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Acoustics (VTAN01) –

Building Acoustics (2) Flanking Transmission

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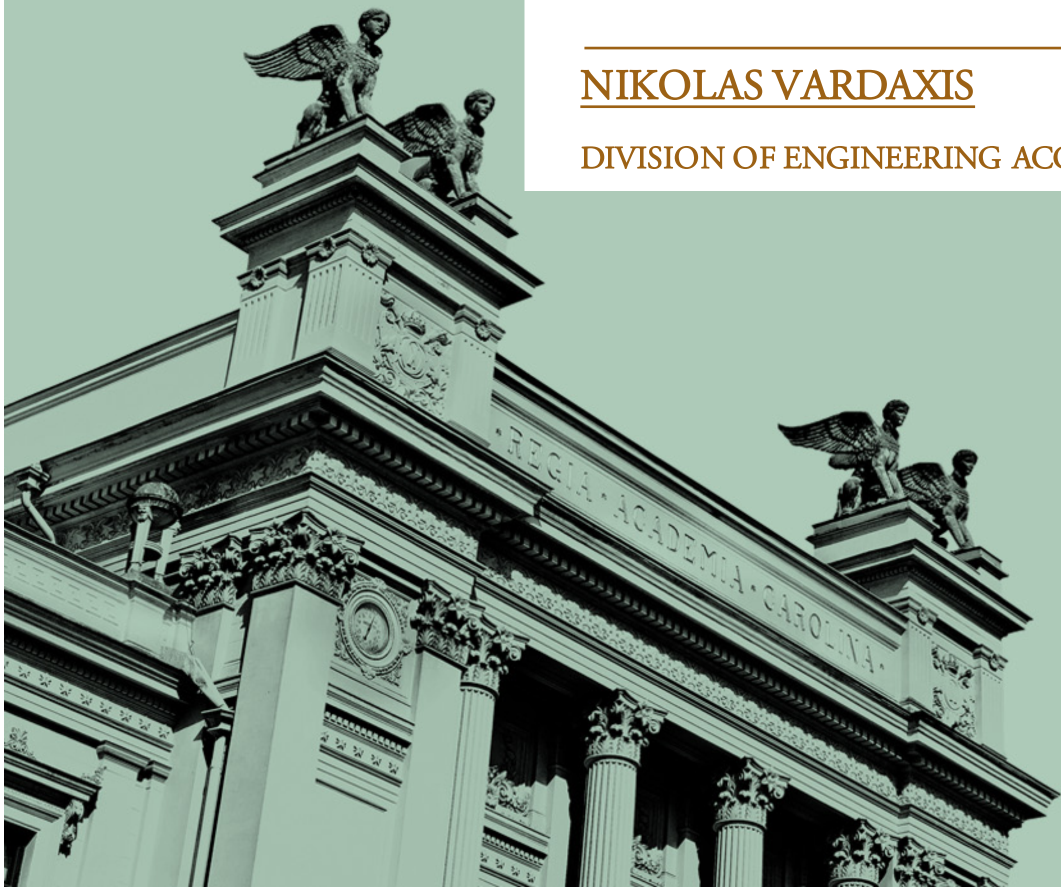
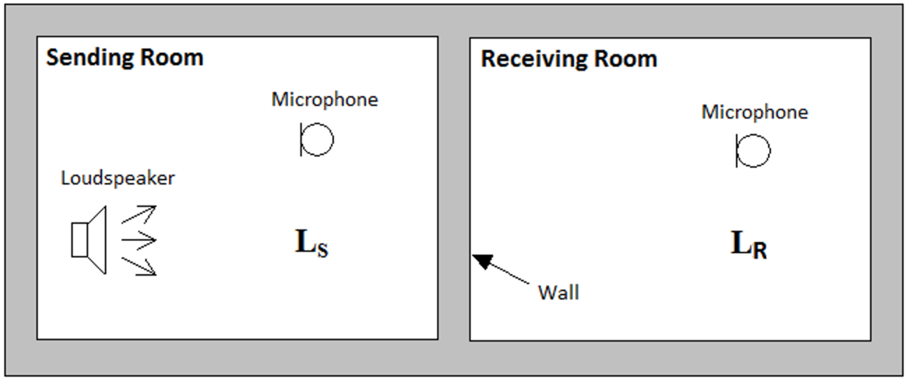
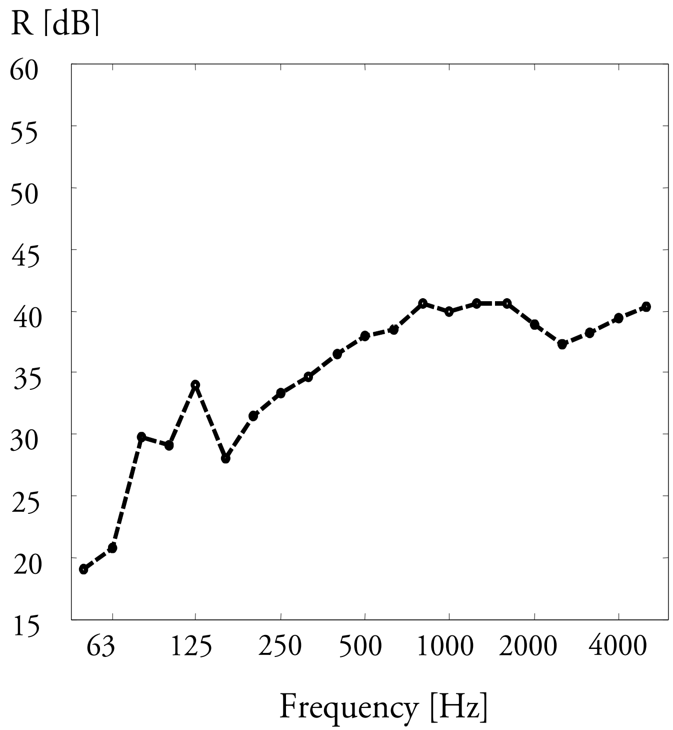


… recap from last lecture (I)

- Airborne sound insulation measurements (ISO standards)



$$R(f) = L_S(f) - L_R(f) + 10\log\left(\frac{S}{A(f)}\right)$$

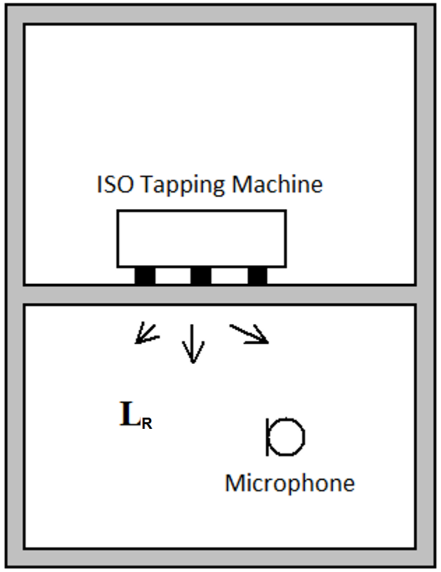


Statement of results:

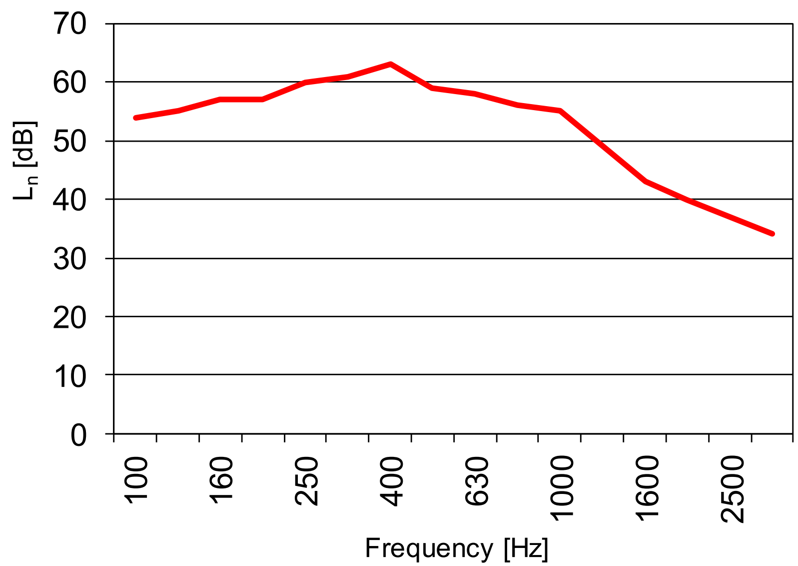
- $R'_w\ (C_{50\text{-}3150}\ ;\ C_{tr})$
- $R_w\ (C_{50\text{-}3150}\ ;\ C_{tr})$

… recap from last lecture (II)

- Impact sound insulation measurements (ISO standards)



$$L_n(f) = L_R(f) + 10\log\left(\frac{A(f)}{10}\right)$$

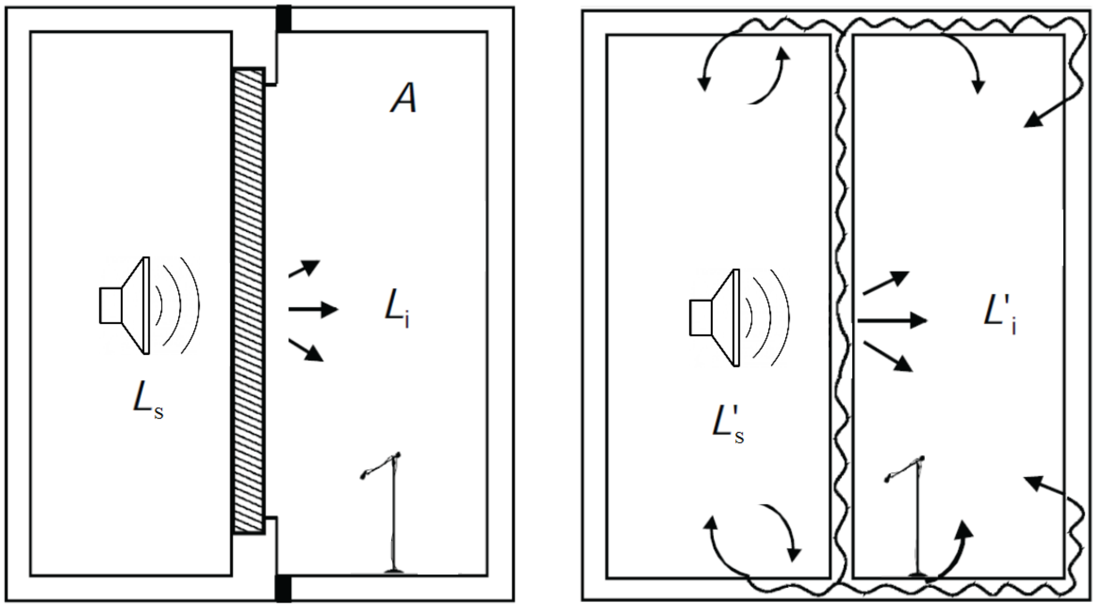


Statement of results:

- $L'_{nT,w}\,(C_{I,50\text{-}2500})$
- $L'_{n,w}\,(C_{I,50\text{-}2500})$
- $L_{n,w}\,(C_{I,50\text{-}2500})$

Remember…

… Laboratory vs. Field situation (flanking transmission comes into play)



[REF] Vigran(2008)

ISO 717-1:2013
ISO 10140-2:2010

R_w

ISO 717-1:2013
ISO 16283-1:2014

R'_w

SS-EN12354-1:2000

Prediction of R'_w from the individual acoustic performances (R_w) of the elements involved in the junction, as sum of individual contributions

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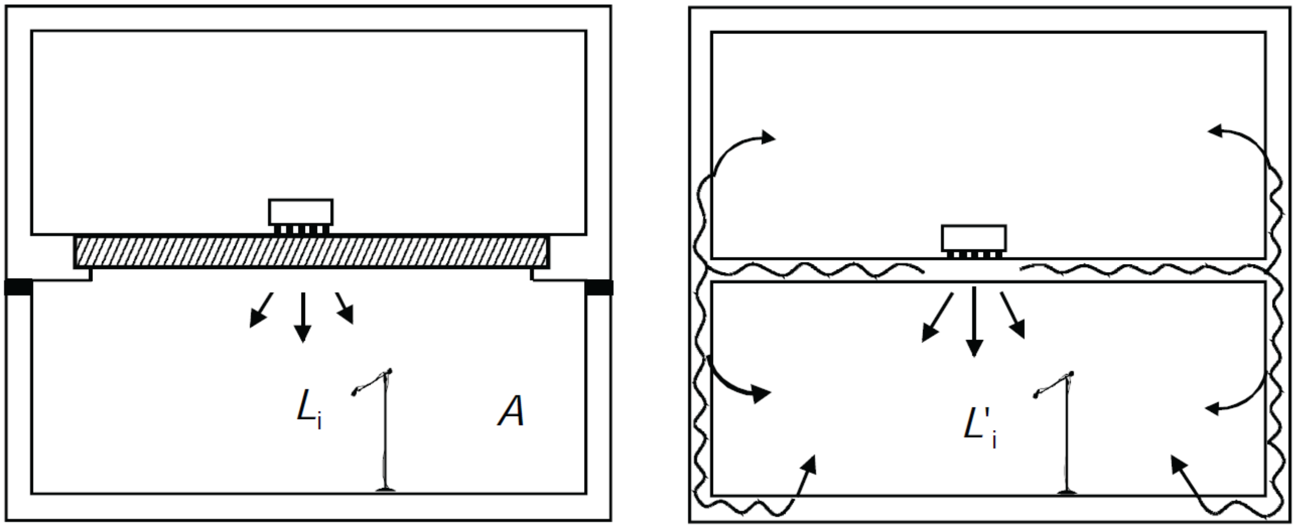
Remember…

… Laboratory vs. Field situation (flanking transmission comes into play)



[REF] Vigran(2008)

ISO 717-2:2013
ISO 10140-3:2010
$L_{n,w}$

ISO 717-2:2013
ISO 16283-2:2014
$L'_{n,w}$

SS-EN12354-2:2000
Prediction of $L'_{n,w}$ from individual acoustic performances ($L_{n,w}$)

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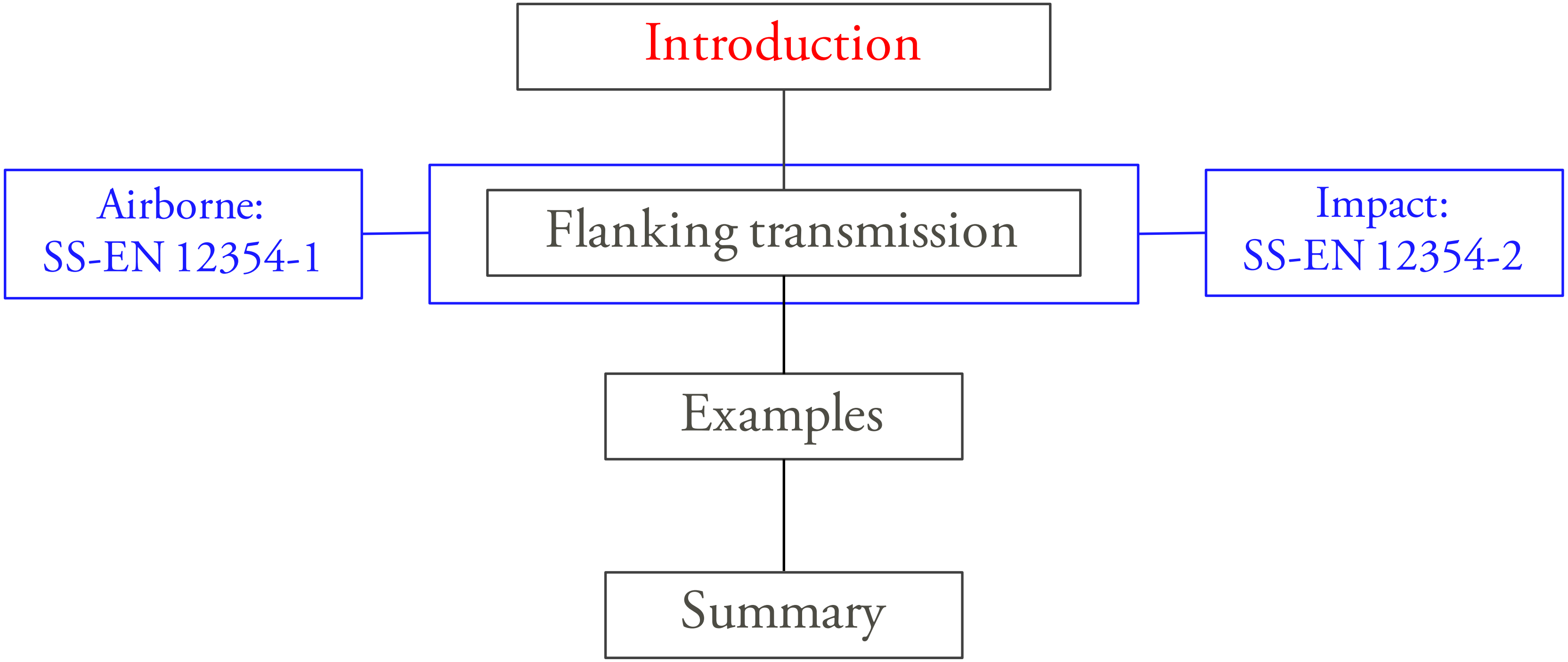
Outline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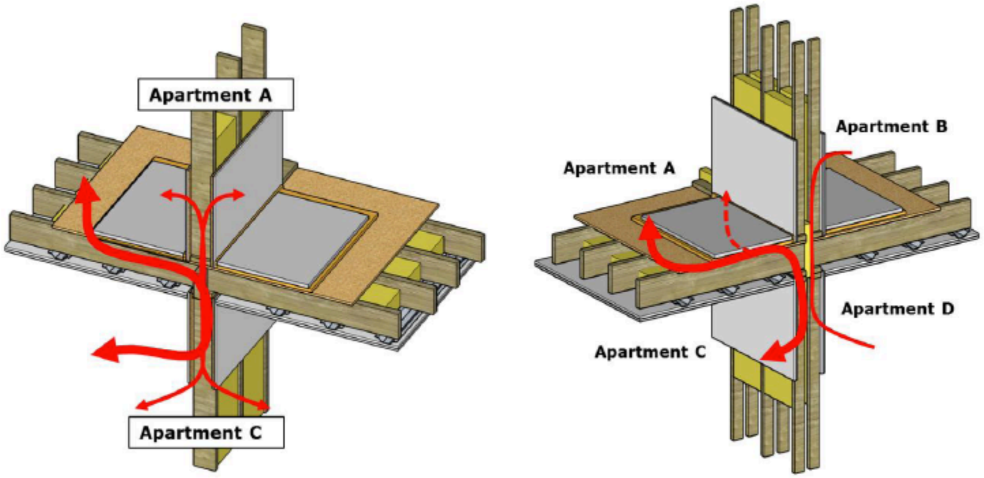
References: SS-EN 12354 series

- SS-EN12354-1:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 1: Airborne sound insulation between rooms (2000).
- SS-EN12354-2:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 2: Impact sound insulation between rooms (2000).
- SS-EN12354-3:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 3: Airborne sound insulation against outdoor sound (2000).
- SS-EN12354-4:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 4: Transmission of indoor sound to the outside (2000).
- SS-EN12354-5:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 5: Sound levels due to service equipment (2000).
- SS-EN12354-3:2000, Building Acoustics– Estimation of acoustic performance of buildings from the performance of elements – Part 6: Sound absorption in enclosed spaces (2000).

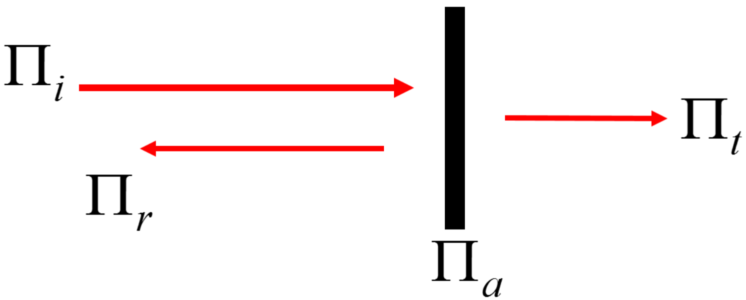
Introduction (I)

- Sound transmission
  - Airborne
  - Structure-borne
- Transmission paths
  - Direct transmission (*D*)
  - Flanking paths (F_i)



- Flanking: cause of problems related with acoustic comfort
  - Difference between lab and in-situ measurements ~4 dB
    - » Estimation methods described in SS-EN 12354:2000
      - Acoustic performance as sum of individual contributions

Introduction (II)



$$R \equiv 10 \cdot \log\left(\frac{\Pi_i}{\Pi_t}\right) = 10 \cdot \log\left(\frac{1}{\tau}\right) \quad \text{[dB]}$$

$$\tau = \Pi_t / \Pi_i$$

- Laboratory measurements → good control → "just" direct transmission
- In reality, more transmission paths

$$\tau' = \tau_d + \tau_f + \sum \tau_{dt} + \sum \tau_{it}$$

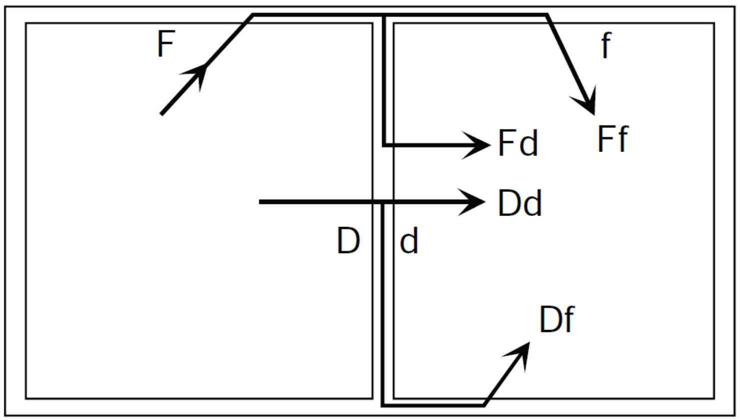
- τ_d: Direct
- τ_f: Flanking
- $\sum \tau_{dt}$: Parts added to wall (windows, doors, leaks…). May be included in τ_d
- $\sum \tau_{it}$: Indirect transmission between rooms (ducts, suspended ceiling…)

$$R' = 10 \cdot \log\left(\frac{1}{\tau'}\right) \quad \text{[dB]}$$

Introduction (III)

$$\tau' \approx \tau_d + \tau_f$$

$$\tau_d = \tau_{Dd} + \sum_n \tau_{Fd} \qquad \tau_f = \sum_m \tau_{Df} + \sum_k \tau_{Ff}$$



NOTES: The sketch only indicates first-order paths; paths involving one element in the sending room, one junction or connection and one element in the receiving room. // The number of elements n, m and k are normally 4. // Main contributions are normally the *Ff* paths.

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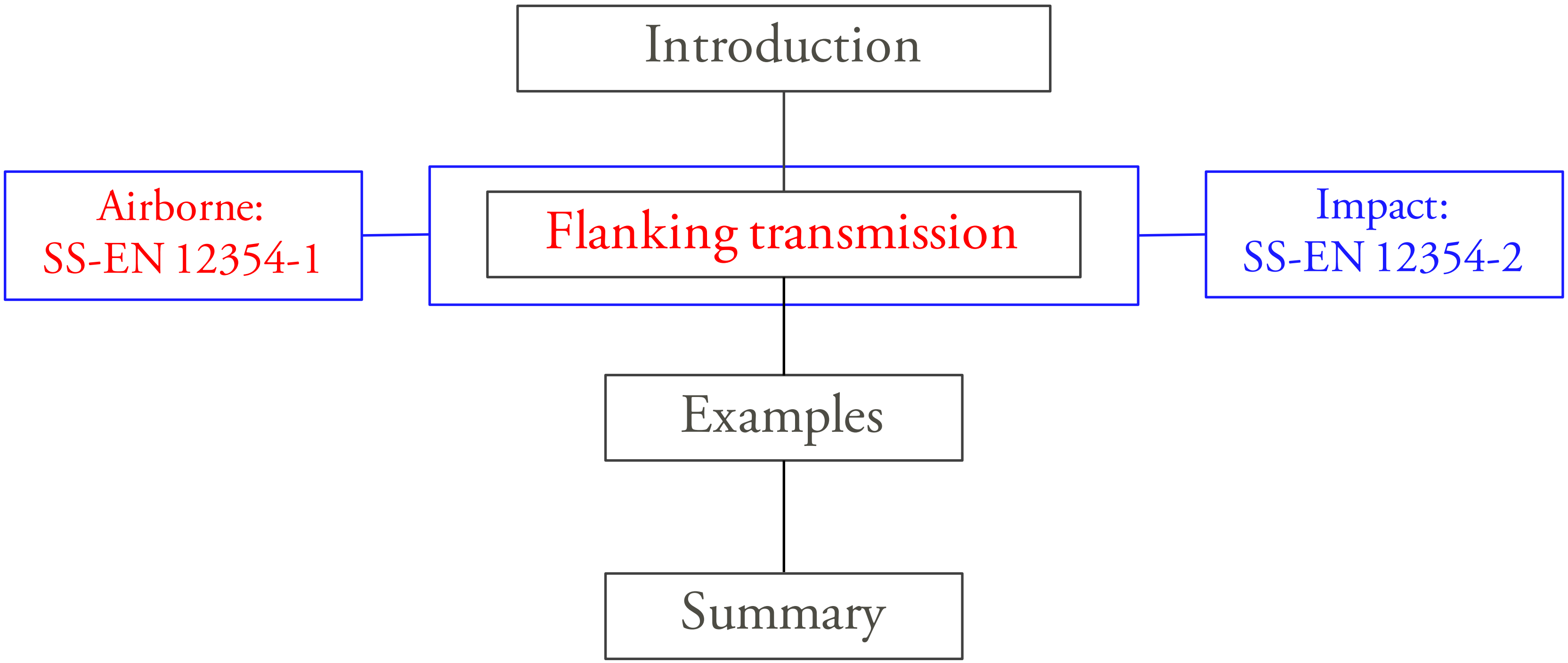
Outline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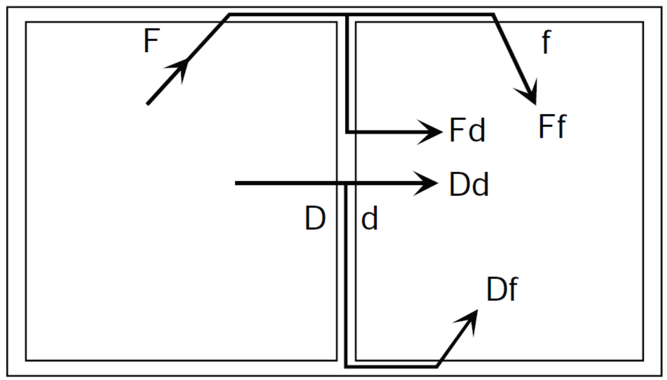
Flanking transmission reduction index (I)

- Apparent sound reduction index (13 paths)

$$R'_w = -10\log\left[10^{\frac{-R_{Dd,w}}{10}} + \sum_{F=f=1}^{n} 10^{\frac{-R_{Ff,w}}{10}} + \sum_{f=1}^{n} 10^{\frac{-R_{Df,w}}{10}} + \sum_{F=1}^{n} 10^{\frac{-R_{Fd,w}}{10}}\right]$$

- If only *Ff* paths are assumed:

$$R'_w = -10\log\left[10^{\frac{-R_{d,w}}{10}} + \sum 10^{\frac{-R_{f,w}}{10}}\right]$$



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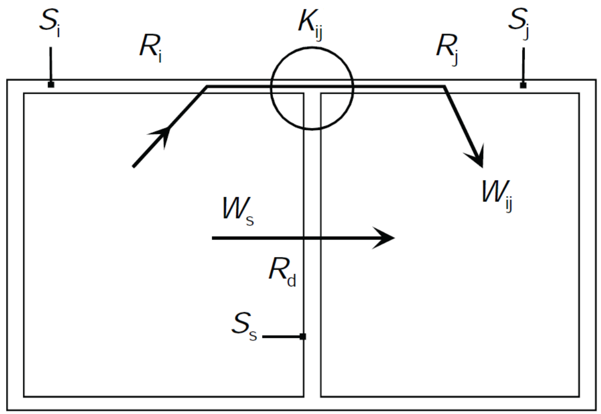
Flanking transmission reduction index (II)

- Flanking sound reduction index R_{ij} (approximation given in the standard SS-EN 12354-1)

$$\left(R_f\right)_{ij,w} = R_{ij,w} = \frac{R_{i,w} + R_{j,w}}{2} + K_{ij} + 10\log\left(\frac{S_s}{l_0 \cdot l_{ij}}\right)$$

R_i & R_j : sound reduction index of flanking element *i* and *j*
K_{ij} : vibration reduction index (junction dependent)
S_s: floor / wall surface
l_0 = 1m
l_{ij} : junction common length



NOTES: K_{ij} is related to the vibrational power transmission over a junction between structural elements under diffuse field conditions, normalised in order to make it an invariant quantity (independent of the energy losses). This quantity can be taken from Annex E of SS-EN 12354-1. // An additional term $+\Delta R_{ij}$ would be added to the right hand side of the equation to account for improvement of sound reduction due to aditional linings (here is omitted).

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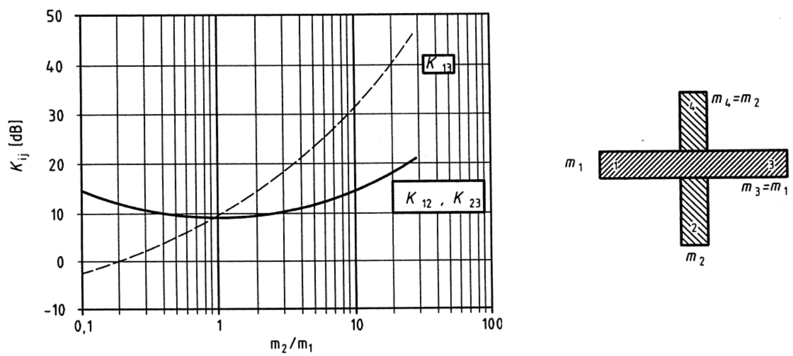
Flanking transmission reduction index (III)

- Vibration reduction indices K_{ij}
  - SS-EN 12354-1:2000 (Annex E)

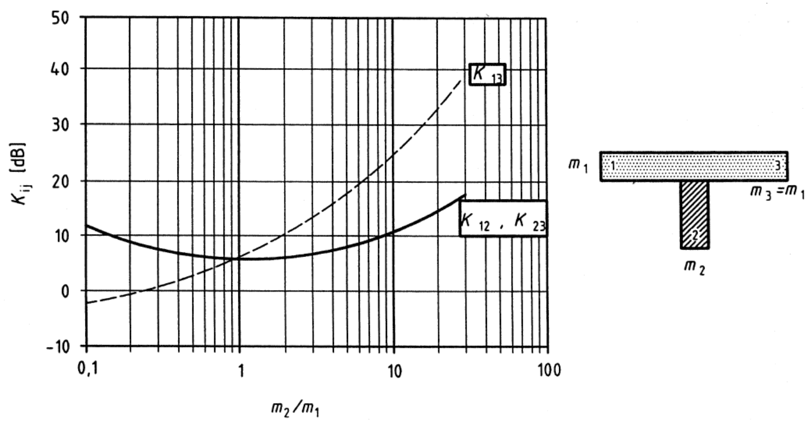
Rigid cross-junction



$K_{13} = 8{,}7 + 17{,}1\,M + 5{,}7\,M^2$ dB ; 0 dB / octave

$K_{12} = 8{,}7 + 5{,}7\,M^2$ ($= K_{23}$) dB ; 0 dB / octave

Rigid T-junction



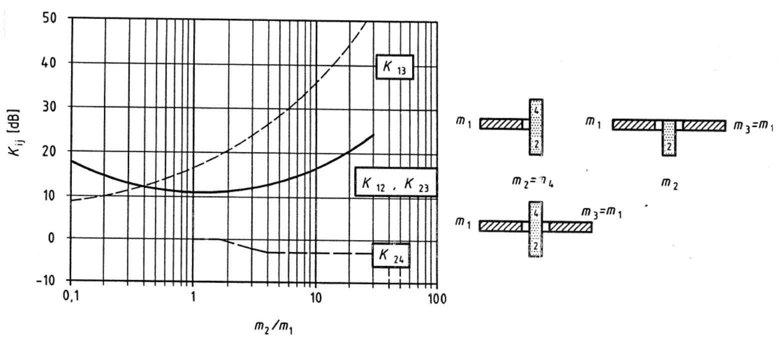
$K_{13} = 5{,}7 + 14{,}1\,M + 5{,}7\,M^2$ dB ; 0 dB / octave

$K_{12} = 5{,}7 + 5{,}7\,M^2$ ($= K_{23}$) dB ; 0 dB / octave

Flanking transmission reduction index (IV)

- Vibration reduction indices K_{ij}
  - SS-EN 12354-1:2000 (Annex E)

Wall junction with flexible interlayers



$K_{13} = 5{,}7 + 14{,}1\,M + 5{,}7\,M^2 + 2\,\Delta_1$ dB

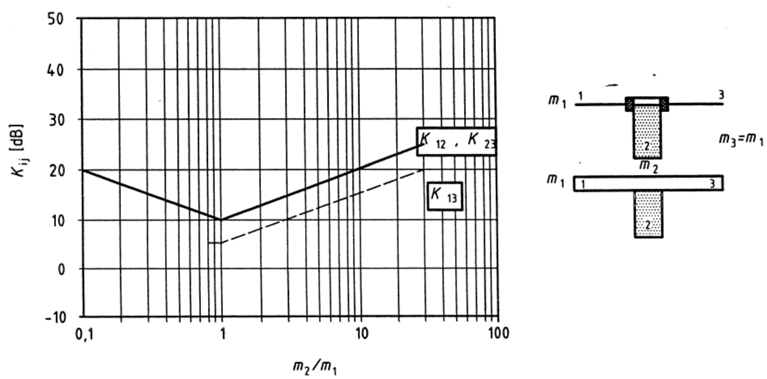
$K_{24} = 3{,}7 + 14{,}1\,M + 5{,}7\,M^2$ dB ; $0 \leq K_{24} \leq -4$ dB ; 0 dB / octave

$K_{12} = 5{,}7 + 5{,}7\,M^2 + \Delta_1 \left(= K_{23} \right)$ dB

$\Delta_1 = 10 \lg \frac{f}{f_1}$ dB for $f > f_1$

$f_1 = 125$ Hz if $\frac{E_1}{t_1} \approx 100$ MN/m^3 ; see text

Lightweight façade junction



$K_{13} = 5 + 10\,M$ dB and minimum 5 dB ; 0 dB / octave

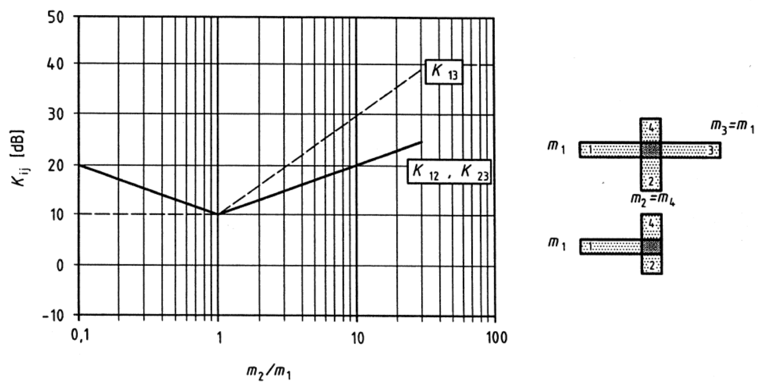
$K_{12} = 10 + 10\,|M| \,(= K_{23})$ dB ; 0 dB / octave

$a_{facade,situ} = S_{facade} / l_o$

Flanking transmission reduction index (V)

- Vibration reduction indices K_{ij}
  - SS-EN 12354-1:2000 (Annex E)

Junction of lightweight coupled double leaf walls

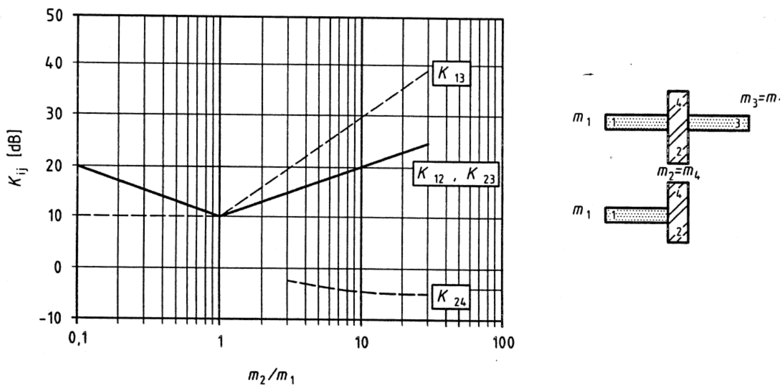


$K_{13} = 10 + 20\,M - 3{,}3\,\lg\frac{f}{f_k}$ dB and minimum 10 dB

$K_{12} = 10 + 10\,|M| - 3{,}3\,\lg\frac{f}{f_k}$ dB $(= K_{23})$

$f_k = 500$ Hz $\quad a_{situ} = S/l_o$

Junction of lightweight double leaf wall and homogeneous elements



$K_{13} = 10 + 20\,M - 3{,}3\,\lg\frac{f}{f_k}$ dB and minimum 10 dB

$K_{24} = 3{,}0 - 14{,}1\,M + 5{,}7\,M^2$ dB ; $\frac{m_2}{m_1} > 3$; 0 dB / octave

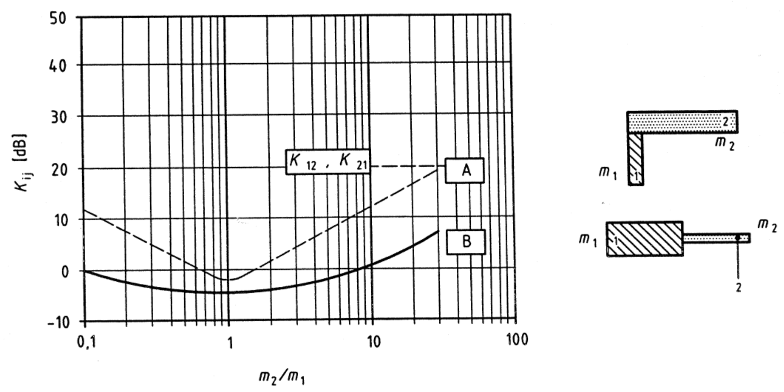
$K_{12} = 10 + 10\,|M| + 3{,}3\,\lg\frac{f}{f_k}$ dB $(= K_{23})$

$f_k = 500$ Hz $\quad a_{\text{lightweight wall,situ}} = S_{\text{lightweight wall}} / l_o$

Flanking transmission reduction index (VI)

- Vibration reduction indices K_{ij}
  - SS-EN 12354-1:2000 (Annex E)

Corner or thickness change



A Corner :

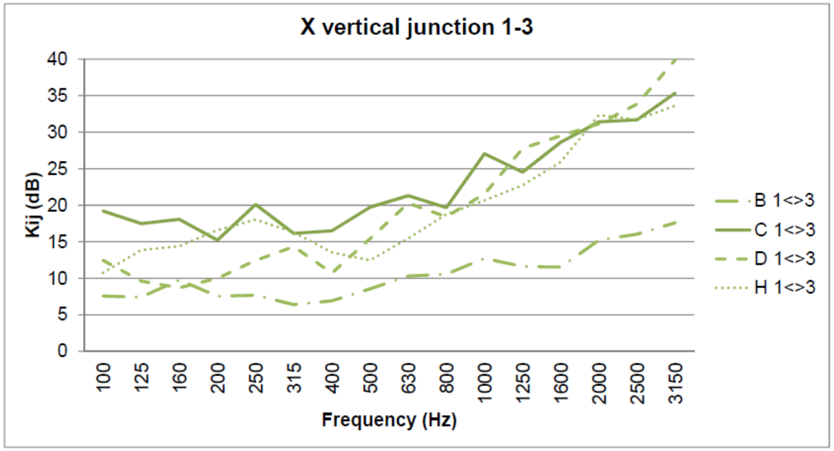
$K_{12} = 15\,|M| - 3$ dB and minimum -2 dB $(= K_{21})$; 0 dB / octave

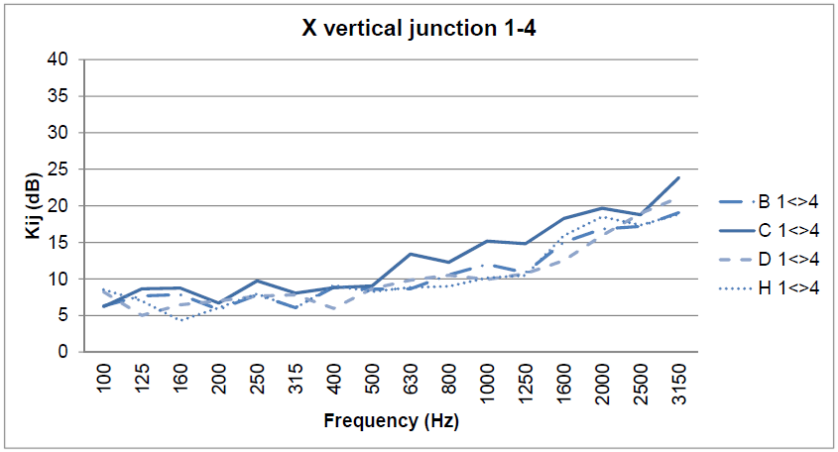
B Change :

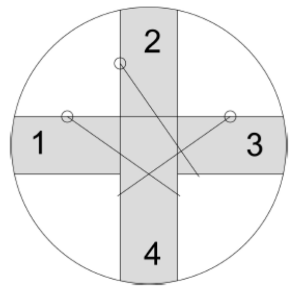
$K_{12} = 5\,M^2 - 5$ dB $(= K_{21})$; 0 dB / octave

Other experimental K_{ij}

- "X" CLT junction (example)
  - 4 configurations







Source: Barbaresi (2016)

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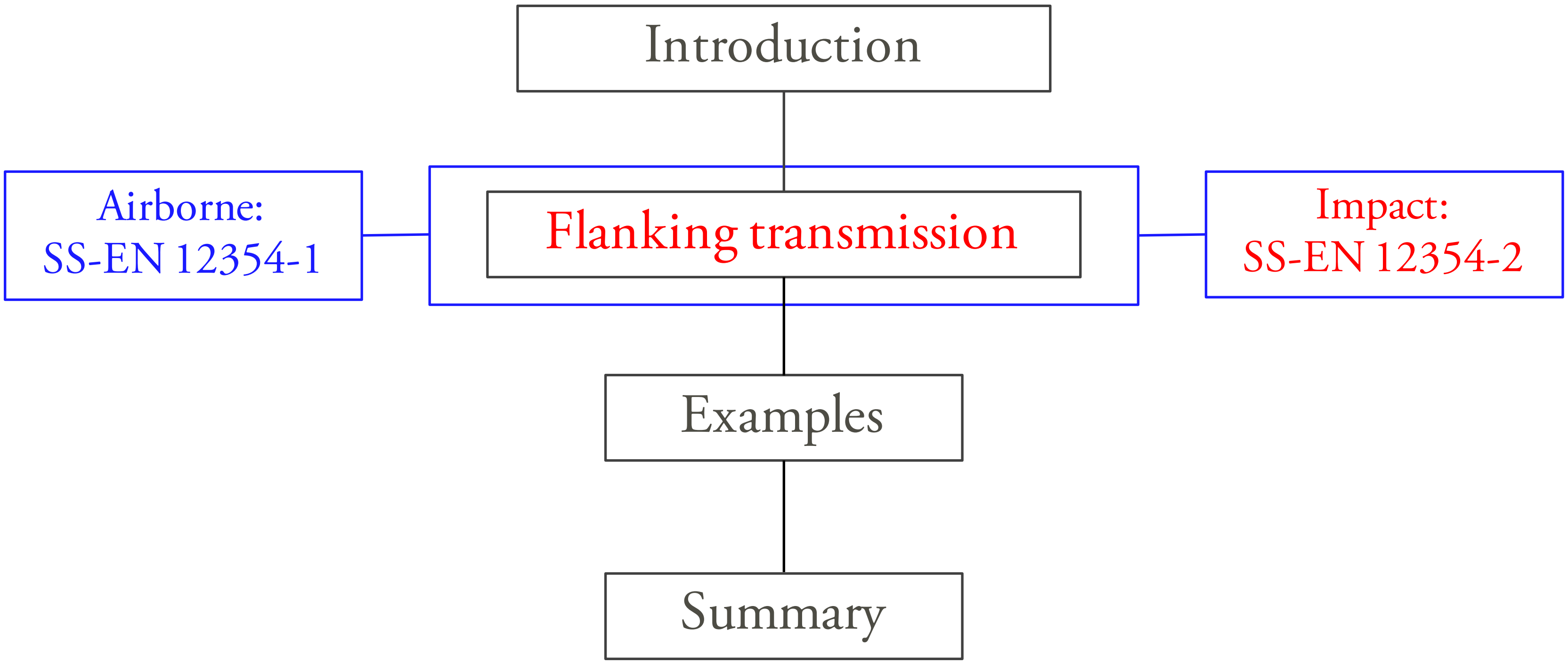
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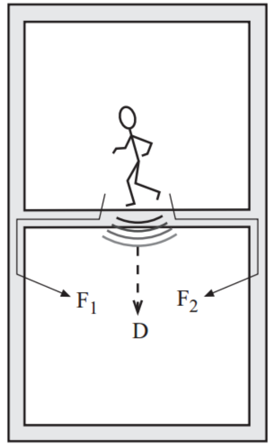
Impact sound with flanking transmission (I)



- Impact sound pressure level in the receiving room

$$L'_n = 10\log\left[10^{\frac{L_{n,d}}{10}} + \sum_{j=1}^{n} 10^{\frac{L_{n,ij}}{10}}\right]$$

- If the SS-EN 12354-1 simplified model is assumed, the weighted normalised impact sound pressure level is:

$$L'_{n,w} = L_{n,w,eq} - \Delta L_w + K$$

$$L_{n,w,eq} = 164 - 35\log\left(\frac{m'}{m_0'}\right)$$

$$m_0' = 1kg/m^2$$

$L_{n,w,eq}$: equivalent weighted normalised impact sound pressure level of the floor base (Annex B)

ΔL_w : weighted reduction of impact sound pressure level of the floor covering (obtained according to EN ISO 717-2:1996) and given in Figures in the Standard.

NOTES: K is the correction for impact sound transmission over the homogeneous flanking constructions in decibels, and it is given in a tabular form in the standard. // Limitations: the simplified model is only applied to homogeneous building constructions with floating floors or soft coverings on a homogeneous constructions, and only for rooms one above each other which are of conventional sizes in dwellings.

Impact sound with flanking transmission (II)

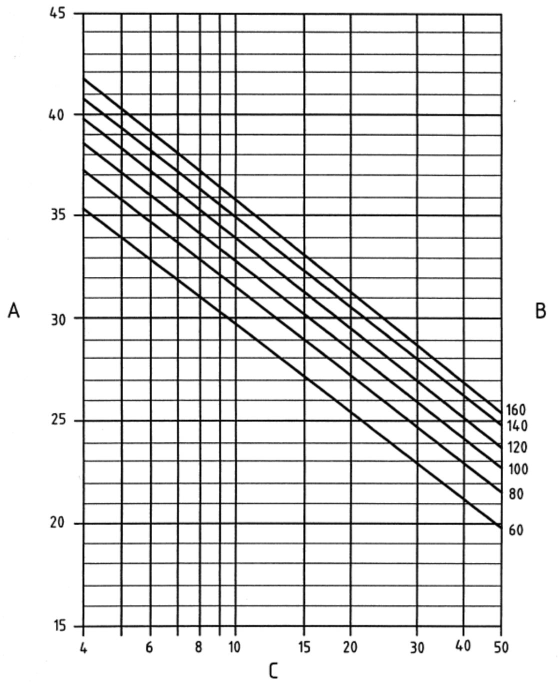
Table 1 - Correction *K* for flanking transmission in decibels

Mass per unit area of the separating element (floor) in kg/m²	**Mean mass per unit area of the homogeneous flanking elements not covered with additional layers in** kg/m²								
	100	150	200	250	300	350	400	450	500
100	1	0	0	0	0	0	0	0	0
150	1	1	0	0	0	0	0	0	0
200	2	1	1	0	0	0	0	0	0
250	2	1	1	1	0	0	0	0	0
300	3	2	1	1	1	0	0	0	0
350	3	2	1	1	1	1	0	0	0
400	4	2	2	1	1	1	1	0	0
450	4	3	2	2	1	1	1	1	1
500	4	3	2	2	1	1	1	1	1
600	5	4	3	2	2	1	1	1	1
700	5	4	3	3	2	2	1	1	1
800	6	4	4	3	2	2	2	1	1
900	6	5	4	3	3	2	2	2	2

If one or more massive flanking constructions are covered by additional layers (wall lining) with a resonant frequency f_0 < 125 Hz according to D.2 of EN 12354-1 : 2000 the surface masses of the covered elements are not considered in the calculation of the mean mass value.

NOTE In principle a correction term K to express the contribution of flanking transmission could also be derived for other room configurations than rooms above each other.

Impact sound with flanking transmission (III)



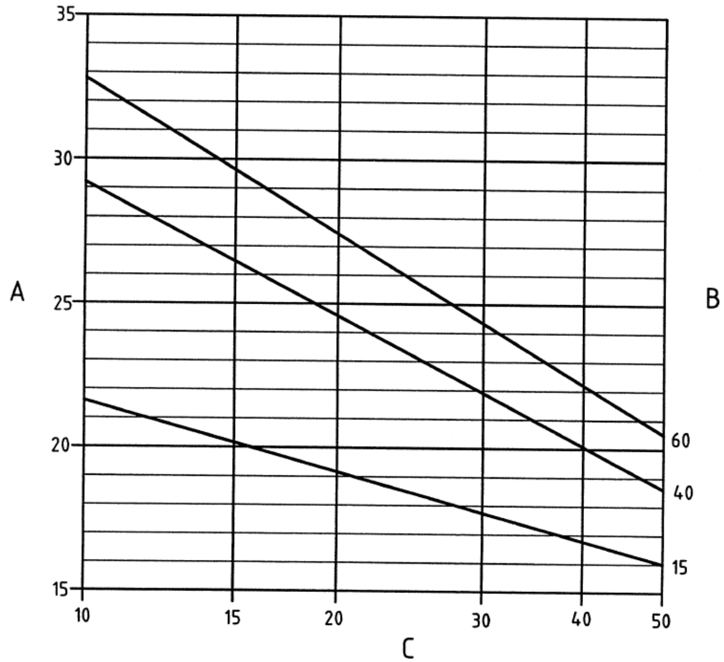
Legend

A Weighted impact sound reduction index ΔL_w in dB

B Mass per unit area of the floating floor in kgm^{-2}

C Dynamic stiffness per unit area s' of the resilient layer in MNm^{-3}

Figure C.1 - Weighted reduction of impact sound pressure level for floating floor screeds made of sand/cement or calcium-sulphate



Legend

A Weighted impact sound reduction index ΔL_w in dB

B Mass per unit area of the floating floor in kgm^{-2}

C Dynamic stiffness per unit area s' of the resilient layer in MNm^{-3}

Figure C.2 - Weighted reduction of impact sound pressure level for asphalt floating floors or dry floating floor constructions

NOTES: The weighted reduction of impact sound pressure level ΔL_w depends on the mass per unit area *m'* of the floating floor and the dynamic stiffness per unit area *s'* of the resilient layer according to EN 29052-1

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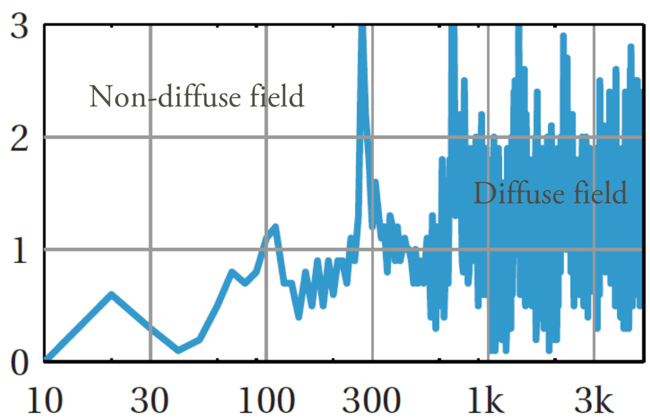
Some comments about SS-EN 12354:2000

- The standard describes a simplified statistical energy analysis (SEA) model to predict R'_w and $L'_{n,w}$
  - Lightweight elements typically don't meet the requirements of an SEA subsystem:
    - Vibratory fields show large variances (lack of diffuseness)
    - Low modal density at low frequencies
    - …



- The latter may result in inaccurate predictions when using SS-EN 12354:2000 applied to wooden lightweight constructions

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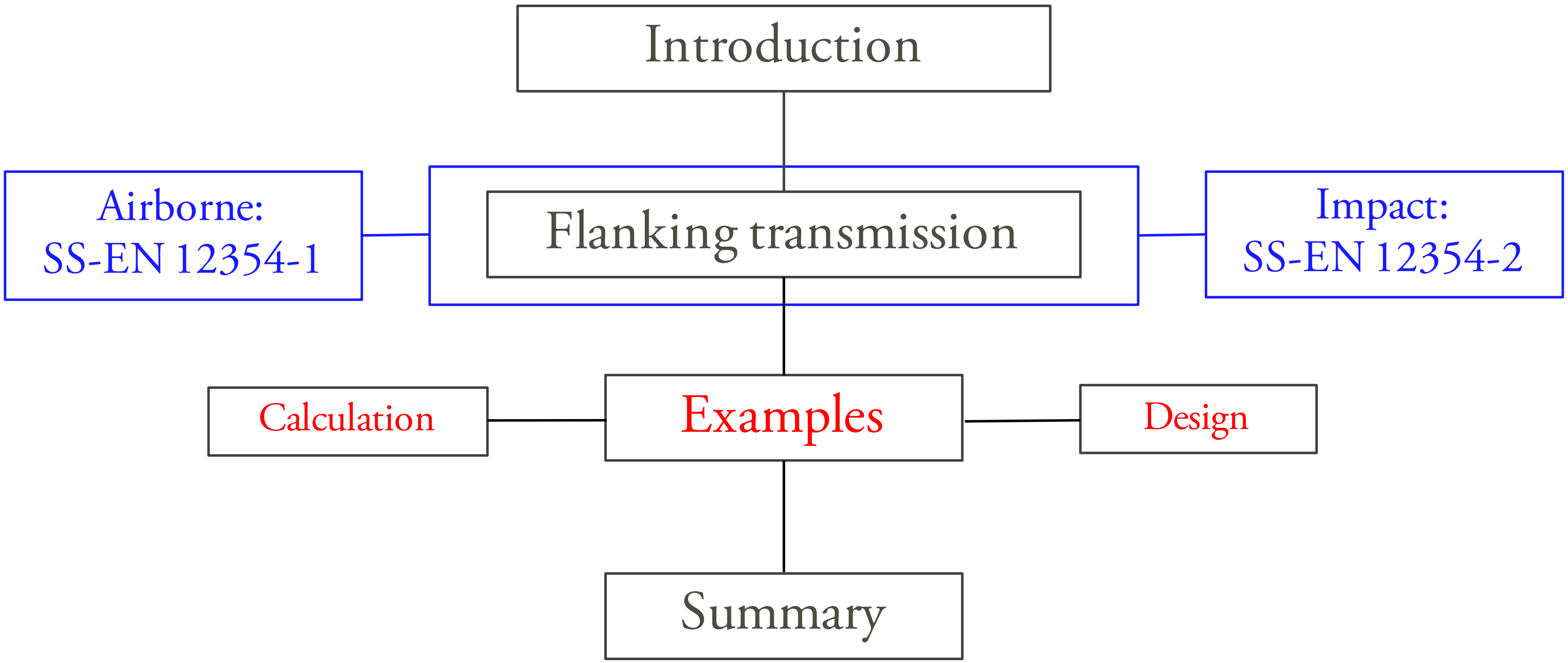
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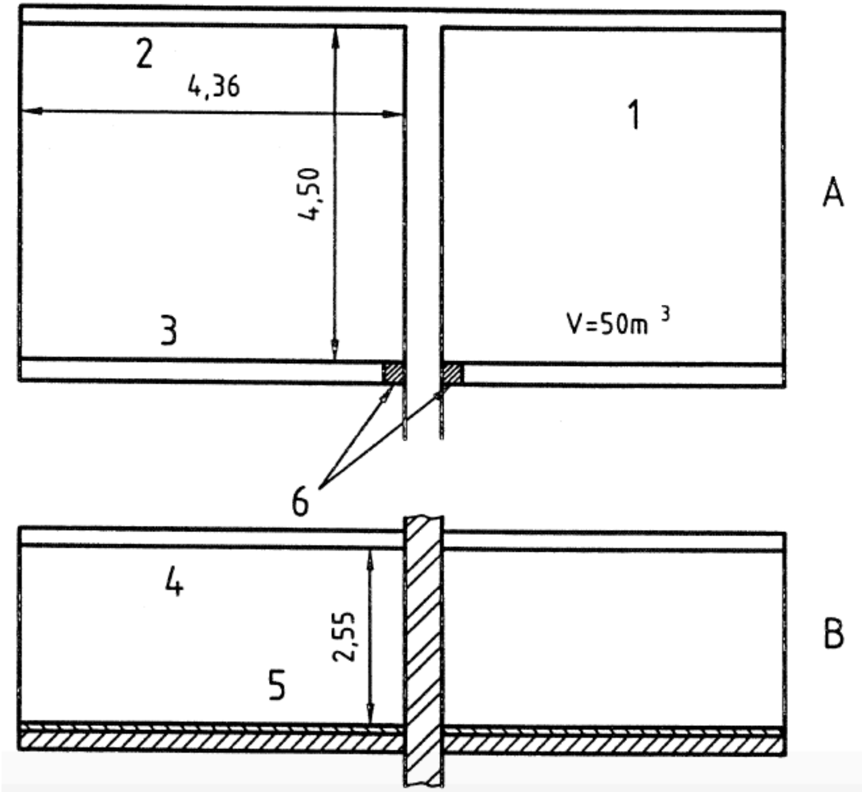
Calculation example 1 (SS-EN 12354-1:2000)



Key

A Ground plan

B Sectional view

Separating element :

1 wall 4,50 m × 2,55 m = 11,5 m^2 ; 200 mm concrete, 460 kg/m^2.

Flanking elements (identical on both sides) :

2 Façade : 4,36 m × 2,55 m = 11,1 m^2 ; rigid T junction ; 100 mm calcium-silicate blocks, 175 kg/m^2.

3 Internal wall : 4,36 m × 2,55 m = 11,1 m^2 ; cross junction with elastic layer ; 70 mm gypsum blocks, 67 kg/m^2.

4 Ceiling : 4,36 m × 4,50 m = 19,6 m^2 ; rigid cross junction ; 100 mm concrete, 230 kg/m^2.

5 Floor : 4,36 m × 4,50 m = 19,6 m^2 ; rigid cross junction ; 100 mm concrete / 30 mm finish, 287 kg/m^2.

6 flexible connection

Calculation example 1 (SS-EN 12354-1:2000)

- Data:

INPUT DATA :	ELEMENTS		JUNCTIONS			
	m' (kg/m^2)	R_w (dB) Annex B	m'_s/m'_f	K_{Ff} (dB)	K_{Fd} (dB) Annex E	K_{Df} (dB) Annex E
Wall (s)	460	57				
Floor (F = f = 1)	287	49	1,61	12,4	8,9	8,9
Ceiling (F = f = 2)	230	46	2,00	14,4	9,2	9,2
Façade (F = f = 3)	175	42	2,63	12,6	6,7	6,7
Internal wall (F = f = 4)	67	33	6,97	33,5	15,7	15,7

- Solution:

Wall :

R_{Dd} = 57,0 dB

R_{1d} = 49/2 + 57/2 + 8,9 + 4,1 = 66,0 dB

R_{2d} = 46/2 + 57/2 + 9,2 + 4,1 = 64,8 dB

R_{3d} = 42/2 + 57/2 + 6,7 + 6,5 = 62,7 dB

R_{4d} = 33/2 + 57/2 + 15,7 + 6,5 = 67,2 dB

Floor :

R_{D1} = 49/2 + 57/2 + 8,9 + 4,1 = 66,0 dB

R_{11} = 49 + 12,4 + 4,1 = 65,5 dB

Ceiling :

R_{D2} = 46/2 + 57/2 + 9,2 + 4,1 = 64,8 dB

R_{22} = 46 + 14,4 + 4,1 = 64,5 dB

Façade :

R_{D3} = 42/2 + 57/2 + 6,7 + 6,5 = 62,7 dB

R_{33} = 42 + 12,6 + 6,5 = 61,1 dB

Internal wall :

R_{D4} = 33/2 + 57/2 + 15,7 + 6,5 = 67,2 dB

R_{44} = 33 + 33,5 + 6,5 = 73,0 dB

Total (equation (26)) R'_w **= 52,2 ≈ 52 dB**

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Calculation example 2 (SS-EN 12354-2:2000)

- Task:

The impact sound pressure level L'_n between two dwellings is to be calculated for two rooms above each other, separated by a concrete floor slab covered with a floating floor. The volumes of the rooms are 50 m^3, the other construction details are given below.

Separating element :

floor	S_i = 5,00 m x 4,00 m = 20,0 m^2 ;
	140 mm concrete, m' = 0,14 m x 2300 kg/m^3 = 322 kg/m^2 ;
floating floor :	35 mm concrete on 20 mm mineral wool slab with s' = 8 MN/m^3.

Flanking elements (identical on both sides) :

internal walls	S_j = 5,00 m x 2,50 m = 12,5 m^2 ; rigid cross junction ;
	120 mm aerated concrete, m' = 0,12 m x 800 kg/m^3 = 96 kg/m^2 ;
external walls	S_j = 4,00 m x 2,50 m = 10,0 m^2 ; rigid T junction ;
	100 mm brickwork, m' = 0,1 m x 1900 kg/m^3 = 190 kg/m^2.

Calculation example 2 (SS-EN 12354-2:2000)

- Solution:

— equivalent weighted normalized impact sound pressure level of the concrete floor slab : from annex B :

$L_{n,w,eq}$ = 164 - 35 lg(m'/m'_o) with m'_o = 1 kg/m^2
= 164 - 35 lg (322/1) = 76,2 dB ≈ 76 dB

— weighted impact sound improvement index of the floating floor :

with the dynamic stiffness per unit area s' = 8 MN/m^3 of the mineral wool slab and the mass per unit area m' = 80 kg/m^2 of the floor screed follows from Figure C.1 :

ΔL_w = 33 dB

— correction K for flanking transmission :

mean surface mass of the homogeneous flanking elements, not covered with resilient layers, m' = 0,25 [(2 x 190) + (2 x 96)] kg/m^2 = 145 kg/m^2 ; so from Table 1 :

K = 2 dB

— weighted normalized impact sound pressure level between the two rooms :

from equation (21) :

$L'_{n,w} = L_{n,w,eq} - \Delta L_w + K$ = (76 - 33 + 2) dB = 45 dB

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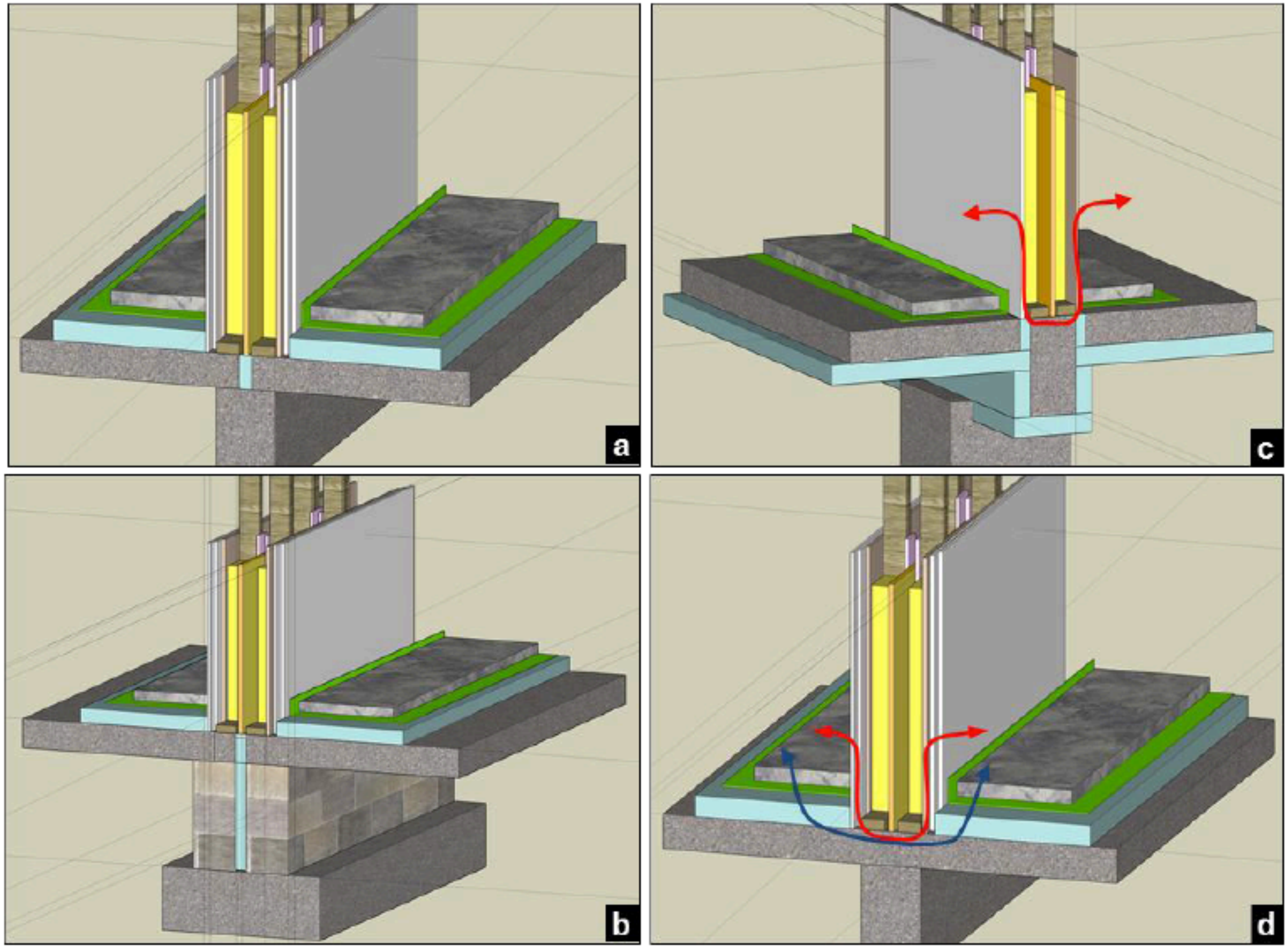
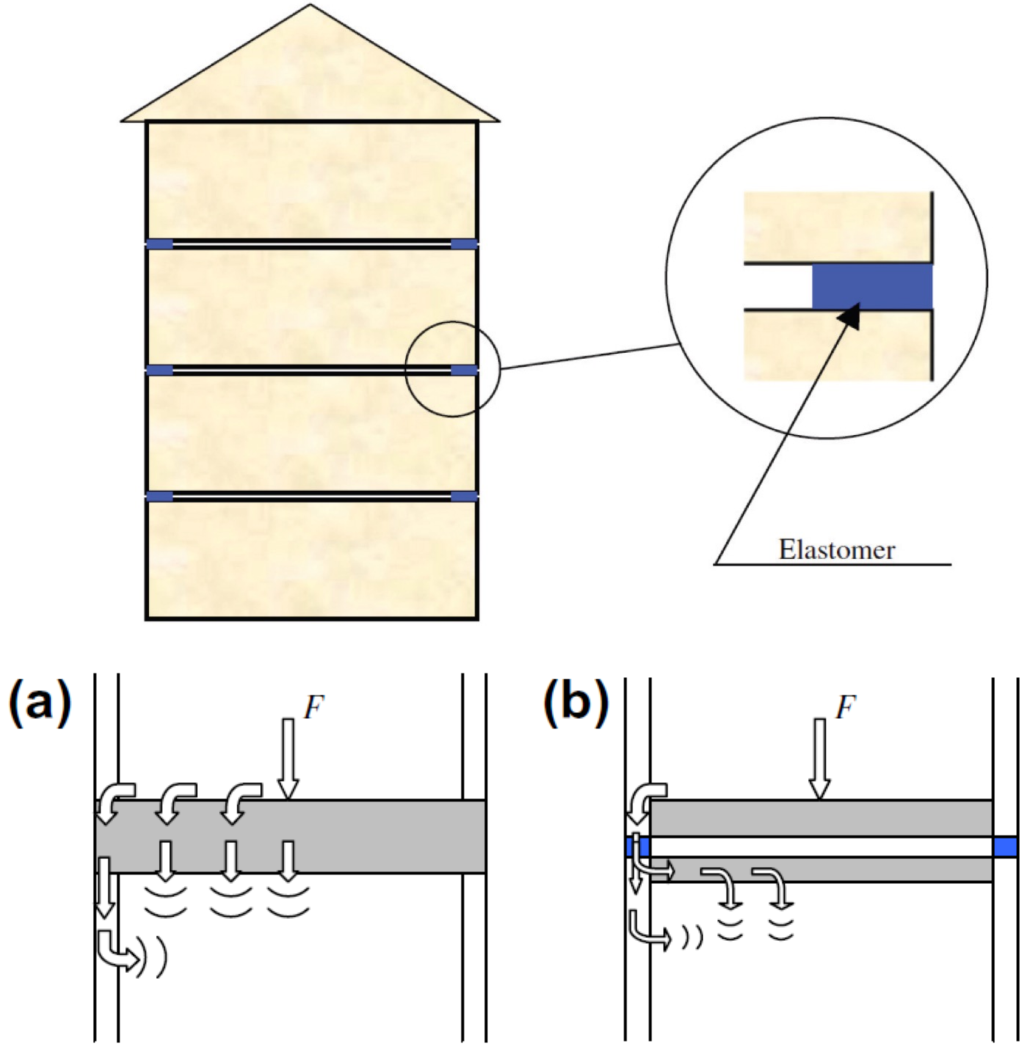
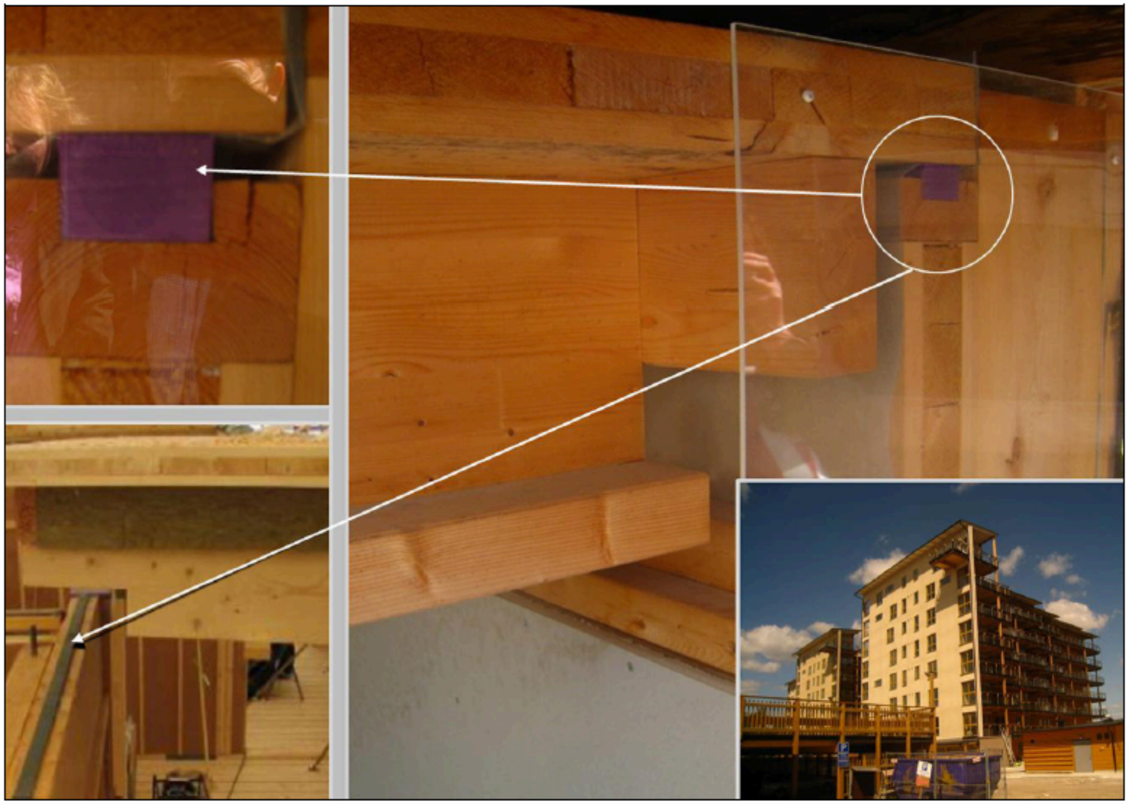
Design example: decoupling structural elements

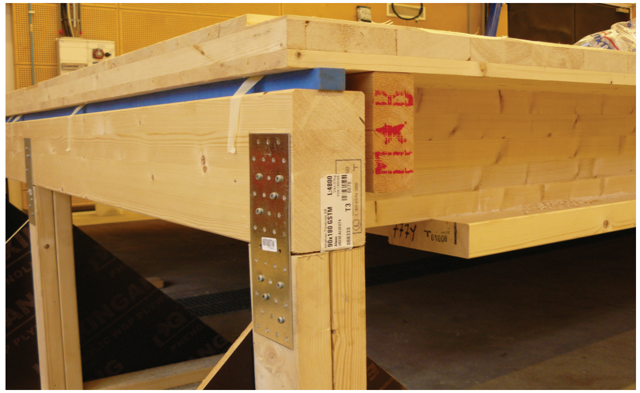


Design example: timber volume elements



Design example: elastic interlayers





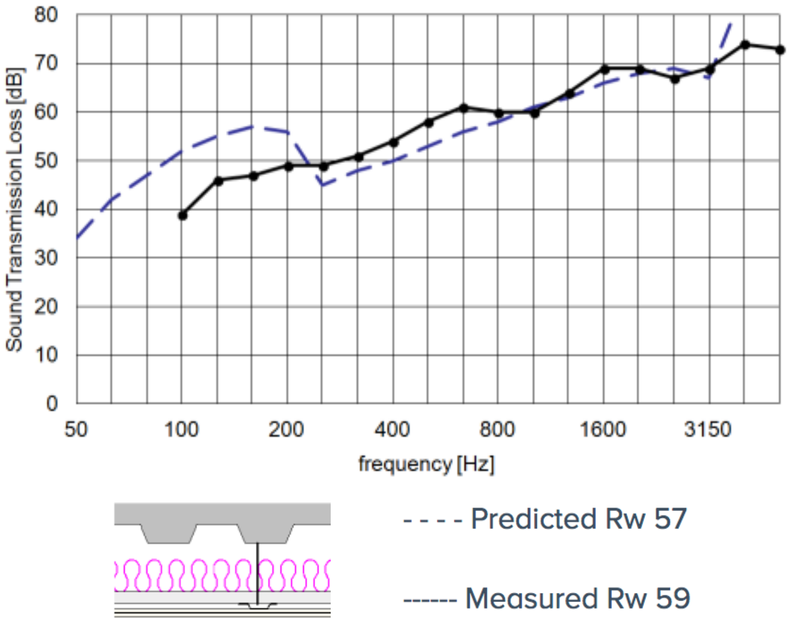
Prediction

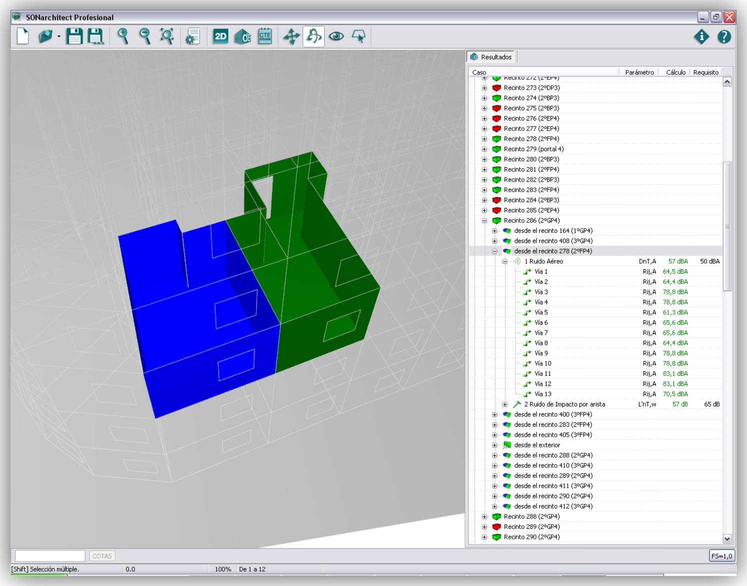
– Is it posible to predict vibroacoustic performance of buildings?

We slowly know more and more but…
… still many things left to be done,
especially in the woodenn constructions…

Prediction: commercial software (I)

- Insul
  - Example: Composite Steel floor (Hibond) 120mm thick with suspended light steel grid with 2 layers of 13mm fire rated plasterboard. 75mm fibreglass blanket in the cavity.

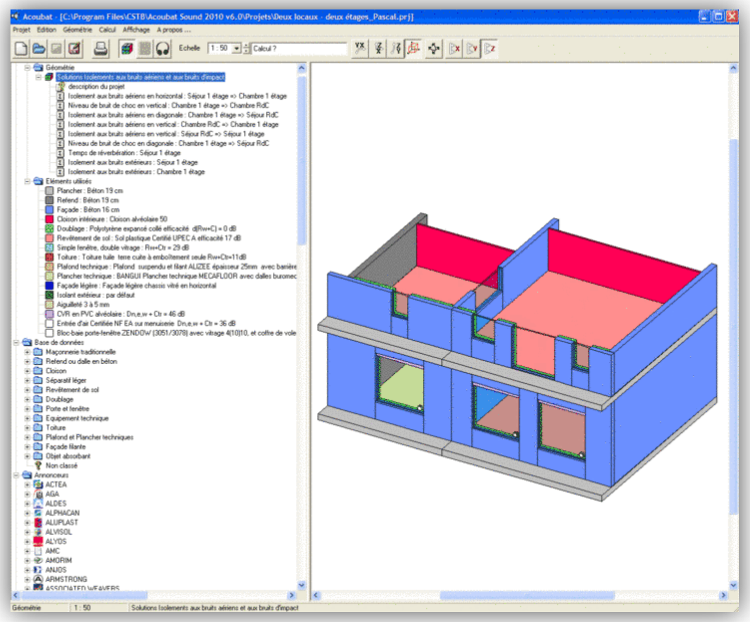




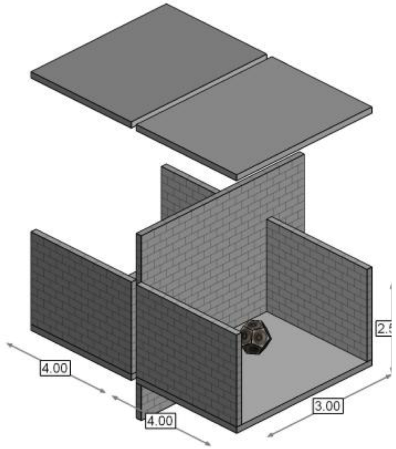
- Son-Architect (ESP)

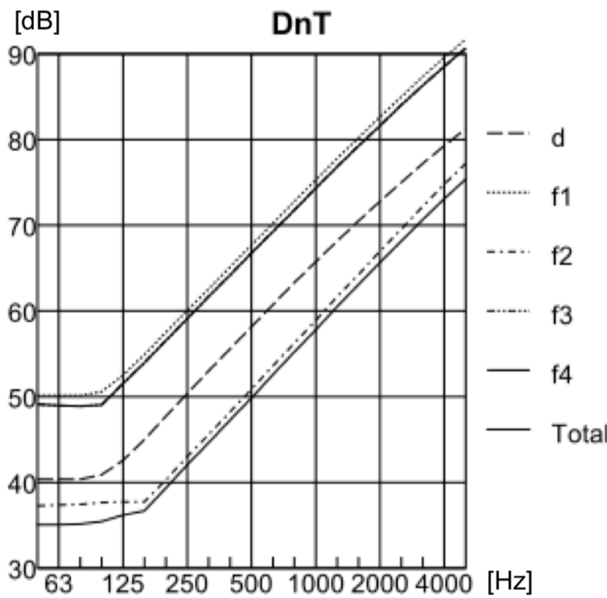
Prediction: commercial software (II)

- Acoubat (CSTB France)



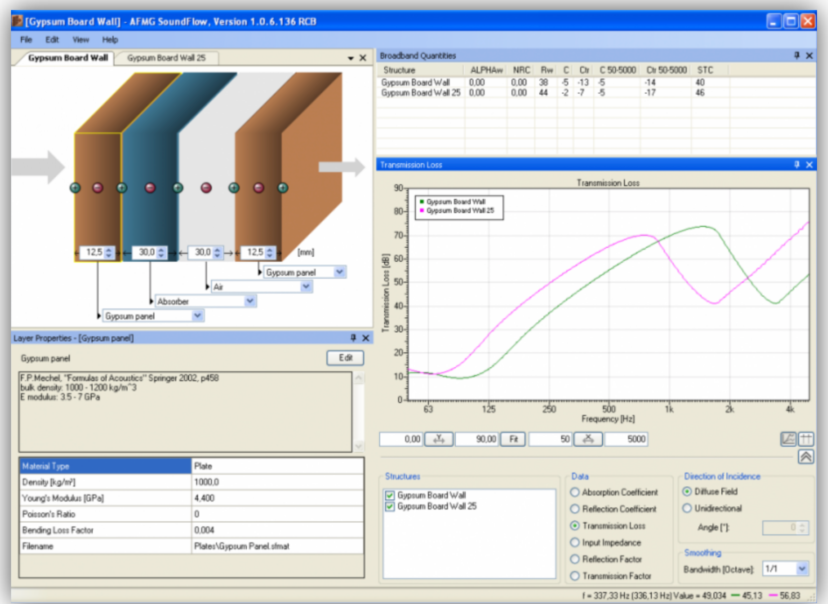
- Bastian
  - No update since a while ago (?)

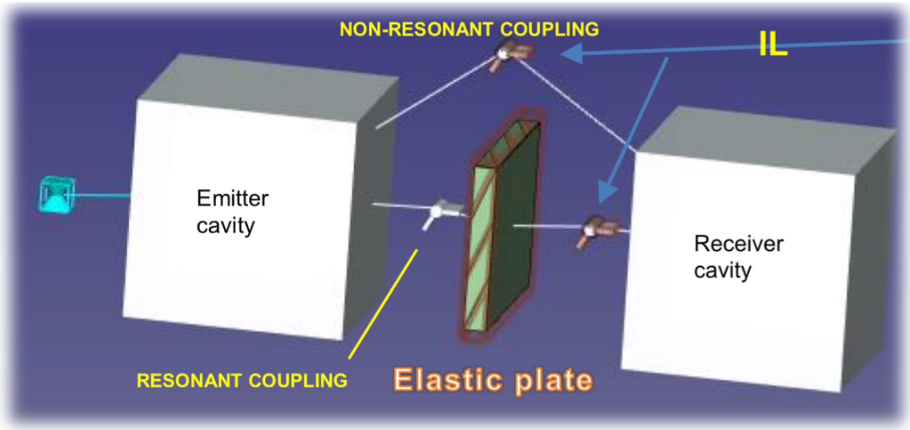




Prediction: commercial software (III)

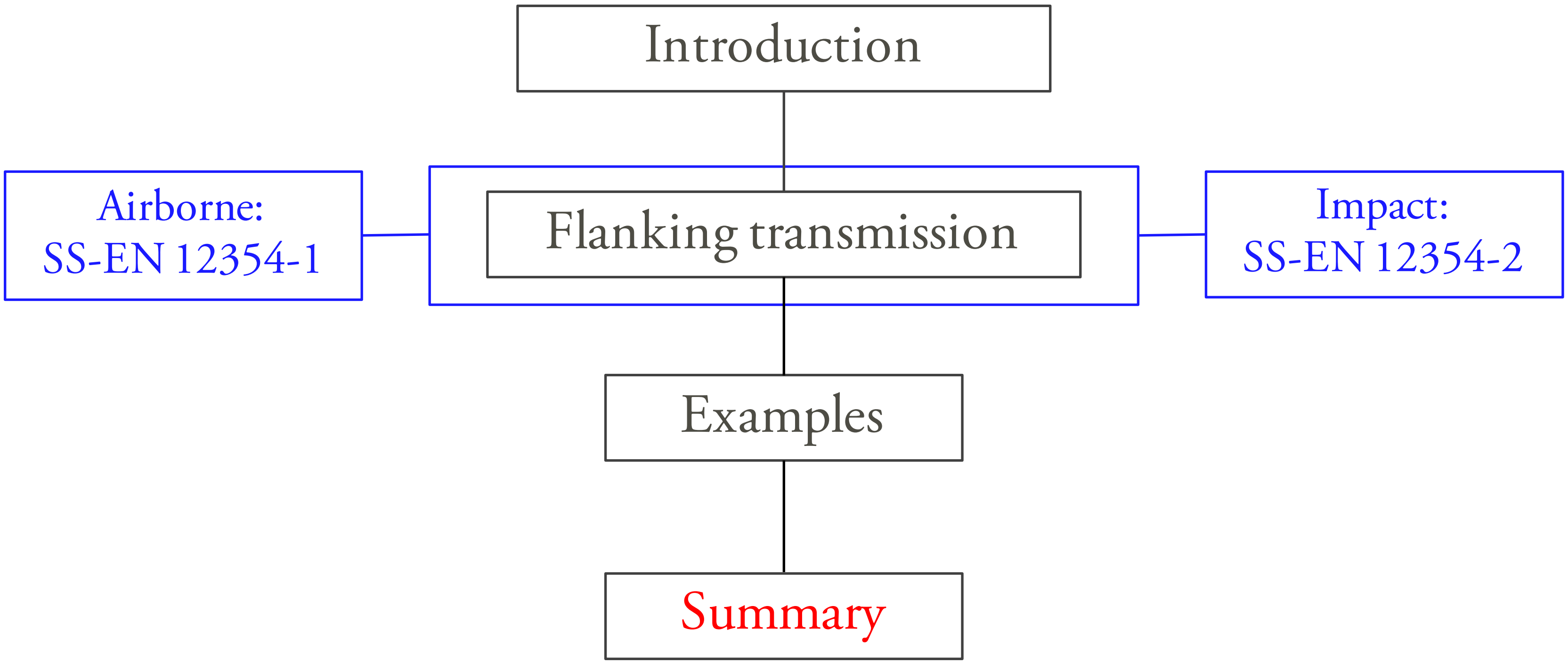
- AFMG Soundflow





- SEA-Wood
  - Works good for airborne sound (less well for impact)
  - not very adapted to engineers yet

Outline



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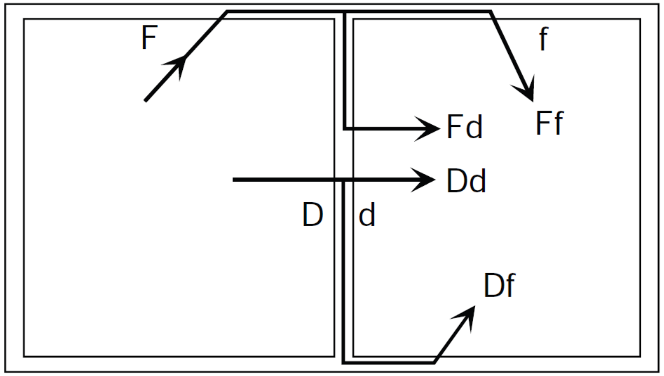
Summary (I)

- Flanking transmission (airborne)



$$R'_{w,total} = R'_{w} + C_{50\text{-}3150}$$

$$R'_{w} = -10\log\left[10^{\frac{-R_{Dd,w}}{10}} + \sum_{F=f=1}^{n} 10^{\frac{-R_{Ff,w}}{10}} + \sum_{f=1}^{n} 10^{\frac{-R_{Df,w}}{10}} + \sum_{F=1}^{n} 10^{\frac{-R_{Fd,w}}{10}}\right]$$

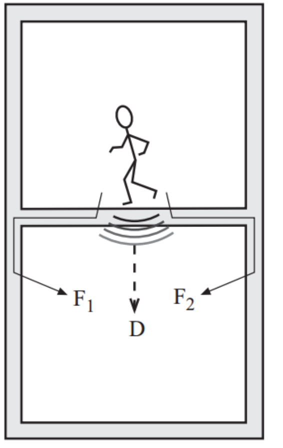
$$C_{50-3150} = -10\log\left(\sum_{i} 10^{\frac{L_i - R_i}{10}}\right) - R'_{w}$$

Lab measurements (ISO)

$$\left(R_f\right)_{ij,w} = R_{ij,w} = \frac{R_{i,w} + R_{j,w}}{2} + K_{ij} + 10\log\left(\frac{S_s}{l_0 \cdot l_{ij}}\right)$$

Summary (II)

- Flanking transmission (impact)



$$L'_n = 10\log\left[10^{\frac{L_{n,d}}{10}} + \sum_{j=1}^{n} 10^{\frac{L_{n,ij}}{10}}\right]$$

$$L'_{n,w} = L_{n,w,eq} - \Delta L_w + K$$

$$L_{n,w,eq} = 164 - 35\log\left(\frac{m'}{m_0'}\right)$$

$$m_0' = 1kg/m^2$$

Figures in SS EN12354-2

Table in SS EN12354-2

Thank you for your attention!

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