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The WOODSOL project: summary of the acoustic activities and preliminary results

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WOODSOL is a project funded by the Norwegian Research Council that has been running from 2017 and is about to be completed. WOODSOL is a multidisciplinary project aimed at designing a construction system for timber urban buildings based on moment resisting frames and long span floor elements. The acoustic activities started with identifying an assessment strategy for the acoustic properties of the building system and its element. After building a physical prototype of the system, we performed vibroacoustic measurements leading to a clear definition of the acoustic properties of the system. Additional measurements in the SINTEF test facilities in Oslo allowed for the validation of the methods and an evaluation of possible impact sound insulation solutions. In this paper we want to present our activities, give a brief insight in the advanced measurement methods we used and highlight some of the main results we obtained.

1 Introduction

Woodsol aims at developing timber urban buildings up to ten stories with large architectural flexibility. Three substantial targets were set: the extension of the floor span length without increased story height, the horizontal stabilization of the building by moment resisting frames and the development of prefabricated couplings to allow rapid erection on site. The project focuses on four main subjects: production and assembly of structural systems and component, moment resisting frames, flooring systems and acoustics. In this paper, we briefly present the acoustic activities performed during the project and highlight the main results. Both were documented in several publications and the aim here is to guide the reader through the available material. The paper is structured as follow: in section 2 we introduce the project and its components, section 3 presents the strategy we adopted and the tools we used. In section 4 we present selected measurements result from the activities on the Woodsol system mock-up. Section 5 presents preliminary results for different practical applications and section 6 focuses on the acoustic solution for Woodsol applied to an office building.

2 The WOODSOL building concept

The WOODSOL building concept is based on a moment resisting frame with hollow-box floor elements with a span up to 10 m. In order to facilitate industrial production, the load bearing structure should primarily be based on grids and repetitions. The three key elements of the system are i) the floor elements, ii) the connector and iii) the use of threaded rods to install the connectors.

The floor element has a standard width of 2.4 m to ease the transport and a height of 0.5 m for span length up to 10 m. The cross section is shown in Figure 1. The top and bottom plates are KERTO-Q plates with thickness of 43 mm and 61 mm respectively. The thickness of the bottom flange is designed to be the first fire safety layer. The outermost stringers are glulam GL30c, while the inner ones are glulam GL28c [1]. The total weight of the floor element is 2.6 tons including the filling of gravel and can be adjusted according to the acoustic requirements.

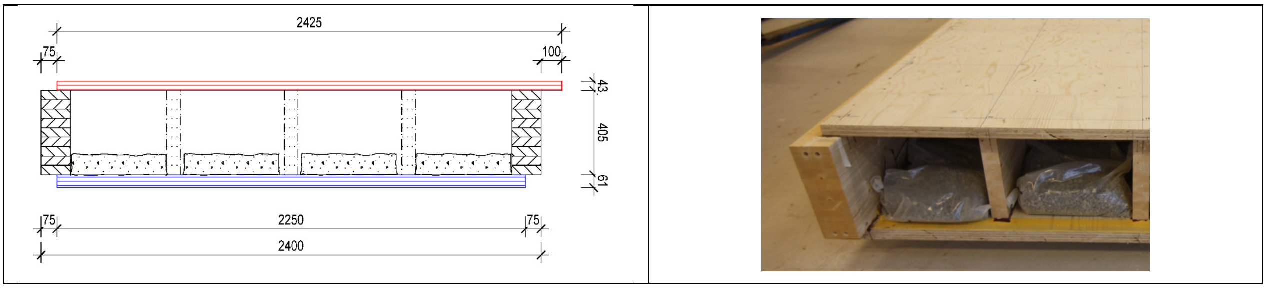

Figure 1: Floor element cross section (left) [1] and gravel bags positioned inside the element cavity (right).

At each corner of the floor element, one WOODSOL connector is used to establish a moment resisting connection between the floor itself and the column. The current version of the connector is shown in Figure 2 along with a schematic of the principle. It is based on metal brackets connected by friction bolts. The brackets are mounted to the timber by means of threaded metal rods [2].

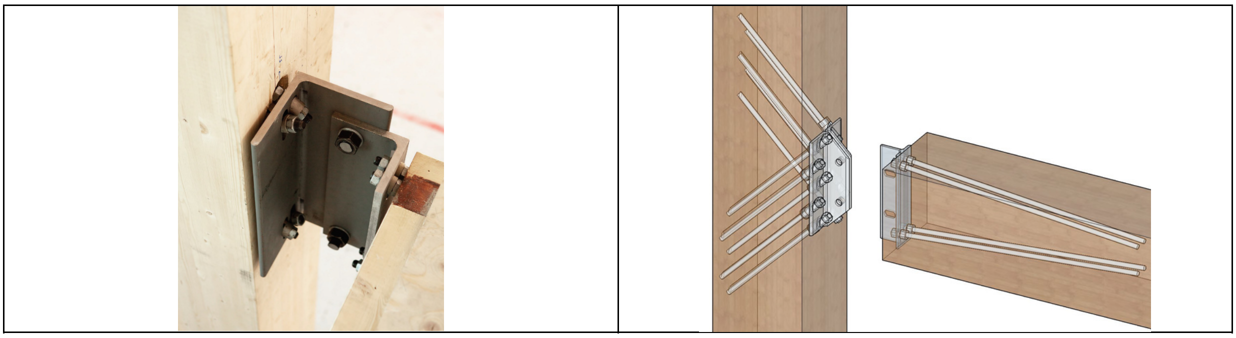

Figure 2: Picture of the connector installed between the floor element and the column (left) and principle of the connector showing the threaded rods (right) (Source: NTNU/Sintef).

A system mock-up was built to allow for experimental investigation. The mock-up was built as the smallest unit of the building system to allow for measurements of both the direct impact sound transmission and the flanking transmission through the connectors and the columns. We build in total 5 floor elements in three different lengths (9 m, 4.7 m and 3.7 m). The elements were then mounted to the columns in different configurations. In Figure 3, we show the configuration with two 4.7 m long elements mounted side by side on total six columns. The material for the columns is glulam and they have dimensions of 0.40 m x 0.45 m x 5.20 m. Their size is given by the structural and fire safety requirement for an eight to ten story building, which is the target building of the WOODSOL project. The floor is mounted with the bottom flange at 2 m above the floor of the lab.

Figure 3: Woodsol prototype installed at Charlottenlund Videregående Skole, Trondheim (Foto: NTNU/Sintef)

3 Acoustic in Woodsol: task and strategy

Our main goal was to investigate the acoustic properties of these structural solutions and develop acoustic solutions to meet sound insulation requirements for several different purposes. Both direct sound transmission and flanking sound transmission were to be addressed. The strategy that we are following to develop suitable acoustical solution within the project includes the following three main steps: i) assess basic vibroacoustic properties and collect data for model validation using the experimental modal analysis (EMA), ii) study the sound radiation and impact sound insulation using the integral transform method (ITM) and iii) perform junction transmission measurements to study flanking transmission in the system. The strategy is documented in detail in [3]. Figure 4 show the measurement setups for the EMA and the ITM measurements.

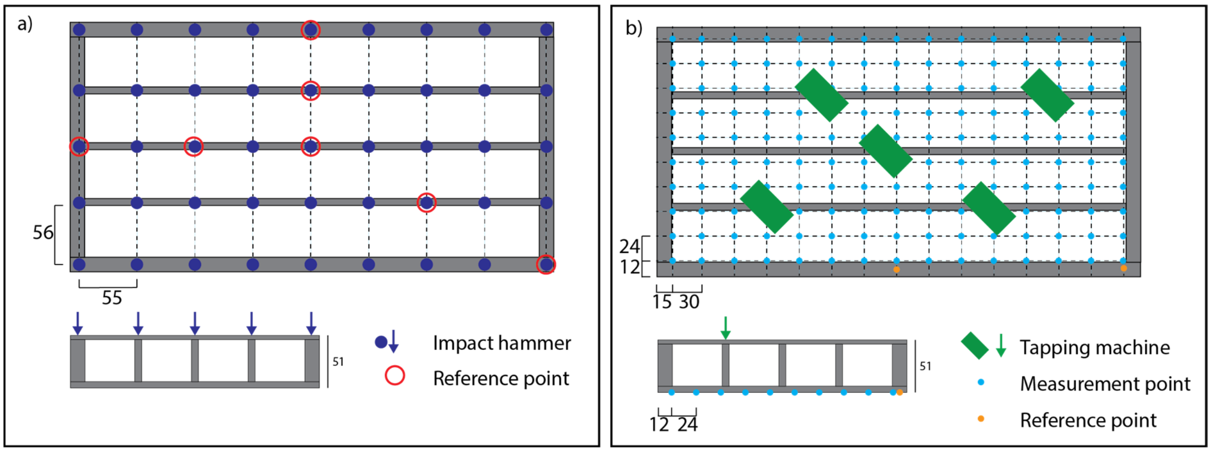

Figure 4: a) EMA excitation and measurement positions, b) ITM excitation and measurement positions [4]

Among the tools we used, it is worth highlighting the Integral Transform Method. It allows to determine the radiated sound power from vibration velocity measurements in three steps: 1) the measurement of vibration velocity on a relatively fine grid on the sound radiating surface, 2) a two-dimensional Fourier transform transforming the data in the wavenumber domain and 3) the calculation of the radiated sound power in the wavenumber domain. Details of the implementation of the method can be found in [4, 5].

4 Measurements on the mock-up

The measurement campaign on the floor elements and on the mock-up focused on the modal properties of the floor elements and on the impact sound insulation. We studied the effect of element size, boundary conditions and gravel filling. We published the results of the experimental modal analyses in [6] and more comprehensive results showing the parameters effect and the dependency on the modal behavior in [4]. We shall highlight here only some of the findings.

One interesting effect that we observed, is that in contradiction to our expectation, the radiated sound power and hence the impact sound level is lower on the longer element (9 m) than in the shorter element (4.7 m). This result is presented in Figure 6: the diagram shows the measured radiated sound power under impact excitation for a 9 m long floor element and a 4.7 m long element. Both elements had empty cavities. The difference below 25 Hz seems to relate to the measurements setup and shall be disregarded here. The relevant difference is in the frequency range from 40 Hz to 80 Hz and is up to 10 dB. The difference is due to the different distribution in frequency of the vibration modes. The observation is very important considering that the frequency range below 100 Hz is determining the perception of annoyance in lightweight buildings [7]. This highlight the contribution of advanced measurement methods as the ITM in improving the design accuracy at low frequencies. These methods indeed make it possible to perform acoustic measurements on full size objects, without the size limitation of acoustic laboratories.

In Figure 6, we show the results obtained varying the cavity filling. The two diagrams show the radiated sound power from the bottom surface of the element under excitation by a tapping machine. a) shows the case with the floor element installed with free-free boundary conditions and b) shows the case with the element mounted in the mock-up with the

Woodsol system. The sound power reduction can be interpreted directly as impact sound level reduction. The results show that a gravel filling with 100 kg/m^2 is most effective from 50 Hz and upwards and can achieve more than 20 dB reduction.

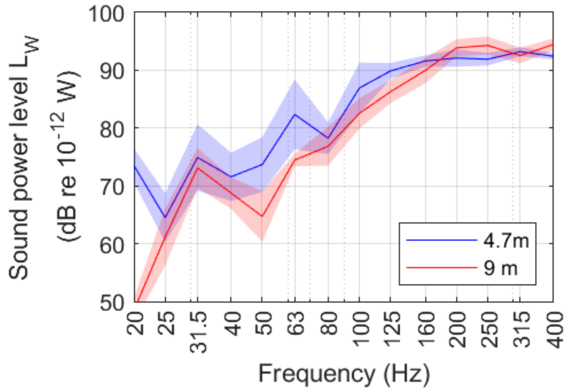

Figure 5: Radiated sound power measured on the bottom surface of the 9 m and 4.7 m element. Both elements without gravel, BC: free-free [4].

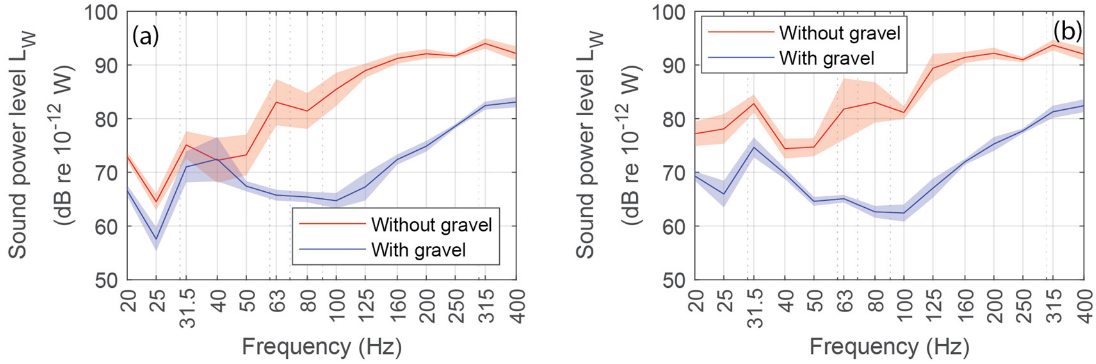

Figure 6: Radiated sound power measured with and without gravel for the WOODSOL floor element. (a) Element installed with free-free boundary conditions and (b) element installed on the mock-up [4].

5 Floor coverings to meet different requirements

One element was produced to fit the size of the SINTEF acoustic laboratory in Oslo. The dimensions were 3.7 m x 2.4 m x 0.5 m. We performed several measurements at the laboratory testing various practical solutions for the Norwegian market. The solutions were aimed at fulfilling the requirements for different uses, including offices, school and apartment buildings. We chose to investigate a whole range of solutions ranging from simple to rather advanced and including typical Norwegian build-ups. The tested solutions are: bare floor with varying filling inside the cavity (empty, wood fiber, gravel 100 kg/m^2), a single layer of vinyl flooring, chipboard on wood fiber plates, plasterboard and chipboard on mineral wool panels and flooring system based on battens and Sylodyn pads. Figure 7 summarizes the tested configurations and shows selected preliminary results. The complete results shall be presented in a future publication.

The preliminary results show that low requirements might be met already with an acoustic vinyl covering, provided that the gravel filling is adjusted. The lowest requirement for office buildings might be met with chipboard panels mounted on wood fiber plates (e.g. Hunton Silencio) with the current gravel filling (100 kg/m^2). Higher requirements (e.g. schools or apartments) can be met using mineral wood impact sound insulation panels with low dynamic stiffness or with the Sylodyn solution suggested in the figure. The empty floor elements cannot fulfill any requirement. A combination of sound absorption in the cavity (e.g. low-density wood fiber) and the Sylodyn solution might fulfill simple requirements.

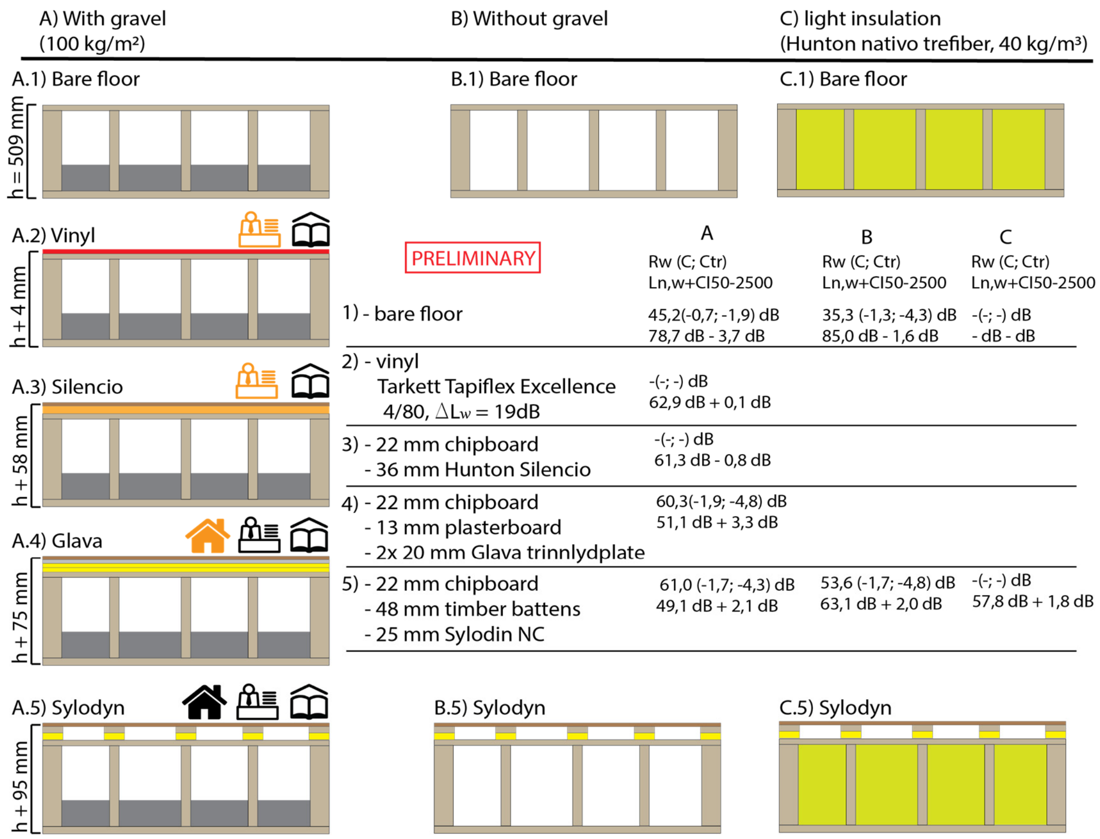

Figure 7: Selection of the configurations tested at the SINTEF acoustic laboratory in OSLO with preliminary results. When the requirements are fulfilled for a possible use, the corresponding icon is set (office, school, apartment).

6 Woodsol for office buildings

Woodsol has a strong focus on the practical documentation of the developed solutions. As a first application example, the architect and project partner Løvseth + Partner AS is developing an office building concept. We are contributing with the acoustic part of the design. Information about how to achieve satisfactory sound insulation in an office building based on the Woodsol project is provided in [8] along with prediction formulas.

Figure 8 show one of the construction details developed to fulfil the acoustic requirements in an office building. It features a standard Woodsol floor element filled with 100 kg/m^2 gravel. The build up on top can be as simple as 36 mm impact sound insulation mat with relatively high dynamic stiffness (e.g. Hunton Silencio), chipboard panels and floor finishing on top. This can achieve $L_{n,w} = 62 – 65$ dB and $R_w \geq 47$ dB and fulfil the minimum office requirements.

On the bottom side, an acoustic lining might be required to tackle flanking transmission, e.g. between meeting rooms with higher sound insulation requirement. Walls shall be built with plasterboard to ensure flexibility, provide enough direct sound insulation and reduce flanking transmission to a minimum. Further work is in progress in the project and will give more detailed information regarding the horizontal flanking transmission and the flanking transmission through the columns and the connectors system.

7 Summary

The Woodsol project started with the aim to provide the building sector with a well-documented solution for urban buildings in wood that is competitive with traditional building systems and solutions. In this paper we summarized the acoustic results that come closer to application and provided guidance to the relevant publications produced within the project. We showed the advantages of using a strategy based on advanced measurements methods on the example of the size effect. We documented the effect of gravel in the cavity on the sound insulation and listed several possible practical solutions to achieve different requirements. Finally, we introduced a practical solution for office buildings.

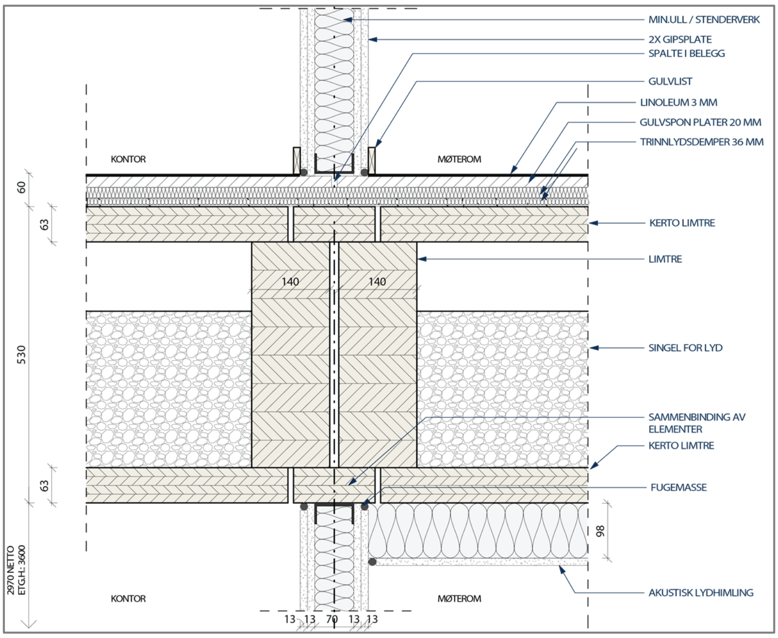

Figure 8: construction detail for office building, adapted from [8].

Acknowledgements

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