Bergen, Norway

BNAM 2010

May 10-12

Experiences with sound insulation for cross-laminated timber floors

Anders Homb
SINTEF Building & Infrastructure, Høgskoleringen 7b, NO - 7465 Trondheim, Norway, anders.homb@sintef.no

Jan Arne Austnes
Sweco Norway AS, Fornebuv. 11, NO – 1366 Lysaker, Norway, jaa@sweco.no

During the last years, cross-laminated timber floor constructions have been introduced in Norway, due to an interest among architects and producers. A more extensive use of wood in buildings is of strategic interest in the wood industry. One possibility is to develop products and designs for extended use in multistorey buildings. In today's solutions, the sound insulation properties of cross-laminated timber floors are undermined due to excessive flanking transmission of the supporting walls. Research has been conducted at SINTEF Byggforsk in collaboration with field measurements from Sweco with respect to the development of knowledge and support node solutions.

1 Introduction

Several projects have been carried out to investigate the properties of cross-laminated timber floors concerning airborne and impact sound insulation. Research has been conducted earlier to develop design criteria and vibration controlled span width, see reference [1]. But, due to preliminary calculations and field measurement results, the main challenge is the airborne sound insulation in the vertical direction. Sound insulation measurements have been carried out both in the SINTEF Byggforsk laboratory and at different completed constructions in buildings. In Norway, the most interesting solution has been with an optimized top floor solution and visible cross-laminated timber in the room below. It was found that it is possible to fulfill impact sound insulation requirements for multifamily houses with such solutions, but in combination with load bearing massive wood solutions, the airborne sound insulation is limited. The paper presents some effects of different solutions at the junctions in combination with the floor solution itself. Planned activities to develop improved junctions with respect to airborne sound insulation will also be presented.

2 Laboratory measurements

Sound insulation properties of cross-laminated timber floors have been studied in several countries the last 5 to 10 years. In central Europe, solutions with concrete have been of main interest, but in the Scandinavian countries such solutions have not attracted much attention. In Sweden, different laboratory measurements have been carried out with additional ceiling solutions below the cross-laminated floor element to fulfill sound insulation requirements in the vertical direction. Results from these investigations are given in reference [2]. In Norway, the most interesting solution among architects has been some sort of floating floor on the cross-laminated timber floor to get a visible surface in the room below. Vibration insulation properties of the connection between the floating floor and the timber element are of course necessary. Both surface elastic, point elastic and line elastic principles have been investigated. Figure 1a and 1b present principal drawings, respectively of line elastic and point elastic constructions on cross-laminated timber floors. Figure 2 show some results from laboratory measurements and a test house with low flanking transmission carried out by SINTEF Building & Infrastructure. Results are given with one type of line elastic solution and two types of point elastic solutions.

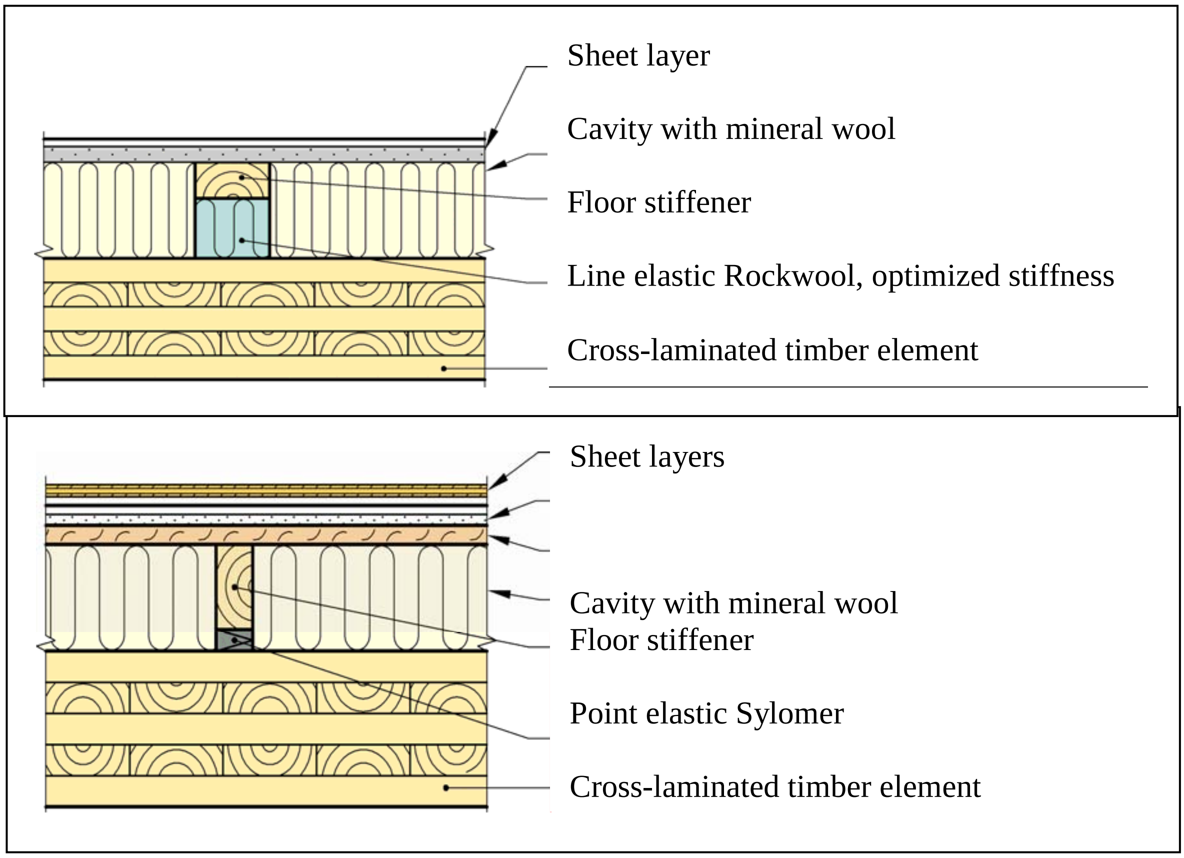

Figure 1a and b: Principal drawings of line elastic (upper figure) respectively point elastic constructions.

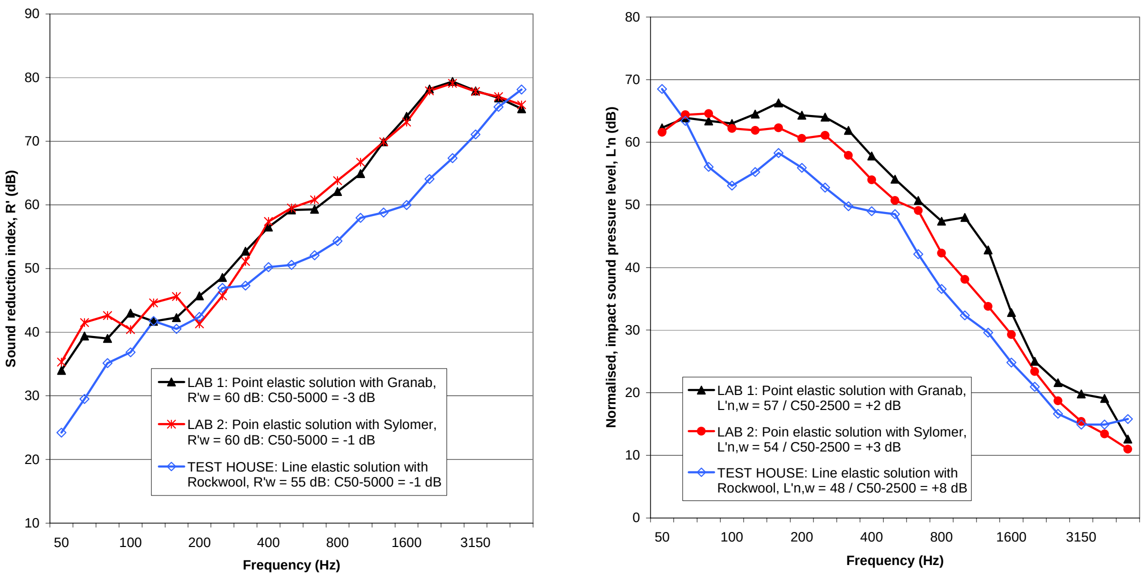

Figure 2: Airborne and impact sound insulation for cross-laminated timber floor solutions:
- LAB 1:180 mm element, Granab, 200 mm insulated cavity and sheet layers
- LAB 2: 180 mm element, Sylomer, 123 mm insulated cavity and sheet layers
- TEST HOUSE: 160 mm element, Rockwool, 128 mm insulated cavity and sheet layers

Measurement results show that it is possible to fulfill sound insulation requirements between apartments if the flanking transmission is limited, except for the point elastic solution with Granab. But the airborne sound insulation is also critical for the line elastic solution with 128 mm cavity. For these elements, the calculated coincidence frequency appears between approximately 140 Hz and 160 Hz. In this frequency range, the sound reduction curve is not increasing due to this resonance frequency. Above the coincidence frequency, the laboratory measurements show an increase of about 9 dB per octave band as expected due to general theory. If we increase the element thickness from 160 to 220 mm, we could expect an increase of the sound reduction index theoretically of about 4 dB in the frequency range above about 160 Hz. Figure 2 also show results concerning spectrum adaptation term $C_{50-5000}$ (airborne sound insulation) and $C_{I,50-2500}$ (impact sound insulation). Some more results from measurements with different solutions are presented in reference [3]. Due to promising laboratory measurements, a number of building projects have been established with small or large modification of these floor constructions.

3 Field measurements

Different research projects have been carried out the last years to develop cross-laminated timber floor solutions. Field measurements have been a part of the investigations to increase the knowledge and document sound insulation properties in buildings for residential housing. Field measurement results from Sweco Norway and SINTEF Building & Infrastructure, with solutions similar to Chapter 2 have been collected. Table 1 shows seven different solutions from five field objects. Measurement results are given in figure 3.

Table 1: Field measurement objects

Measurement object and element thickness	Top floor solution	Load bearing cross-laminated wall elements *
S1 and S2-test: 218 mm floor element (wall-to-floor area difference)	Line elastic, RW connection 128 mm cavity, insulated	Stiff line connection
N-test: 220 mm floor element	Line elastic, RW connection 128 mm cavity, insulated	Stiff point connection
E1/E2-test: 220 mm floor element (highest/lowest R'_w)	Point elastic, Sylomer connection, 223 mm cavity, insulated	Line elastic, Sylomer connection Some stiff connections between wall and floor element
K1-test: 120 mm floor element	Point elastic, Sylomer connection, 123 mm cavity, insulated	Point elastic, Sylomer connection
K2-test: 120 mm floor element	Point elastic, Sylomer connection, 123 mm cavity, insulated	Stiff line connection

* 144 mm thickness for object S and 100 mm thickness for the other objects

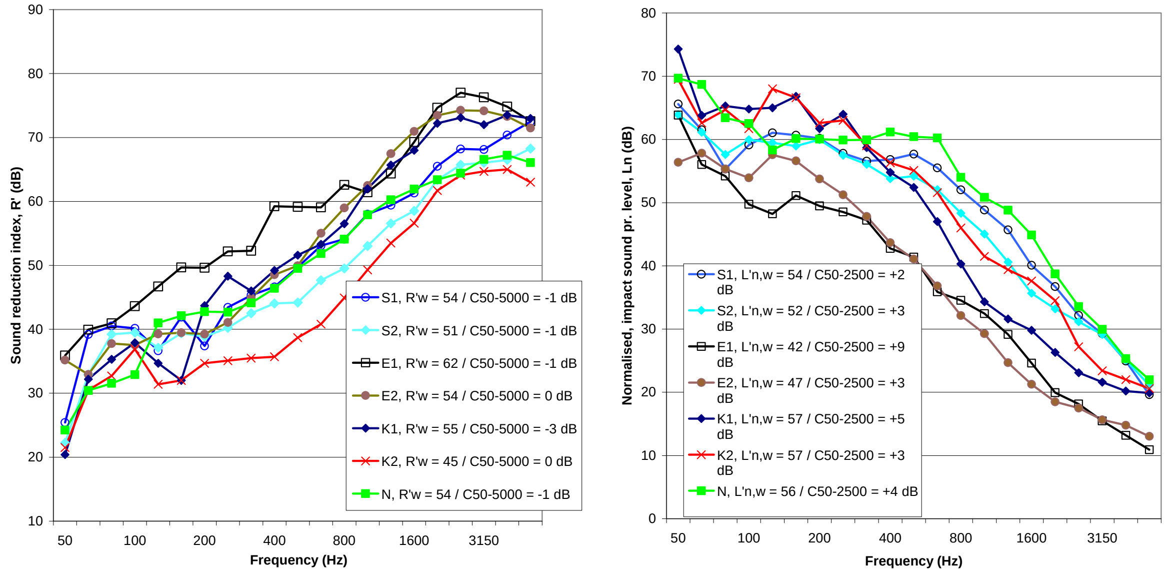

Figure 3: Field measurements of airborne and impact sound insulation for cross-laminated timber floor solutions. Measurement objects according to Table 1.

Figure 3 shows large differences between the measurement results due to different floor constructions and flanking transmission. The sound reduction index varies from R'_w = 45 dB to 62 dB. In the first case, the flanking transmission is the main reason for the moderate sound insulation. The increased sound transmission is caused by a stiff line connection and a wall-to-floor ratio of 2:1 combined with a thin floor element. In the last case, high sound reduction index is caused by a combination of thick floor element, large cavity and low flanking transmission due to wall elements on elastic Sylomer connections. An increase of floor element thickness from 120 to 220 mm increases the vibration damping property of the T-junction theoretically with about 6 dB. Theoretically we could also expect an increase of the airborne sound insulation of approximately 5 dB due to the difference in cavity thickness between object E1 or E2 in figure 2 (largest cavity) and LAB 2 in figure 2.

The impact sound insulation of these constructions varies from $L'_{n,w}$ = 57 dB to 42 dB. The best impact sound insulation result coincides with the best sound reduction index. The vibration insulation material (Sylomer) between the top floor and the cross-laminated wood elements limits the flanking transmission contribution from the impact source to the cross-laminated load bearing wall, see for instance the difference between object E-1 and S-1 or N. But even in this case the line elastic Sylomer between the loadbearing walls and floor construction improves the impact sound insulation. The difference between E1 and E2 with respect to both airborne and impact sound insulation (respectively 8 and 5 dB) is probably caused by different wall-to-floor area and amount of stiff connections between wall and floor elements.

4 Support node limitations

For timber constructions, the airborne and impact sound insulation of the building is normally planned with rather basic methods and no reliable computation models are available. Whereas the computation of sound insulation is quite robust for concrete building constructions, it often fails for timber based constructions. This is due to the fact that the sound propagation across junctions, the so-called transmission along flanking paths is the most important one but the less understood. More precise models cannot be applied due to missing input data used for the description of sound and vibration propagation through and across the building elements.

From the first research studies, results and experiences show possible flanking transmission (especially the airborne sound insulation) when the construction consists of cross-laminated, load bearing walls visible in the apartments. See for instance reference [2] for further information. Measurements of a single cross-laminated element in the laboratory show moderate sound insulation properties, especially in the frequency range below about 800 Hz. If the vibration transmission index at the junction also is low, we would expect limited sound insulation depending on the floor construction itself and the ratio between flanking transmission area and floor area.

Combining laboratory and field measurement results, we present some examples on the flanking transmission limitation. In some cases, field constructions are comparable with construction measured in the laboratory or test house. Figure 4 present differences between laboratory measurement and comparable field measurement with respect to the airborne sound insulation. The laboratory sound reduction index is adjusted with respect to cavity and floor element thickness according to principles presented in chapter 2 and 3.

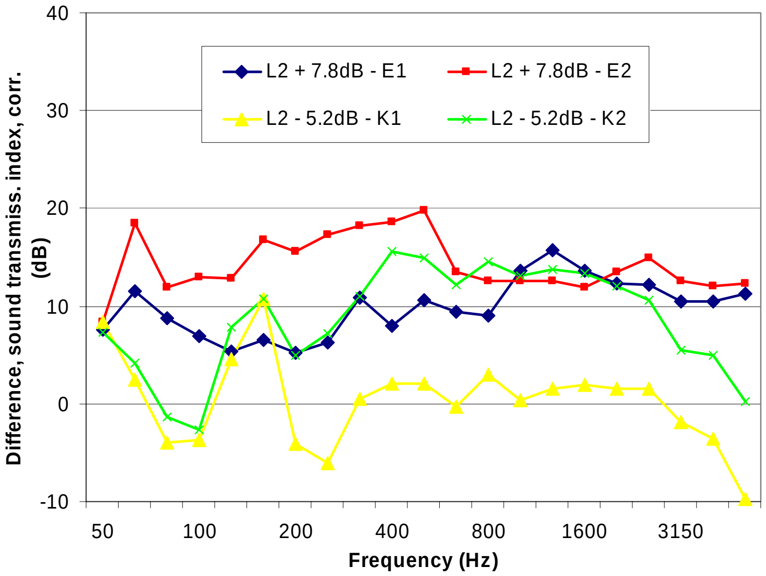

Figure 4: Difference in sound reduction index between laboratory and field measurement results. Measurement objects according to Figure 2 and Table 1.

Assuming satisfactory corrections of the sound reduction indexes, the yellow curve show that the point elastic, Sylomer connection in the K1 case almost eliminate the flanking transmission (the difference is below 3 dB in major part of the frequency range). On the opposite side, object E2 (both elastic and stiff connection) and object K2 (with stiff line connection) show an effect of the flanking transmission between 10 and 20 dB in major part of the frequency range. The ratio between the floor area and the flanking transmission area is not taken into account. These results show the necessity of reducing the vibration transmission from load bearing wall to load bearing wall or floor element, especially to improve the airborne sound insulation of the system. Use of vibration insulation materials (like Sylomer) is of course possible, but it implies other solutions to ensure stability of the building with respect to wind loads etc. Another possibility is to increase the vibration damping property of the T-junction with mass and/or stiffness components or thicker floor elements. Along these ideas, an untraditional experiment has already been conducted with moderate gravel mass load in a floating floor design. The results in a residential building cope well with criteria due to reduced flanking transmission of the fixed point supported walls. In addition, this measure show favourable low impact sound levels both in laboratory and field tests. This experiment illustrates that T-junction vibration damping can be solved also with fixed support design.

Figure 5 present differences between airborne sound insulation of two solutions in two measurement cases. In the first case, the flanking transmission area varies, while the support condition of the load bearing wall varies in the other case.

Blue line of Figure 5 shows the effect of the flanking transmission area when other parameters are unchanged. The difference refers of course to the actual cross-laminated wood element thicknesses in the wall and floor and the type of connection in the T-junction. Calculated critical frequencies to the wall and floor elements are about 180 Hz respectively about 120 Hz and the ratio between the (cross-laminated) wall and floor area is 1.9:1 for object S-1.

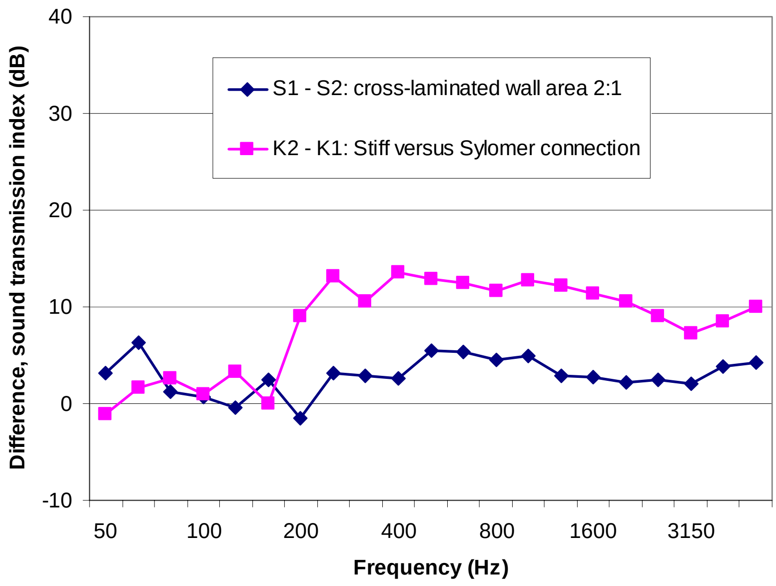

Figure 5: Difference in sound reduction index between two solutions in two measurement cases. Measurement object according to Table 1.

The red line of Figure 5 shows the effect of the line elastic, Sylomer connection at the T-junction. But since this elastic connection almost eliminates the flanking transmission according to Figure 4 (except at lower frequencies) the difference also presents the flanking transmission caused by the stiff connection between wall and floor elements. The ratio between the (cross-laminated) wall and floor area is 2:1. Calculated critical frequencies to the wall and floor elements are about 260 Hz respectively about 190 Hz. In both cases, significant flanking transmission occurs in the whole frequency range above about 200 – 250 Hz. We may adjust the difference between these results due to different thickness of wall and floor elements. But, the difference will decrease only 2 to 3 dB according to general theory of vibration damping at the T-junction. Therefore, other effects contribute to the difference and make it necessary with vibration transmission measurements of such junctions.

5 Vibration transmission measurements

Some preliminary measurements have been carried out with respect to vibration transmission for the K1 object. ISO 10848 specifies measurement methods to be performed in a laboratory test facility or similar in order to characterize the flanking transmission of one or several building constructions. In this case a shaker was used to excite the wall and floor construction, and accelerometers were used to measure the vibration levels of the constructions. In the test situation with point elastic, Sylomer connection, the input energy from the system was too low to ensure reliable results in the whole frequency range of interest. Figure 6 therefore show some preliminary results concerning the vibration level difference between the source and receiving (cross-laminated, load bearing) wall at the test house.

Preliminary results presented in figure 6 show vibration level difference of 20 to 25 dB in the frequency range below about 630 Hz with the point elastic, Sylomer connection between the load bearing wall and floor element. In the higher frequency range, the difference increase rapidly and will probably not limit the sound transmission this path. For further calculation of vibration reduction index, additional input data concerning structural reverberation time/energy loss factor is necessary. We did not succeed with this measurement at the preliminary test. But we are planning further measurements at this test house with another measurement set up and equipment to determine the vibration reduction index. The goal is to determine this parameter for a number of wall-to-floor connections, K1 and K2 object included. These results will be used in SEA calculations of the total sound transmission between the rooms.

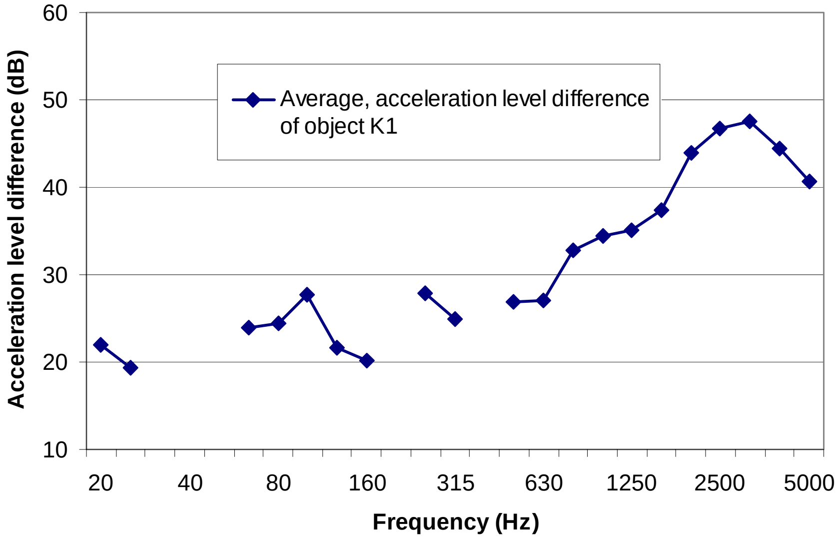

Figure 6: Acceleration level difference between source and receiving wall of object K-1. Measurement objects according to Table 1.

6 Summary

Results presented in this paper show a number of measurements and measurement objects with different types of top floor solution and visible cross-laminated timber in the room below. The sound insulation properties vary very much between the different objects. Results also show that the flanking transmission may reduce the airborne sound insulation within about 15 dB, which makes it necessary to develop solutions increasing the vibration damping at the junction. As a summary we recognize that the design for residential housing is at a state of art where experienced solutions can be recommended as "safe design" with respect to sound insulation. The following aspects are highlighted:

- Vibration measurements in test house condition for clarification of flanking transmission parameters
- Adaptation of measurement results to the prediction methods of EN 12354
- Thorough measurement follow-up of residential housing developments
- Close follow-up on advice to architects and the building industry generally

To open for more varied designs and documentation methods there is a need for further measurement investigation and development of prediction methods.

References

[1] Homb, A. Vibrasjonsegenskaper til dekker av massivtre (Vibration properties of cross-laminated timber floors). *Prosjektrapport SINTEF Byggforsk, serienr. 24*. Oslo, Norway 2008 (in Norwegian).

[2] Industrikonsortiet Massivträ. Massivträ. Håndboken (Cross-laminated elements, handbook). www.solidwood.nu. Sweden, 2006.

[3] Homb, A. & Brevik, B.G. Etasjeskillere i massivtre (Cross-laminated timber floors). *SINTEF Building & Infrastructure, Building Detail Sheet no. 522.891*. Oslo, Norway, November 2009 (in Norwegian).