods with concrete as the main building material result in heavy floor structures while light-weight floor structures could be made out of steel, light-weight concrete or timber [1]. The development of lighter floor structures is driven by the aim to be more efficient and use less materials, as well as to use materials which are considered environmentally friendly, such as timber. Due to an increased awareness of sustainability aspects, the interest for building even higher wooden buildings is increasing, and today, about one tenth of new multi-family houses built in Sweden are built out of timber [2].

All light-weight floor structures are prone to unwanted vibrations [3] and humans are vibration sensitive beings, programmed to take notice of noise and vibrations as possible sources of danger [1, 4, 5] . People in motion often tolerate greater vibrations than people who are still [6]. Vibrations where the source is obvious, for example when the vibration originates from the own apartment, result in a lower disturbance than vibrations from less obvious sources from neighbouring apartments [1]. A vibration which decrease fast is perceived as less disturbing than a prolonged vibration [1, 7]. The human body is especially susceptible to vibrations between 4–8 Hz as this is frequencies at which the body's organs could start to resonate [8]. Thus, special focus in the design for vibrations in residential floors is laid on this range of frequencies.

The Eurocode series provides support when designing buildings and encompasses a set of design methods provided by the European Committee for Standardisation (CEN). The Eurocode is divided into general chapters and chapters for specific building materials. Eurocode 5, EC5, specifically contains design methods for timber constructions. It includes a chapter on vibrations in floor structures, [9], which is currently under revision. A draft for a revised design method for vibrations was presented in April 2019 and is investigated in this paper.

Today the building industry uses the current Eurocode 5, cEC5, when designing buildings. Changing from the current to a revised standard might change the classification of floor systems and thus, could lead to increased costs for the building industry. It is of utmost importance to the building industry to prepare for corresponding changes of standardisation.

Herein, the performance of floor structures, commonly used in Sweden today, are investigated based on the criteria provided in the draft for a revised design method for vibrations in Eurocode 5, and compared to the current version of the code. Both more traditional floor structures consisting of joists covered by sheathing, and less traditional floor structures with CLT as a main building material, are included in the study.

The study focuses exclusively on non-acoustic structural vibrations in timber floors. The design calculations were performed in the Serviceability Limit State (SLS) in accordance with the cEC5 and rEC5.

Three limited parametric studies with length, mass, modal mass, centre to centre distances and support conditions as variables, have been conducted in order to assess the sensitivity of the design method and to highlight corresponding influence parameters for the classification of floor systems.

2. Material and methods

2.1. Investigated floor systems

The design of the six floor structures investigated in this study are presented in Table 1. Due to the fastening methods used between the different layers in the floor structures, composite action is assumed in all floors.

Floor A and B are lightweight joist floors with joists covered by particle board sheathing. In Floor A the joists are made of structural timber and in B of Laminated Veneer Lumber (LVL). These floor structures are normally used in single-family houses. The floors span over two bays where the first span is 4.3 m and the second 3.9 m, which makes the total floor length 8.2 m. The floor width is 10.8 m. The non-rigid beam supporting the floors between the bays is an IPE 200 steel beam with a maximum span of 3.5 m.

Floor C is a glulam and LVL floor structure used in a building system with glulam columns and beams. The building system is often used in taller and larger buildings with more than two storeys and it is able to handle up to 8 m of free span. The floor is most common in multi-family houses or office buildings. The floor is simply supported and single spanning with a floor element width of 1.9 m and a floor length of 5.0 m.

Floor D is a composite floor with lightweight I-joists consisting of flanges of structural timber, C30, and a web of OSB/3. The gypsum boards in the ceiling are connected to the battens via steel profiles, Gyproc AP, developed to optimise the sound insulation. The floor is simply supported and single spanning with a floor length of 5.2 m and a width of 12 m.

Floor E consist of a five-layer CLT slab with a joist system on top. The joist system is made out of lightweight steel joists with damping elements for an efficient sound insulation. The joist system come in different heights and the sound insulation increases with the height of the joists, in this case the height is 190 mm. The floor is a double-spanning floor, the longer span is 5.5 m and the shorter span 3.9 m, which gives a total length of 9.4 m. The floor width is 11 m.

Floor F is a CLT floor with a layer of gypsum screed on top of the CLT. The floor consist of a five-layer CLT slab with a thickness of 150 mm, a layer of macadam, a layer gypsum screed and a parquet flooring. The macadam and the gypsum screed make the floor heavier. The floor system spans over two bays, the first span is 3.9 m and the second 5.5 m, which makes the total floor length 9.4 m. The floor width is 11 m.

2.2. Design according to the current Eurocode 5 method

The chapter on vibrations in timber floors in the cEC5 gives guidance on the design of timber floors with a fundamental frequency of 8 to 40 Hz. The cEC5 uses two criteria, the point load deflection and the unit impulse velocity response [9]. The design process is presented in Figure 1 and includes equations for the natural frequency of the floor, f_1, number of first order modes below 40 Hz, n_{40}, and the impulse velocity response, v. Point load deflection is calculated based on the structural system of the single-of multiple-span floor and corresponding boundary conditions.

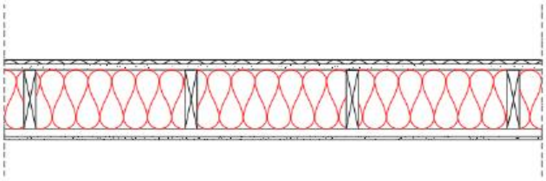
The variables used for the cEC5 are the fundamental frequency, f_1, in Hz, spanning length of the floor, l, in the direction of the load bearing beams in m, spanning width, b, in the transverse direction to the load bearing beams in m, mass of the floor, m, per unit area in kg/m^2, the bending stiffness of the floor, $(EI)_l$, in the direction of the beams and the bending stiffness of the floor, $(EI)_b$, in the direction transverse to the load bearing direction, both in Nm^2/m. The point load deflection, w, divided by a load of 1 kN, F, should be lower than or equal to the limiting value, $\mathrm{a} = 1.5$ mm/kN, given in the national annex [10]. The unit impulse velocity response v should be smaller than or equal to $\mathrm{b}^{f_1\zeta - 1}$ where b is given by the national annex [10] and ζ is the unitless modal damping ratio.

2.3. Design according to the revised Eurocode 5 method

In the rEC5, floor performance levels are introduced. The levels range from I to VII where I is the best floor performance level, VI is the worst still acceptable floor performance level and level VII is unacceptable. The floor performance level is determined by the stiffness criterion, w_{1kN}, and the response factor, R, see Table 2. If the floor performance level is below VII for both the stiffness criterion and the acceleration or velocity criterion then the floor is considered acceptable. The process for the draft design method for vibrations in timber floors is presented in Figure 2. It includes calculation of the natural frequency of the floor, which needs to be higher than 4.5 Hz, for the method to be applicable. In a first step however, the stiffness criterion of the floor is evaluated. The equations given in Figure 2 exemplifies calculation of the deflection of a single span beam under a point load.

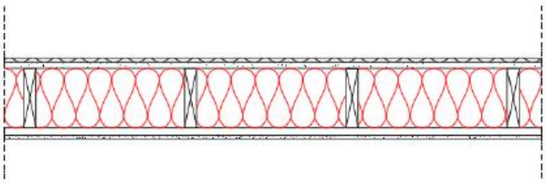
Table 1: Cross section of the investigated floor systems A-F.

Floor A



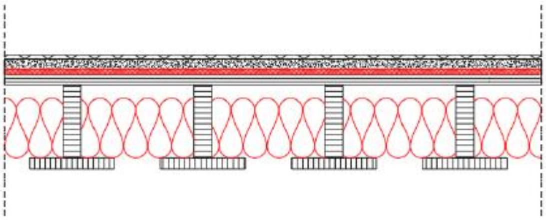
15 mm	PARQUET FLOOR
22 mm	FLOOR PARTICLE BOARD (FPB)
220x45 mm	STRUCTURAL TIMBER C24 cc600
220 mm	STONEWOOL
28x95 mm	BATTENS cc400
13 mm	GYPSUM BOARD

Floor B



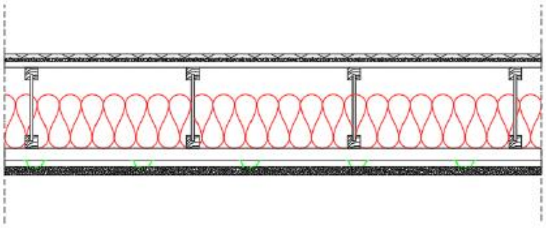
15 mm	PARQUET FLOOR
22 mm	FLOOR PARTICLE BOARD (FPB)
220x45 mm	KERTO BEAMS cc600
220 mm	STONEWOOL
28x95 mm	BATTENS cc400
13 mm	GYPSUM BOARD

Floor C



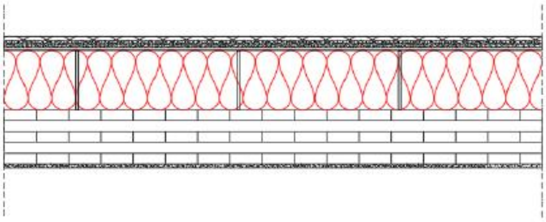
14 mm	PARQUET FLOOR
40 mm	CONCRETE
17 mm	INSULATION
63 mm	LAMINATED VENEER LUMBER BOARD
270x63 mm	GLULAM WEB
42x315 mm	GLULAM FLANGE

Floor D



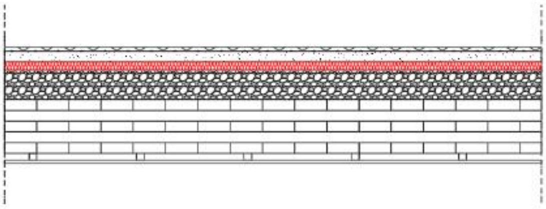
15 mm	PARQUET FLOOR
13 mm	FLOOR GYPSUM BOARD
22 mm	FLOOR PARTICLE BOARD (FPB)
300 mm	I-BEAM H300, c600
200 mm	INSULATION
45x95 mm	BATTENS CC400
25 mm	GYPROC AP
2X15 mm	GYPSUM BOARD (GF)

Floor E



15 mm	PARQUET FLOOR
2x13 mm	GYPSUM BOARD
22 mm	FLOOR PARTICLE BOARD (FPB)
10+190 mm	JOIST
190 mm	INSULATION
200 mm	CLT-SLAB
15 mm	GYPSUM BOARD

Floor F



15 mm	PARQUET FLOOR
40 mm	GYPSUM SCREED
30 mm	SOUND INSULATION
110 mm	MACADAM
150 mm	CLT-SLAB
25x25 mm	BATTENS cc400
13 mm	GYPSUM BOARD

The variables used in the rEC5 are F, a point load of 1 kN, l and b_{ef}, the length and effective width of the floor, both in metres, the mass of the floor, m, in kg/m^2. The bending stiffness of the floor in the direction of the load bearing beams is $(EI)_L$ in Nm^2/m. For the fundamental frequency two multipliers are introduced, $k_{e,1}$ and $k_{e,2}$, which handle the cases single or double spanning floors respectively one- or two-way spanning floors.

When using the acceleration criterion, for $4.5 < f_1 \leq 8$ Hz, $\alpha = e^{-0.4 f_1}$ is a Fourier coefficient, F_0 is a vertical load of 700 N coming from the person giving rise to the disturbance, ζ is the unitless modal damping ratio and M^* is the modal mass in kg. The modal mass is a measure for how much of the total floor mass contribute to the vibration of a specific mode and it depends on how many sides the floor structure is supported on.

For the velocity criterion, when $f_1 > 8$ Hz, I is the mean modal impulse depending on the walking frequency, f_w, and the fundamental frequency, f_1. In the peak velocity response $V_{1.peak}$, K_{red} is a reduction factor, I is the mean modal impulse and M^* the modal mass in kg. The impulsive multiplier, K_{imp}, depend on the length, l, width, b, in m and the bending stiffnesses, $(EI)_L$, in the load bearing direction and, $(EI)_T$, in the direction transverse to the load bearing direction, both in Nm^2/m.

The limit of applicability for the rEC5 is that the fundamental frequency of the floor has to be 4.5 Hz or above. The deflection criterion in the cEC5 is kept for coherency, it changes name to the stiffness criterion and it is accompanied by two new criteria namely the acceleration criterion and the velocity criterion. The acceleration criterion is used for low-frequency floors with a fundamental frequency of 4.5 to 8 Hz, and the velocity criterion is used for high-frequency floors with a fundamental frequency above 8 Hz. Both the stiffness criterion and the acceleration or velocity criterion result in response factors, R. For a visible representation of the relation between the limiting values for the point load deflection, which affect the stiffness criterion, the R-factors, coming from the acceleration or velocity criterion, and the floor performance levels, see Figure 3.

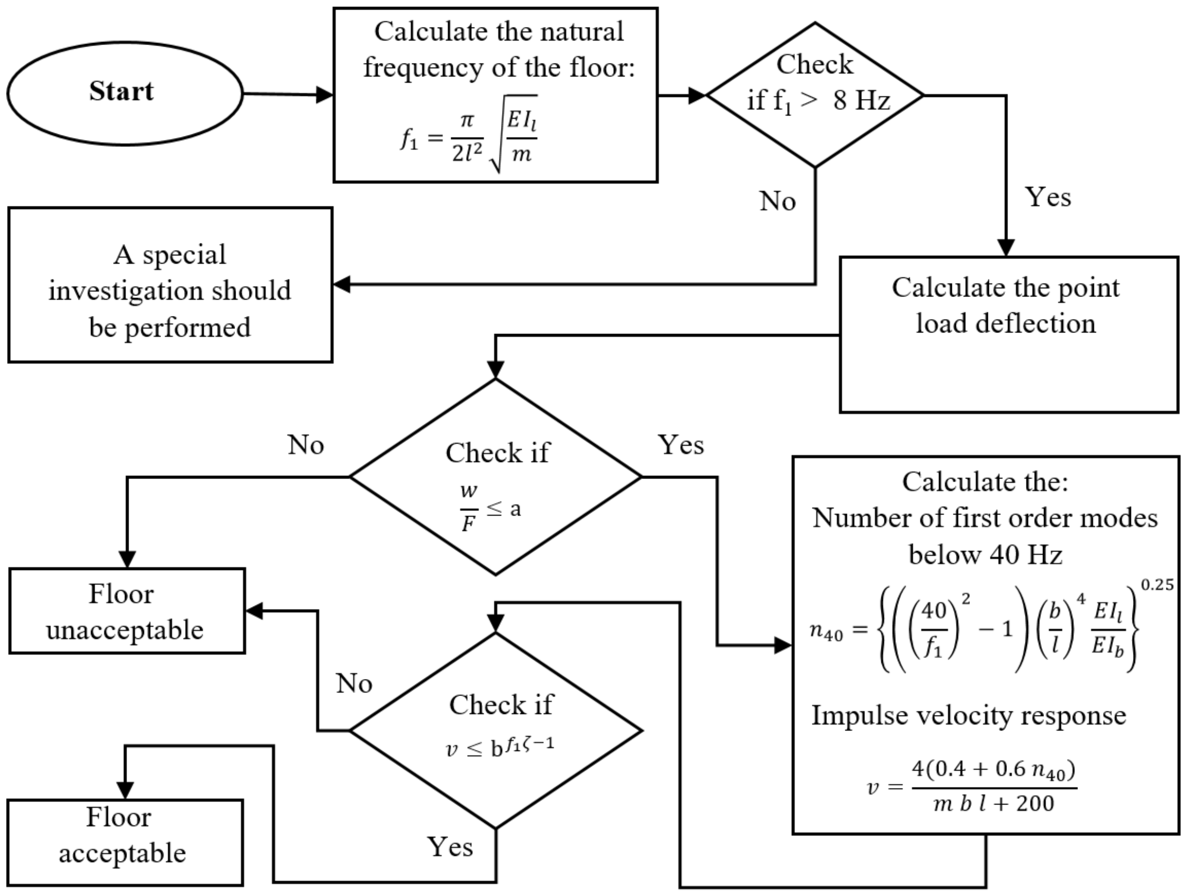


Figure 1: Illustration of the design process for timber floors according to the chapter on vibrations in the current Eurocode 5, cEC5.

Table 2: Floor vibration criteria of the classification system in the rEC5 [9].

	Floor performance levels						
Criteria	**I**	**II**	**III**	**IV**	**V**	**VI**	**VII**
Frequency f_1 [Hz] $\geq$	4.5						
Stiffness criteria w_{1kN} $[mm] \leq$	0.25		0.5	0.8	1.2	1.6	Unacceptable
Response factor R	4	8	12	16	24	32	Unacceptable
Acceleration criteria when $f_1 < 8$ [Hz] a_{rms}[m/s^2] $\leq$	R× 0.005						
Velocity criteria when $f_1 \geq 8$ [Hz] v_{rms} [m/s] $\leq$	R× 0.0001						

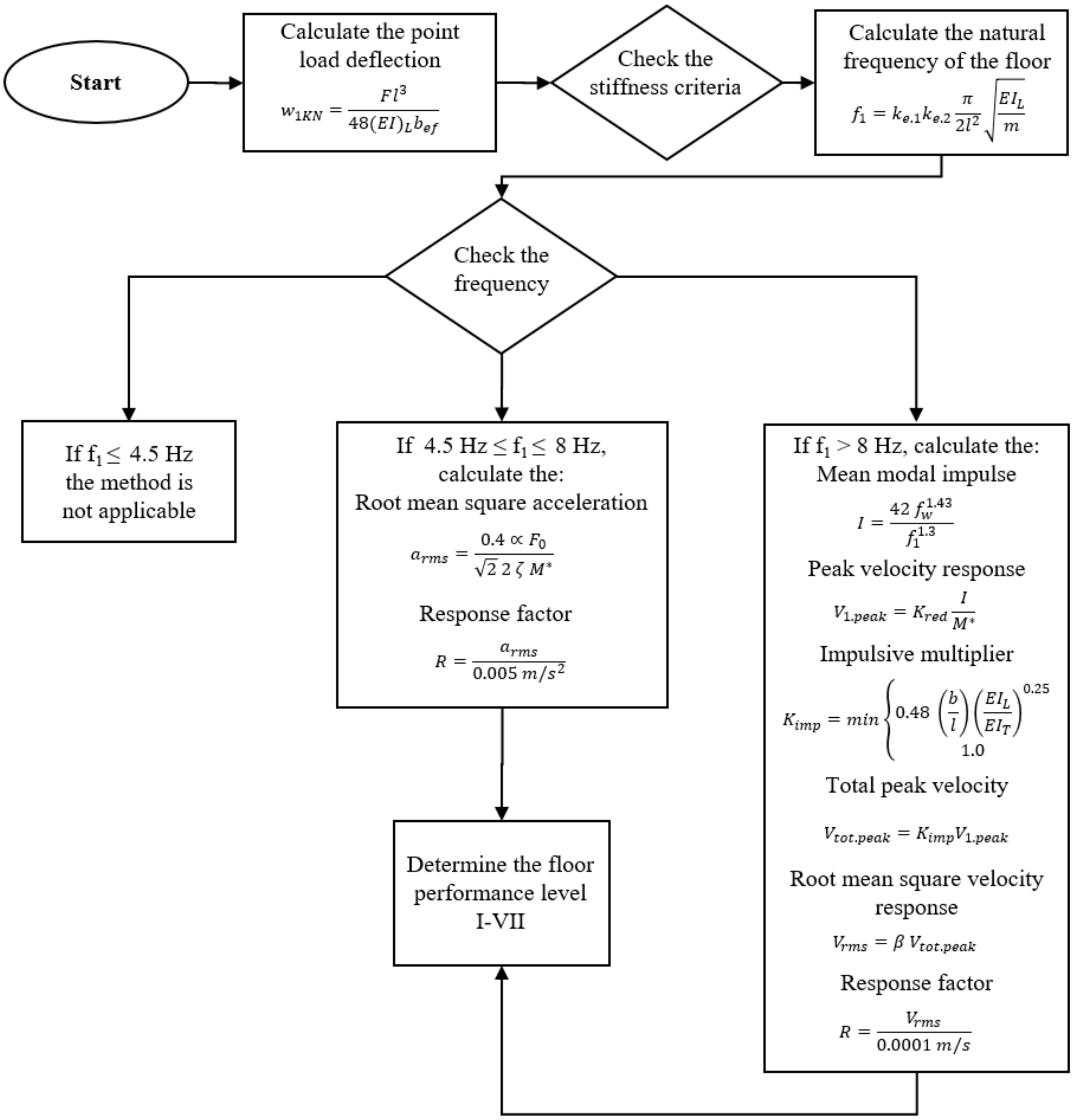


Figure 2: Illustration of the design process for timber floors according to the draft chapter on vibrations in the revised Eurocode 5, rEC5.

2.4. Parametric study – Effect of length, mass and modal mass on R-factors

Three parametric studies were performed, of which one is presented herein. In this parametric study, the length and mass per unit area were varied to study the effect of these variables on the R-factor. Calculations were made for the self-weight of the floor, m, i.e. the mass per square metre. In m_p the mass from partitions are added to the self-weight. The weight from imposed loads could be added in two ways, according to EKS 10, the Swedish national annex to the Eurocodes, 30 % of the imposed loads should be added to the mass [10] and according to rEC5 only 10 % of the imposed loads should be added. Calculations have been carried out for both cases, that is $m_{i0.3}$ and $m_{i0.1}$. Calculations have also been done for a combination of loading from partitions and imposed loads, $m_{p,i0.3}$ and $m_{p,i0.1}$. The R-factors are also influenced by whether the floor structure is considered to be one- or two-way spanning as these cases lead to two different modal masses.

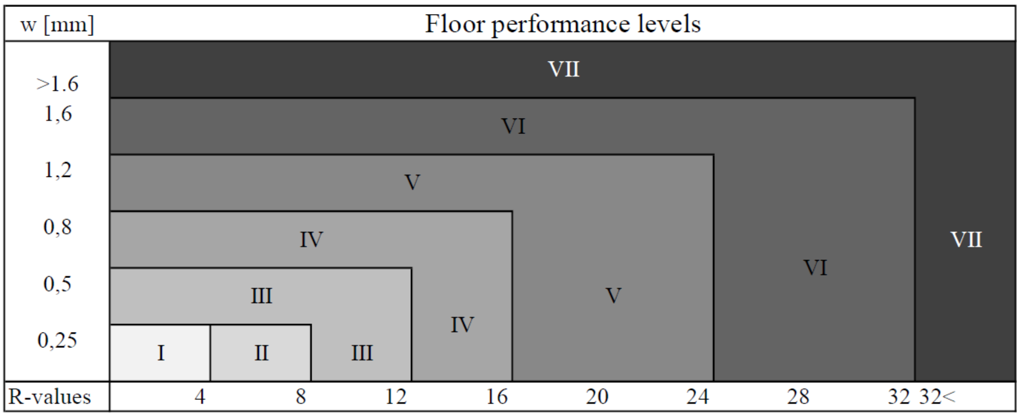


Figure 3: Relation between stiffness criteria, floor performance level and response factors, $\boldsymbol{R}$, in rEC5.

3. Results and discussion

3.1. Floor A – F

Results for the calculations are presented in Table 3 in accordance with cEC5 and rEC5. Regarding the cEC5, the unit impulse velocity response and the limit for the unit impulse velocity response are both given so that a comparison can be made. If the point load deflection is lower than 1.5 mm and if the unit impulse velocity response is lower than the limit for the unit impulse velocity response then the floor has passed the criteria of the current design method, cEC5.

When considering the rEC5, the root mean square acceleration response has been calculated for floor structures with a fundamental frequency of 4.5 to 8 Hz and for floors with a fundamental frequency above 8 Hz the root mean square velocity response is calculated. Based on the acceleration or velocity response the response factor, R, is obtained. For rEC5 a low response factor, R, obtained means that the floor has a better floor performance level, i.e. a floor performance level I is excellent and VII is unacceptable. Two floor performance levels has been calculated and presented for each floor. The first performance level is based on the stiffness criteria and the second is based on the acceleration or velocity criteria dependent on the fundamental frequency of the floor. The highest level obtained is taken as the floor performance level of the floor. If both performance levels obtained are below VII then the floor is acceptable according to the draft design method, rEC5.

A summary of the results for the six floor structures A-F is presented in Table 4. The calculation results for the point load deflection, w, the response factor, R, and the impulse velocity response, v, are given. The floor performance level R for the floor is taken from the worst case, i.e. the highest floor performance level in Table 2. If cEC5 cannot be applied to the floor then this is marked with N.A. which stands for not applicable.

Table 3: Results for A – F.

Floor A

	Design method	
	cEC5	**rEC5**
Fundamental frequency	16.4 Hz	15.2 Hz
Point load deflection	1.03 mm	1.42 mm
Unit impulse velocity response	21.9 mm/Ns^2	
Limit for unit impulse velocity response	45.4 mm/Ns^2	
RMS acceleration response		
RMS velocity response		6.58 mm
Response factor		65.8
Pass or fail	Pass	
Performance level based on deflection		VI
Performance level based on response factor		VII

Floor B

	Design method	
	cEC5	**rEC5**
Fundamental frequency	17.7 Hz	16.3 Hz
Point load deflection	0.84 mm	1.22 mm
Unit impulse velocity response	20.9 mm/Ns^2	
Limit for unit impulse velocity response	51.1 mm/Ns^2	
RMS acceleration response		
RMS velocity response		5.80 mm
Response factor		58.0
Pass or fail	Pass	
Performance level based on deflection		VI
Performance level based on response factor		VII

Floor C

	Design method	
	cEC5	**rEC5**
Fundamental frequency	23.9 Hz	23.9 Hz
Point load deflection	0.11 mm	0.07 m
Unit impulse velocity response	2.6 mm/Ns^2	
Limit for unit impulse velocity response	271.2 mm/Ns^2	
RMS acceleration response		
RMS velocity response		0.38 m
Response factor		3.8
Pass or fail	Pass	
Performance level based on deflection		I
Performance level based on response factor		I

Floor D

	Design method	
	cEC5	**rEC5**
Fundamental frequency	11.3 Hz	11.3 Hz
Point load deflection	0.90 mm	1.18 mm
Unit impulse velocity response	11.5 mm/Ns^2	
Limit for unit impulse velocity response	28.2 mm/Ns^2	
RMS acceleration response		
RMS velocity response		2.12 mm
Response factor		21.2
Pass or fail	Pass	
Performance level based on deflection		V
Performance level based on response factor		V

Floor E

	Design method	
	cEC5	**rEC5**
Fundamental frequency	11.0 Hz	13.4 Hz
Point load deflection	0.09 mm	0.09 mm
Unit impulse velocity response	1.0 mm/Ns^2	
Limit for unit impulse velocity response	35.5 mm/Ns^2	
RMS acceleration response		
RMS velocity response		0.31 mm
Response factor		3.1
Pass or fail	Pass	
Performance level based on deflection		I
Performance level based on response factor		I

Floor F

	Design metho	
	cEC5	**rEC5**
Fundamental frequency	5.6 Hz	6.8 Hz
Point load deflection		0.21 mm
Unit impulse velocity response		
Limit for unit impulse velocity response		
RMS acceleration response		42.0 mm
RMS velocity response		
Response factor		8.4
Pass or fail	–	
Performance level based on deflection		I
Performance level based on response factor		III

From Table 4, it becomes obvious, that the draft revised method for the assessment of floor systems gives more differentiation of the performance. In most assessed floor structures, the stiffness criterion and the response factor, R, yielded similar classification, while it differed for floors A, B and F.

Of the six floor structures studied, five pass the current design criteria and four pass the criteria of the draft revised design method. Section 3.1, Table 4, shows that Floor C, D and E achieve the same floor performance level from both the stiffness criterion and the velocity criterion according to the draft revised design method. The other three floors, A, B and F, perform better according to the stiffness criterion than the acceleration or velocity criterion. Floor A and B get an acceptable floor performance level, level VI, according to the stiffness criterion but achieve level VII according to the velocity criterion. Floor F reaches level I based on the stiffness criterion and level III based on the acceleration criterion. According to the results, both Floor A and B would fail the criteria in the rEC5 and the cEC5 cannot be applied to Floor F as this floor has a fundamental frequency below 8 Hz.

Table 4: Summary of results for Floor A–F with respect to the criteria in cEC5 and rEC5.

Floor structure	Criteria in cEC5 [w/ν]	Floor performance level rEC5 [w/R]
A	Pass/Pass	Level VI/VII
B	Pass/Pass	Level VI/VII
C	Pass/Pass	Level I/I
D	Pass/Pass	Level V/V
E	Pass/Pass	Level I/I
F	N.A. / N.A.	Level I/III

3.2. Parametric study – Effect of length, mass and modal mass on R-factors

The parametric study focused on the effect of length, mass and modal mass on the response factors, R. The variables were varied as described in Section 2.4. The combinations used gave rise to sixty response factors per floor, the results are presented in Table 6. The colour key for the parametric study is presented in grey scale, see Table 5. When the velocity criterion has been used the R-values are given with normal font and when the acceleration criterion has been used the R-factors are given in italic font. When the response value, R, is 32 and above the font is white and when the fundamental frequency is below 4.5 Hz the cell is left empty as none of the criteria are applicable.

A shorter span results in a lower response factor, R. For the velocity criterion, the lowest response factor was generally achieved for the shortest span, 3.5 m, and the largest mass, i.e. when partitions and 30 % of the imposed loads were included in the mass per unit area. To achieve a fundamental frequency below 8 Hz, which leads to using the acceleration criterion, spans of more than 3.5 m are necessary for most floors. The lowest response factor for the acceleration criterion was obtained for a combination of a low mass per unit area and the shortest span needed to trigger the acceleration criterion.

Table 5: Colour key for the point load deflection based on the revised design method, floors with performance level VII fail as the $\boldsymbol{R}$-factor is above 32.

Performance Level	Velocity Criteria	Acceleration Criteria
I	0 to 4	*0 to 4*
II	4 to 8	*4 to 8*
III	8 to 12	*8 to 12*
IV	12 to 16	*12 to 16*
V	16 to 24	*16 to 24*
VI	24 to 32	*24 to 32*
VII	above 32	*above 32*

Assuming that the floor was supported on four sides, the modal mass becomes $M^* = mbl/4$, which result in a response factor R twice as large as if the floor had been assumed to be supported on only two sides.

The modal mass depends on the floor structures support conditions, whether the floor is supported on two or four sides. According to the results in Section 3.1, floors supported on two sides get twice as good response factors as floors supported on four sides. That is, according to the results, floors supported on four sides are more sensitive to vibrations than floors supported on only two sides, this seems counter intuitive.

Table 6: Summary of results from parametric study, respons factor, ***R***.

Floor A

M*=mlb/2	Mass [kg/m^2]	Response factors				
$m_{p.i.0.3}$	139,8	17,8	20,5	*17,8*		
$m_{p.i.0.1}$	99,0	19,1	22,3	*15,1*	*42,9*	
$m_{i.0.3}$	104,1	18,9	22,0	*15,5*	*42,8*	
$m_{i.0.1}$	63,3	20,4	24,5	31,2	*41,7*	
m_p	78,6	19,8	23,5	29,5	*42,9*	
m	42,9	21,1	26,2	34,4	*37,1*	*80,0*
M*=mlb/4						
$m_{p.i.0.3}$	139,8	35,6	41,0	*35,5*		
$m_{p.i.0.1}$	99,0	38,2	44,6	*30,2*	*85,8*	
$m_{i.0.3}$	104,1	37,8	47,0	*25,7*	*85,5*	
$m_{i.0.1}$	63,3	40,9	49,1	62,5	*83,5*	
m_p	78,6	39,7	47,0	59,0	*85,7*	
m	42,9	42,3	52,4	68,8	*74,1*	*160,0*
	Length [m]	3,5	4,0	5,0	6,5	8,0

Floor B

M*=mlb/2	Mass [kg/m2]	Response factors				
$m_{p.i.0.3}$	142,3	15,9	18,4	*13,4*		
$m_{p.i.0.1}$	101,5	16,9	19,9	24,9	*34,9*	
$m_{i.0.3}$	106,6	16,7	19,7	24,6	*35,0*	
$m_{i.0.1}$	65,8	17,8	21,7	27,9	*32,6*	
m_p	81,1	17,4	20,8	26,5	*34,2*	
m	45,4	18,2	22,9	30,5	*28,0*	*65,2*
M*=mlb/4						
$m_{p.i.0.3}$	142,3	31,7	36,8	*26,7*		
$m_{p.i.0.1}$	101,5	33,7	39,8	49,9	*69,9*	
$m_{i.0.3}$	106,6	34,8	39,4	49,2	*70,0*	
$m_{i.0.1}$	65,8	35,7	43,3	55,9	*65,3*	
m_p	81,1	34,8	41,7	52,9	*68,4*	
m	45,4	36,3	45,8	61,0	*56,0*	*130,4*
	Length [m]	3,5	4,0	5,0	6,5	8,0

Floor C

M*=mlb/2	Mass [kg/m2]	Response factors				
$m_{p.i.0.3}$	259,8	1,0	1,5	2,6	4,5	*16,1*
$m_{p.i.0.1}$	219,0	0,9	1,5	2,6	4,7	7,0
$m_{i.0.3}$	224,1	0,9	1,5	2,6	4,6	7,0
$m_{i.0.1}$	183,3	0,8	1,4	2,7	4,8	7,4
m_p	198,6	0,9	1,5	2,7	4,8	7,2
m	162,9	0,8	1,4	2,7	5,0	7,6
M*=mlb/4						
$m_{p.i.0.3}$	259,8	2,0	3,0	5,2	8,9	*32,3*
$m_{p.i.0.1}$	219,0	1,8	3,0	5,3	9,3	14,0
$m_{i.0.3}$	224,1	1,9	3,0	5,3	9,3	13,9
$m_{i.0.1}$	183,3	1,7	2,9	5,4	9,7	14,7
m_p	198,6	1,8	2,9	5,3	9,5	14,4
m	162,9	1,5	2,8	5,4	9,9	15,2
	Length [m]	3,5	4,0	5,0	6,5	8,0

Floor D

M*=mlb/2	Mass [kg/m2]	Response factors				
$m_{p.i.0.3}$	183,6	11,7	13,6	16,8	*28,6*	
$m_{p.i.0.1}$	142,8	12,2	14,3	17,9	*28,2*	
$m_{i.0.3}$	147,9	12,1	14,2	17,8	*28,3*	
$m_{i.0.1}$	107,1	12,6	15,1	19,3	*26,5*	
m_p	122,4	12,5	14,8	18,7	*27,4*	
m	86,7	12,8	15,6	20,3	*24,5*	*53,1*
M*=mlb/4						
$m_{p.i.0.3}$	183,6	23,4	27,1	33,5	*57,1*	
$m_{p.i.0.1}$	142,8	24,4	28,7	35,9	*56,3*	
$m_{i.0.3}$	147,9	24,3	28,4	35,5	*56,5*	
$m_{i.0.1}$	107,1	25,3	30,3	38,6	*53,0*	
m_p	122,4	24,9	29,5	37,4	*54,9*	
m	86,7	25,7	31,3	40,7	*49,1*	*106,2*
	Length [m]	3,5	4,0	5,0	6,5	8,0

Floor E

M*=mlb/2	Mass [kg/m2]	Response factors				
$m_{p.i.0.3}$	275,2	0,8	0,9	1,2	*6,4*	
$m_{p.i.0.1}$	234,4	0,8	0,9	1,2	*6,1*	*12,5*
$m_{i.0.3}$	239,5	0,8	0,9	1,2	*6,1*	
$m_{i.0.1}$	198,7	0,8	1,0	1,3	*5,6*	*12,6*
m_p	214,0	0,8	1,0	1,3	*5,8*	*12,6*
m	178,3	0,8	1,0	1,3	*5,3*	*12,6*
M*=mlb/4						
$m_{p.i.0.3}$	275,2	1,5	1,8	2,4	*12,8*	
$m_{p.i.0.1}$	234,4	1,5	1,9	2,5	*12,1*	*25,0*
$m_{i.0.3}$	239,5	1,5	1,9	2,5	*12,2*	
$m_{i.0.1}$	198,7	1,6	1,9	2,6	*11,3*	*25,3*
m_p	214,0	1,6	1,9	2,5	*11,7*	*25,2*
m	178,3	1,6	2,0	2,6	*10,6*	*25,2*
	Length [m]	3,5	4,0	5,0	6,5	8,0

Floor F

M*=mlb/2	Mass [kg/m2]	Response factors				
$m_{p.i.0.3}$	387,3	1,3	1,5	*5,1*		
$m_{p.i.0.1}$	346,5	1,3	1,5	*5,0*		
$m_{i.0.3}$	351,6	1,3	1,5	*5,0*		
$m_{i.0.1}$	310,8	1,4	1,6	*4,8*		
m_p	326,1	1,3	1,5	*4,9*		
m	290,4	1,4	1,6	*4,7*		
M*=mlb/4						
$m_{p.i.0.3}$	387,3	2,6	2,9	*10,2*		
$m_{p.i.0.1}$	346,5	2,6	3,0	*9,9*		
$m_{i.0.3}$	351,6	2,6	3,0	*10,0*		
$m_{i.0.1}$	310,8	2,7	3,1	*9,6*		
m_p	326,1	2,7	3,1	*9,8*		
m	290,4	2,7	3,2	*9,4*		
	Length [m]	3,5	4,0	5,0	6,5	8,0

4. Conclusions and further research

The hypothesis of this work was that the introduction of the draft of the rEC5 might force some changes to the construction practice and that these changes may increase costs for the industry. Of the six floor systems currently used by companies in Sweden the two floors most commonly used in single-family houses, Floor A and B, only reached floor performance level VII, which is unacceptable according to rEC5. Thus, adaptions of these floor systems would be required in order to fulfil the design criteria in rEC5.

The parametric study showed that Floor A and B achieved floor performance level V for a span of 3.5 metres when they were assumed to be supported on only two sides. If they were assumed to be supported on four sides, the floor performance level would become unacceptable. Floor F is an example of a floor structure which cannot be designed based on cEC5, when considering the floor performance levels in rEC5 it performs exceptionally well.

It can be concluded that changes may have to be implemented for the common Floors A and B to have acceptable performance when a revision of EC5 is introduced and these changes could result in increased costs for the timber construction industry. A broader study including more floor structures should be conducted in order to assess the need of adaptions of further common floor structures in case rEC5 would be introduced.

In the parametric study primarily one discovery seemed contradictory. Floors supported on four sides got worse response factors than floors supported on two sides. This finding should be further assessed for a decision on the suitability of the proposed draft design method. Since the present work was finalised the revision work has continued with national comments and their implementation. A draft version two has been finalised in late October 2019.

5. References

[1] T. Toratti and T. Asko, «Classification of Human Induced Floor Vibrations», *Building Acoustics,* 13(3): 211-221, 2006.

[2] S. Brege, T. Nord and L. Stehn, «Industiellt byggande i trä - nuläge och prognos mot 2015», Linköping University, Linköping, 2017, in Swedish.

[3] K. Jarnerö, A. Brandt and A. Olsson, «Vibration properties of a timber floor assessed in laboratory and during construction.», *Engineering Structures ,* 82: 44-54, 2015.

[4] B. Zhang, B. Rasmussen, A. Jorissen and A. Harte, «Comparison of vibrational comfort assessment criteria for design of timber floors among the European countries», *Engineering Structures,* 52: 592-607, 2013.

[5] M. Basner, W. Babisch, A. Davis , M. Brink, C. Clark, S. Janssen and S. Stansfeld, «Auditory and Non-Auditory Effects of Noise on Health», *The Lancet ,* 383: 1325-1332, 2014.

[6] S. Ohlsson, «Floor vibrations and human discomfort», Chalmers University of Technology, Division of Steel and Timber Structures, 1982.

[7] A. Brandt, K. Jarnerö and A. Olsson, «In situ testing of timber floor vibration properties», in proceedings of the World Conference on Timber Structures, *WCTE 2010*, 2010.

[8] J. Weckendorf, T. Toratti, I. Smith and T. Tannert, «Vibration serviceability performance of timber floors», *European Journal of Wood and Wood Products,* 74(3): 353-367, 2016.

[9] EN 1995-1-1:2004, «Eurocode 5: Design of timber structures - Part 1-1: General - Common rules and rules for buildings», 2004.

[10] Boverket, «Boverkets konstruktionsregler - EKS10 - BFS 2011:10», Boverket, Stockholm, 2016, in Swedish.