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A Parameter Study of Coupling Properties in Finite Element Models of Single-stud Double-plate Panels

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ABSTRACT
Lightweight building techniques are currently progressing fast and using such structures for multi-storey multi-family dwellings is becoming part of the industry standard. Partitions in lightweight buildings are often constructed as plates on frame structures made of either wood or steel. In any case the low frequency sound transmission is often an issue that needs attention. The present paper utilizes a finite element model of a single-stud double-plate panel structure to investigate how different couplings between the plates and the frame structure affect the direct sound transmission. Four different coupling configurations are considered: 1) All structural contact points are completely tied; 2) only nodes on the centre lines of the structure are tied; 3) a narrow strip of tied elements connect the frame to the plates; 4) evenly spaced discrete elements are tied. In all cases the interaction between non-tied elements is neglected. The investigations are performed as parameter studies focusing on the effect of change in the model. The finite element model utilizes solid continuum elements for the entire structure. The computations are carried out in frequency domain in the range below 500 Hz and the load acts as a diffuse field on one side of the panel. The obtained results indicate that in order to accurately model sound transmission through a double-plate panel structure, the choice of coupling is an important factor.
Keywords: Sound transmission, Finite Element Method, Lightweight structure

1. INTRODUCTION

Transmission of sound between rooms in dwellings is an on-going subject of investigation in current research. Lightweight building techniques are advancing due to low production costs, quick installation and easy transportation. Furthermore, there is an increasing awareness regarding the use of environmentally friendly materials. However, lightweight building structures suffer serious drawbacks in terms of poor low frequency sound insulation. This is due to the low mass of the constructions. As the trend is going towards increasing demands to the acoustic performance of building elements, inaccurate prediction methods and poor performance calls for over-dimensioning of the elements. This increases both weight and cost, which contradicts the idea of using lightweight elements in a building. Modern production techniques with prefabricated lightweight modules are rapidly evolving, and encourage re-thinking the design of separating building elements as constructions are now possible that were previously not.

An important tool for development and optimization of the acoustic performance of lightweight elements is a reliable prediction method. For a variety of simple structures, analytical solutions have been established [1], and for heavy structures, statistical methods, such as statistical energy analysis (SEA) [2–5] and the European standard EN 12354 [6] has in general been found to provide a reliable prediction of noise transmission. However, these statistical methods have limited validity for lightweight structures such as wooden floor and wall panels. This is due to the violation of basic assumptions such as non-diffuseness and a non-uniform distribution of eigenmodes. In reference [7], EN 12354 is found to provide imprecise predictions of sound transmission in lightweight building structures.

On-going research is concerned with the loss factors in the different types of couplings that occur in lightweight structures. This includes different types of beams [8, 9] as well as line coupling versus point coupling [5, 8, 9] and rigid versus pinned couplings [10], the main concern being the adaptation of statistical methods to lightweight structures. For the low-frequency range, where the modal density is low, statistical

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methods are not well suited. Instead, the conventional finite element method (FEM) [11] can be used. Recently, research has been presented where sound transmission in the low-frequency range through lightweight structures has been predicted with numerical methods [12, 13]. The results from these papers indicate that FEM tools can give reliable results for prediction of sound transmission loss. However, more investigations have to be performed in this field where the influence of different modeling strategies will be considered.

In the present paper, different rigid coupling configurations between the plates and the frame structure of a single-stud double-plate panel are investigated. The investigations are based on numerical analysis using elements available in the commercial FEM software package Abaqus® [14]. The paper focuses on structural tie constraints, varying the area of the constraint ranging from a full contact surface to a single line coupling ignoring the remaining contact elements. The goal is to determine whether or not the choice of coupling makes a difference on the direct sound transmission through the panel. If the results show significant differences, two conclusions can be drawn: 1) To accurately predict the low frequency sound transmission, the actual behavior of commonly used building elements should be investigated and compared with different modeling approaches. 2) In the design of lightweight elements, the coupling between the plates and the frame structure may be an important parameter that can be tweaked to optimize the acoustic performance. In both cases the variation of craftsmanship needs to be considered when assessing either measured or modeled results [15–18]. In recent work by the authors, the effect of variation in sound transmission due to variation in material properties and geometric properties of the walls have been discussed [19]. The obtained results indicate that the sound transmission is sensitive to variations in material properties and less sensitive to variations in the geometric properties. The present paper considers variation in plate-frame-couplings and is a continuation of the work done by the authors in [19].

The following section presents the double-panel lightweight wall element and different modeling scenarios, whereas the results are presented and discussed in Section 3. The conclusions are given in Section 4.

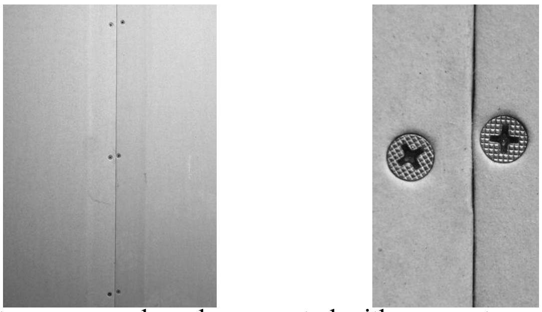

Figure 1 – An example of two gypsum boards connected with screws to a wooden frame. The pictures demonstrate how typical connections are not perfectly straight.

2. COMPUTATIONAL MODEL

The panel consists of two plates mounted on a frame structure with a total of six cavities, see Figure 2. The stud dimensions are 50 mm by 60 mm and the plate thickness is 20 mm. The total wall dimensions are 3350 mm (w) by 2600 mm (h) by 100 mm (d). The studs are placed 550 mm apart (centre-to-centre). Homogeneous and isotropic materials are assumed. The material properties of the timber (both frame and plates) are: Young's modulus $E = 14$ GPa, Poisson ratio $\nu = 0.35$, density $\rho = 500$ kg/m^3. Damping is set to 1% of the stiffness. The damping is applied as structural damping, i.e. the damping forces are assumed proportional to the forces caused by stressing of the structure. This simulates the effects of friction in the timber.

The panel is modeled in the commercial FEM package Abaqus® using solid continuum finite elements. 20-node brick elements with quadratic spatial interpolation of the displacement are adopted. The minimum wavelength in the model is expected to be approximately 10 cm as this is the order of magnitude of the flexural wavelength in the plate at a frequency of 500 Hz:

$$\lambda_b = \sqrt[4]{\frac{E h_p^2}{12\rho\omega^2(1-\nu^2)}}, \tag{1}$$

where h_p is the thickness of the plate. The mesh size is put to 50 mm to ensure a sufficiently high resolution of the model in the investigated frequency range. The mesh is designed such that the nodes constituting the plate mesh align with the nodes on the frame structure. All structural contact points are connected using tie constraints in x, y, and z-directions. As three-dimensional solid continuum elements have no rotational degrees of freedom, only displacements are considered. The boundaries are clamped, i.e. all nodes on the top, bottom and side surfaces of the structure are constrained in all directions. Only direct structural transmission is considered. In the present paper four different coupling configurations are investigated to determine if minor imperfections and variation in craftmanship (see Figure 1) can be expected to have an impact:

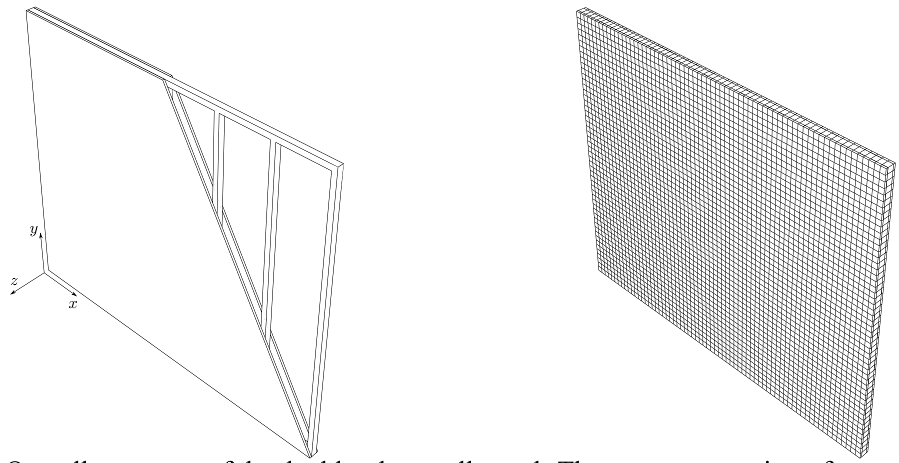

Figure 2 – Overall geometry of the double-plate wall panel. The structure consists of two plates tied to a stud frame. Left: Part of the plates are removed for illustrative purposes. Right: A Finite element mesh model of the panel.

1. All structural contact points are completely tied,
2. Only nodes on the centre lines of the structure are tied,
3. A narrow strip of tied elements connect the frame to the plates,
4. Evenly spaced discrete elements are tied.

In all cases the interaction between non-tied elements is neglected. Thus, effects such as friction—or even hard contact—between non-tied elements are not taken into account and the results can be considered to be extremes of a parametric study. The four coupling scenarios are shown in Figure 3.

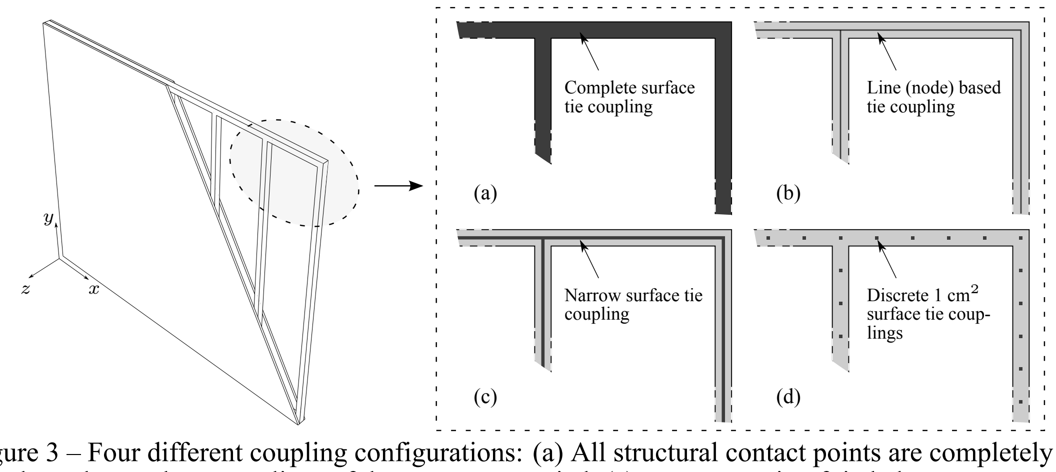

Figure 3 – Four different coupling configurations: (a) All structural contact points are completely tied; (b) only nodes on the centre lines of the structure are tied; (c) a narrow strip of tied elements connect the frame to the plates; (d) evenly spaced discrete elements are tied. In all cases the interaction between non-tied elements is neglected.

2.1 Excitation

As the present paper is dealing with transmission of sound through the entire panel, a diffuse field excitation model has been utilized. In Abaqus®, a diffuse field loading condition may be approximated by a number of deterministic incident plane waves coming from angles distributed over a hemisphere encapsulating the loaded surface. The number of incident plane waves used for the approximation in the present analyses is 30×30. In previous investigations the use of 900 incident plane waves has proven to provide reliable results in terms of convergence of the response [20].

2.2 Response

Due to the computational complexity associated with including an acoustic medium in the receiving room, this is not implemented at the present stage of modeling. Usually, the sound transmission loss of a structure would be calculated to evaluate the results, but as the sound pressure in the receiving room is not included in

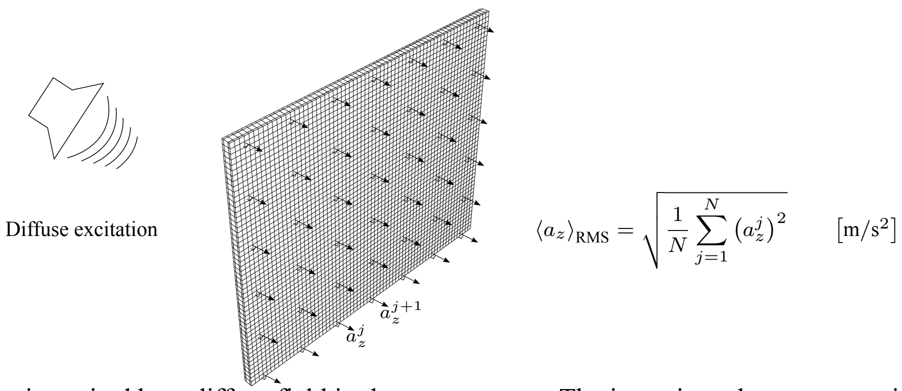

Figure 4 – The structure is excited by a diffuse field in the source room. The investigated output quantity in the receiving room is the translational surface acceleration, normal to the plane of the plate, expressed as the root-mean-square (spatial average) acceleration. Here a_z^j is the magnitude of the acceleration (z-direction) of the jth node on the plate surface.

the present model, this is not possible. Instead, the investigated output quantity in the receiving room,

$$\langle a_z \rangle_{\text{RMS}} = \sqrt{\frac{1}{N}\sum_{j=1}^{N}\left(a_z^j\right)^2}, \tag{2}$$

is the translational surface acceleration, normal to the plane of the plate, expressed as the spatial root-mean-square (RMS) acceleration. This is depicted in Figure 4. The results are presented in dB re 1μm/s^2.

3. RESULTS AND DISCUSSION

In the following section, results of numerical calculations are presented. The FE model used for the calculations essentially consists of two plates and a frame. The difference between the performed calculations lies in the plate-to-frame couplings (and vice versa) determining how contact points in the finite-element mesh interact. The different investigations cover various widths of the surface contact area as well as line coupling and discrete coupling surfaces (1×1 cm^2 surface ties spaced approximately 10 cm apart). In total, six different calculations have been performed. The results are shown in Figure 5. Figure 6 shows only the full coupling and the narrow surface couplings, whereas Figure 7 shows line and discrete couplings.

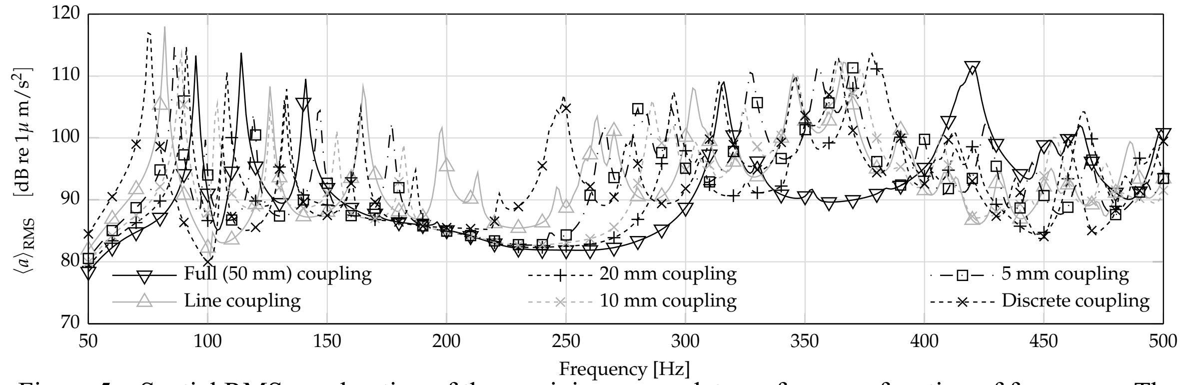

Figure 5 – Spatial RMS acceleration of the receiving room plate surface as a function of frequency. The structure is excited by simulating a diffuse field using 900 incident plane waves from random angles and of random phase. $\Delta f = 1$ Hz. The results are given separately in figures 6 and 7.

As expected, the results clearly demonstrate how the stiffness of the structure is reduced when going from a full contact tie to a less tied configuration. This is depicted in Figure 8, which shows eigenfrequencies of the structure in the investigated frequency range. In Table 1 the ten lowest eigenfrequencies for each configuration are listed. The results in Figures 5, 6 and 7 indicate that the choice of coupling in the model has a significant effect on the overall response of the structure. The higher modal density of the looser couplings gives rise to a number of resonance peaks in the response. These peaks are not seen in the fully tied case.

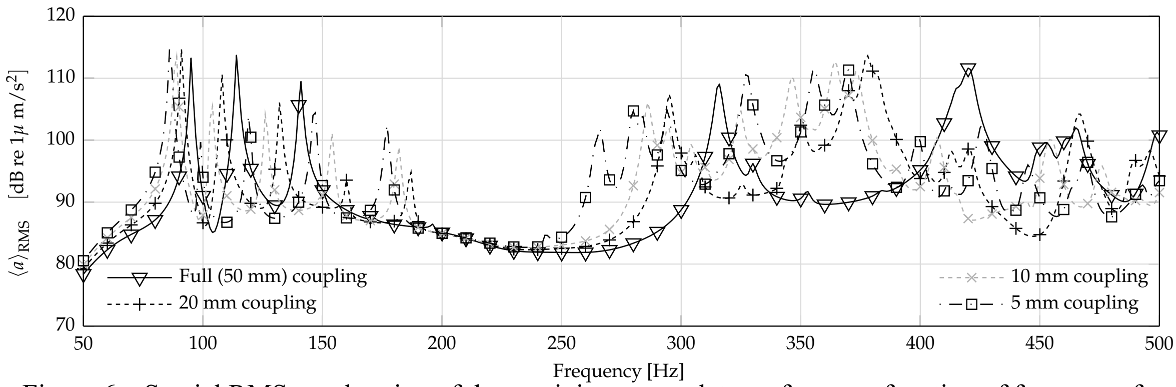

Figure 6 – Spatial RMS acceleration of the receiving room plate surface as a function of frequency for various widths of surface tie constraint. The structure is excited by simulating a diffuse field using 900 incident plane waves from random angles and of random phase. $\Delta f = 1$ Hz.

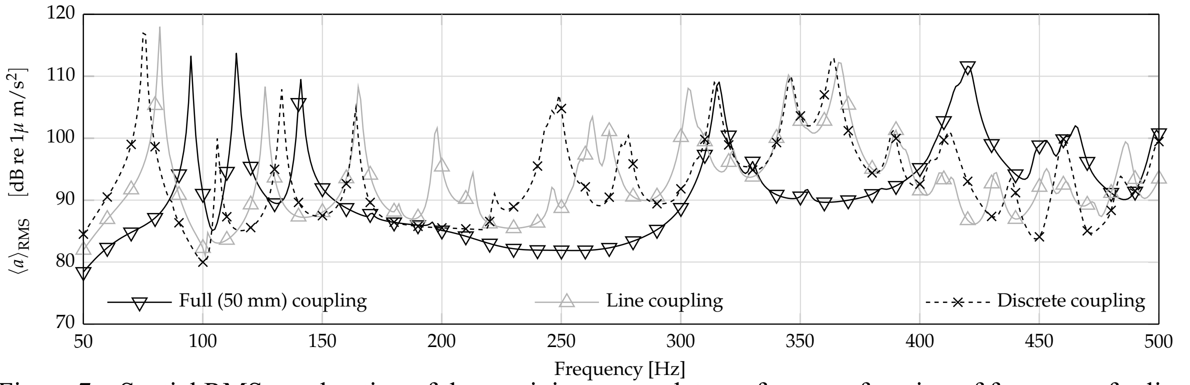

Figure 7 – Spatial RMS acceleration of the receiving room plate surface as a function of frequency for line coupling and discrete coupling surfaces. The structure is excited by simulating a diffuse field using 900 incident plane waves from random angles and of random phase. $\Delta f = 1$ Hz.

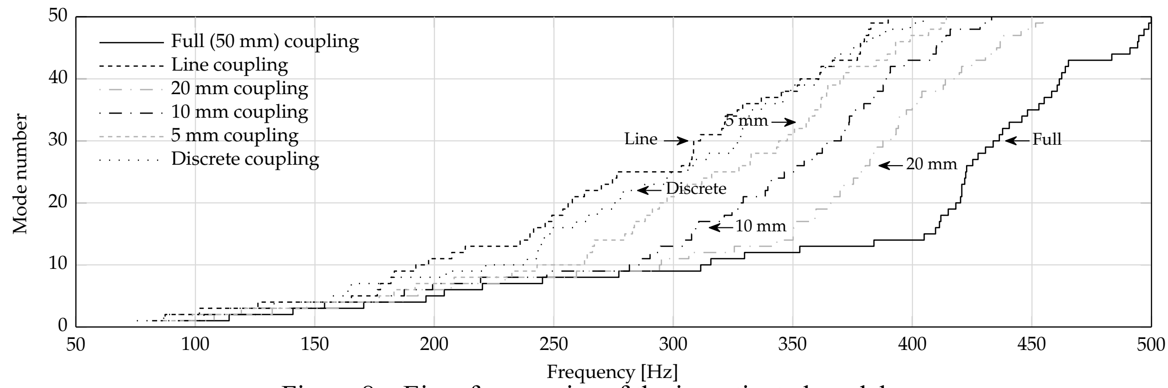

Figure 8 – Eigenfrequencies of the investigated models.

Table 1 – The ten lowest eigenfrequencies.

Mode number	Full [Hz]	Line [Hz]	20 mm [Hz]	10 mm [Hz]	5 mm [Hz]	Discrete [Hz]
1	95.1	81.9	91.1	88.6	86.3	75.5
2	114.1	87.3	107.8	103.6	98.7	86.7
3	140.8	101.7	132.1	126.3	119.2	106.1
4	170.4	126.2	160.4	154.0	146.6	132.9
5	196.5	165.3	186.8	181.9	176.9	156.7
6	204.1	176.1	193.1	187.4	183.1	163.8
7	220.1	177.4	207.0	199.2	191.9	165.2
8	245.2	181.8	229.6	219.3	208.2	181.0
9	277.2	183.2	259.4	247.0	232.4	204.9
10	311.4	192.2	294.2	281.6	242.9	221.5

4. CONCLUSION

In the present paper, low-frequency sound transmission through a single-stud double-plate panel has been investigated utilizing FEM with different rigid coupling configurations between the plates and the frame structure. It is seen that the choice of connection has significant effect on the outcome of the model. From this, two conclusions can be drawn:

1. To accurately predict the low frequency sound transmission, the actual behavior of commonly used building elements should be investigated and compared with different modeling approaches;
2. In the design of lightweight elements, the coupling between the plates and the frame structure may be an important parameter that can be tweaked to optimize the acoustic performance.

The results indicate, that a looser coupling does not necessarily transmit less sound, which is thought to be caused by the fact that looser couplings allow the plates to bend easier compared with stiff frame–plate couplings. Furthermore, the loose couplings have a higher mode count in the investigated frequency range.

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REFERENCES

[1] L. Cremer, M. Heckl and B.A.T. Petersson, *Structure-Borne Sound* (Springer-Verlag, 2005), 3rd edition.

[2] R.H. Lyon and R.G. DeJong, *Theory and Application of Statistical Energy Analysis* (Butterworth-Heinemann, 1996), 2nd edition.

[3] R. J. M. Craik, *Sound Transmission Through Buildings using Statistical Energy Analysis* (Gower, 1996).

[4] C. B. Burroughs, R. W. Fischer and F. R. Kern, “An introduction to statistical energy analysis,” The Journal of the Acoustical Society of America, 101(4), 1779–1789 (1997).

[5] F. Fahy and P. Gardonio, *Sound and Structural Vibration* (Elsevier, 2007), 2nd edition.

[6] EN 12354-1:2000, “Building Acoustics. Estimation of Acoustic Performance in Buildings from the Performance of Elements. Airborne Sound Insulation between Rooms,” (2000).

[7] J. Mahn, “Prediction of Flanking Noise Transmission in Lightweight Building Constructions: A Theoretical and Experimental Evaluation of the Application of EN12354-1,” Technical report, University of Canterbury, Acoustics Research Group (2007).

[8] R.J.M. Craik and R.S. Smith, “Sound transmission through lightweight parallel plates. Part II: structure-borne sound,” Applied Acoustics, 61, 247–269 (2000).

[9] L. Galbrun, “Vibration transmission through plate/beam structures typical of lightweight buildings: Applicability and limitations of fundamental theories,” Applied Acoustics, 71, 587–596 (2010).

[10] R.J.M. Craik and L. Galbrun, “Vibration transmission through a frame typical of timber-framed buildings,” Journal of Sound and Vibration, 281, 763–782 (2005).

[11] K. J. Bathe, *Finite Element Procedures* (Prentice Hall, 1995), 1 edition.

[12] J. Brunskog and P. Davidsson, “Sound Transmission of Structures. A Finite Element Approach with Simplified Room Description,” Acta Acustica united with Acustica, 90, 847–857 (2004).

[13] P. Davidsson, *Structure-acoustic analysis, finite element modelling and reduction methods,*, Ph.D. thesis, Lund University, Department of Structural Mechanics (2004).

[14] Dassault Systèmes Simulia Corp., Providence, RI, USA, *ABAQUS Anaysis. User’s Manual Version 6.10*.

[15] R. Oeqvist, F. Ljunggren and A. Aagren, “Variations in sound insulation in nominally identical prefabricated lightweight timber constructions,” Building Acoustics, 17, 91–103 (2010).

[16] J. M. Craik and J. A. Steel, “The Effect of Workmanship on Sound Transmission through Buildings: Part 1 – Airborne Sound,” Applied Acoustics, 27, 57–63 (1989).

[17] J. M. Craik and D. I. Evans, “The Effect of Workmanship on Sound Transmission through Buildings: Part 2 – Structure Borne Sound,” Applied Acoustics, 27, 137–145 (1989).

[18] J. W. Trevathan and J. R. Pearse, “The Effect of Workmanship on the Transmission of Airborne Sound through Light Framed Walls,” Applied Acoustics, 69, 127–131 (2008).

[19] P. H. Kirkegaard, L. Andersen, K. A. Dickow and P. G. Domadiya, “FEA of the variations in sound transmission in nominally identical prefabricated lightweight timber panel structures,” in “Proceedings of ICSV 18,” (18th International Congress on Sound & Vibration, Rio De Janeiro, Brazil, 2011).

[20] K. A. Dickow, P. G. Domadiya, L. Andersen and P. H. Kirkegaard, “Transmission of sound through double-plate panel structures – a numerical study of coupling parameters in lightweight panel structures,” in M. Papadrakakis, M. Fragiadakis and V. Plevris, editors, “Proceedings of COMPDYN 2011,” (ECCOMAS Thematic Conference on Computational Methods in Structural Dynamics and Earthquake Engineering, 2011).