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# FH-IPTOOLS: PREDICTING WASTEWATER NOISE IN TIMBER CONSTRUCTIONS - A PROJECT INTRODUCTION

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## ABSTRACT

The research project FH-IPTOOLS is a joint project between Rosenheim Technincal University of Applied Sciences (THRo) and the University of Applied Sciences Döpfer (HSD) in collaboration with industrial partners and timber construction associations. The aim is to develop prediction tools for sound insulation, focusing on acoustic comfort and the perception of noise from technical service equipment. The project focuses on wastewater systems in timber and lightweight constructions.

Concepts need to be developed to ensure that acoustic comfort is taken into account in the design process. HSD is working on the psychoacoustic aspects. Signal detection theory will be used to formulate suitable evaluation methods to assess noise from building service equipment. Listening tests and field measurements will be used to develop criteria for sound insulation in timber construction to improve acoustic comfort.

As part of the project, structure-borne sound characterisation will be carried out at THRo on a reception plate test rig. Therefore a reception plate with similar properties to timber frame constructions will be used. The aim is to develop methods for the direct measurement of structure-borne sound power in timber and lightweight constructions, while also determining airborne sound power. Initial results will be presented in the paper.

**Keywords:** *Structure-borne sound, Source characterisation, building acoustics, psychoacoustics*

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## 1. INTRODUCTION

Timber constructions are in the focus of the transition towards sustainable and energy-efficient buildings. Sound insulation is a key issue, as it is crucial for the acceptance and perceived quality of timber buildings. However, regulatory uncertainties and the lack of planning tools hinder the reliable prediction of acoustic comfort, particularly with regard to noise from building service installations, such as wastewater systems. These systems can exhibit an increased disturbance potential in timber and lightweight structures. The latest revision of DIN EN ISO 12354-5 [1] provides prediction methods for estimating the sound pressure levels in receiving rooms due to service equipment. In most cases however, the source input data required for such predictions are not available. In addition, predictions are not suitable to describe the subjective perception of disturbance experienced by occupants.

## 2. PROJECT INTRODUCTION

The research project FH-IPTOOLS ("Research in Timber Construction for Engineering-Based and Psychoacoustically Validated Planning and Advisory Tools for Sound Insulation") is a joint initiative between THRO and HSD in close cooperation with renowned industry partners. The primary objective is to develop engineering-relevant and psychoacoustically validated methods that enable a reliable prediction and optimisation of acoustic comfort in timber and lightweight buildings. The project covers the whole acoustic transmission chain. This starts with the sound source (with a focus on wastewater systems), then energy transmission into the building structure, propagation within the building, and finally perception and assessment by the occupants. Building acoustics measurements are carried out under real building conditions to compare with the applicable normative requirements, while simultaneous binaural recordings are performed for listening tests aiming psychoacoustic evaluation.

### 2.1 Project targets

HSD is focusing on the development of psychoacoustically based assessment methods. These methods reliably predict the subjective perception of acoustic comfort by building occupants. Technical and psychoacoustic parameters are combined to establish an evidence-based prediction model that provides realistic and reliable estimates of the expected acoustic quality. In collaboration with partners from industry, legally robust and practice-oriented tools for prediction and consultancy that can be used by construction companies, designers and users are developed. These tools aim to contribute to the acceptance and quality of sustainable timber buildings. THRo focuses on the characterisation of wastewater systems specifically for the application in timber constructions. This includes the use of methods introduced in EN 15657:2009-10 [2]. New measurement techniques for the indirect determination of the structure-borne sound power under installed building conditions will be developed. ISO 20270:2019 [3] already provides methods for the indirect measurement of the installed source power and these may also be applicable within building environments. However, the associated measurement effort is considerably great compared to conventional building acoustics measurements. For prediction purposes, a technically simplified method with acceptable uncertainties is derived from the existing procedure. Also, the project will identify and quantify the acoustic optimisation potential of wastewater systems in timber frame buildings.

## 3. TEST RIG

To determine the spatially averaged vibration velocity on the surfaces of conventional timber frame building elements is a challenging task. Structural inhomogeneities, caused by stiffening timber frames and multi-layer claddings, lead to significant fluctuations in the spatial distributions of velocity levels [4–6]. Therefore, in an initial methodological development phase, an idealised receiving structure is employed. This structure is intended to exhibit vibro-acoustic characteristics comparable to those of typical timber frame constructions. The driving-point mobility of such an idealised reception plate should lie within a similar order of timber frame structures. For this purpose a $15\,\mathrm{mm}$ thick perspex plate was chosen. The objective is, that the installed power of building service equipment, due to similar structural properties, will be in comparable range one either the $15\,\mathrm{mm}$ thick perspex plate or any typical timber-frame structure. The perspex reception plate is mounted at the reception plate test rig at THRo and is coated with a highly reflective surface layer to enable measurement of vibration velocities using a 3D laser doppler vibrometer (see Figure 1). In accordance with the support requirements for reception plates with high mobility, as defined in [2], the perspex reception plate is currently mounted on a fully elastic support and has no direct contact with adjacent structural elements. Investigations of lightweight reception plates made from a perforated steel sheet [7] showed, that boundary conditions significantly influence the damping loss factor of a plate. The perspex plate is joined (cold welded) perpendicularly at two positions across its width, as the material is not available in the required dimensions of $3.7\,\mathrm{m} \times 2.18\,\mathrm{m}$ and a thickness of $15\,\mathrm{mm}$.

**Figure 1**: Test Rig showing the $15\,\mathrm{mm}$ perspex reception plate coated with a highly reflective surface layer (silver-grey) in combination with a 3D Laser Scanning Vibrometer.

## 4. FIRST RESULTS

To enable the characterisation of structure-borne sound sources in accordance with EN ISO 15657:2019-10 [2], the properties of the receiving structure must be well de-

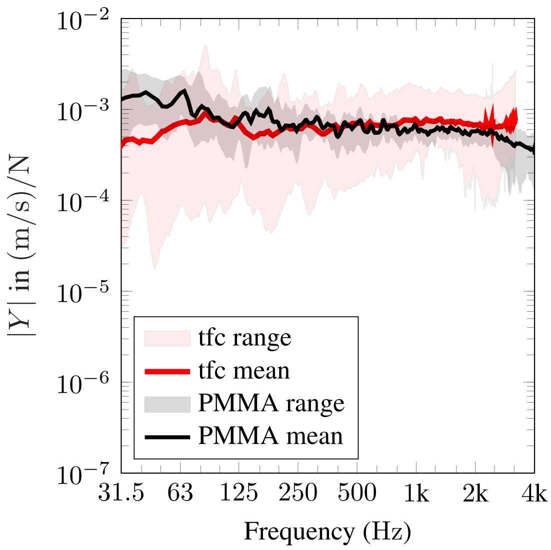



**Figure 2**: Magnitude of the point mobility from the perspex reception plate (PMMA) and timber frame construction (tfc). Shaded areas represent the envelopes of all measurement points (range).

fined. It is essential to ensure that the joints in the plate do not exert any significant influence on the spatial distribution of velocity levels. A series of measurement-based investigations have been carried out to characterise the perspex reception plate. This includes the determination of the longitudinal wave velocity, the velocity level distribution with point excitation and the loss factor of the plate.

### 4.1 Mobilities of reception structures

Figure 2 shows the arithmetic mean of driving-point mobilities of typical timber frame walls (tfc) in black and the perspex (PMMA) reception plate in red. The shaded areas represent the envelopes of the individual measurement points for the perspex plate and the range of mobilities across 20 measurements on different timber wall specimen which is in the order of $10^{-3}$ $(\mathrm{m/s})/\mathrm{N}$ [8, 9]. The mobility behaviour of timber frame walls typically shows a decreasing mobility characteristic in the low frequency range, corresponding to that of an infinite beam, and a flat mobility characteristic in the higher frequency range, similar to that of an infinite plate. In the transition zone the mobility increases [6, 8]. This transition is also evident in the trend of the averaged mobilities considering the envelope in particular.

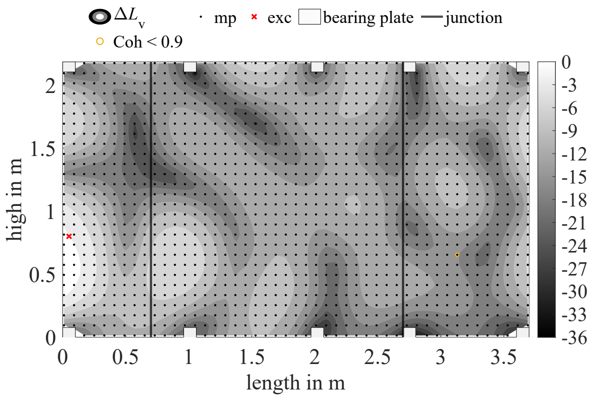
The averaged mobility values of the PMMA plate were determined at a distance of $0.87\,\mathrm{m}$ from the edge, with vertical increments of $10\,\mathrm{cm}$. This area corresponds to potential mounting positions of pipe clamps used in the wastewater systems under investigation. The PMMA mobility curves show a relatively flat frequency response, indicating high material damping and exhibit significantly less scatter compared to the timber structures. The decreasing trend in the PMMA mobility between $31.5\,\mathrm{Hz}$ and $100\,\mathrm{Hz}$ is investigated as it differs from the typical behaviour of timber-frame walls in this frequency range. Nevertheless, the magnitude of the mobilities of both receiving structures is of the same order, allowing for meaningful comparison.

### 4.2 Contour plots from measured velocity levels

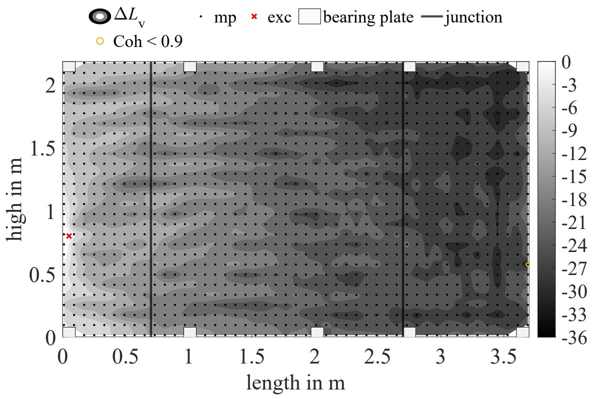
The velocity level distribution was measured by exciting the (PMMA) plate on the backside using point excitation with an electrodynamic shaker. The vibration velocities on the plate surface were measured on a grid with a resolution of $8\,\mathrm{cm} \times 8\,\mathrm{cm}$. The contour plots shown in Figure 3 correspond to the one-third octave bands at $31.5\,\mathrm{Hz}$, $1250\,\mathrm{Hz}$ and $3150\,\mathrm{Hz}$, respectively. These are normalised to the velocity level at the excitation point. The colour gradation is shown in steps of $3\,\mathrm{dB}$. Measurement points with a mean arithmetic coherence $< 0.9$ in the one-third octave band are marked with a yellow circle and measurement points with a signal-to-noise ratio (SNR) $\leq 10\,\mathrm{dB}$ are marked with a purple dot.
In Figure 3a, distinct vibration antinodes and nodal lines are visible, indicating modal shapes within the $31.5\,\mathrm{Hz}$ band, with differences reaching up to approximately $18\,\mathrm{dB}$. In contrast, Figure 3b and Figure 3c show no identifiable modal patterns. But here, a clear decay in velocity level with increasing distance from the excitation point is observed. The decay is up to $20\,\mathrm{dB}$ in the $1250\,\mathrm{Hz}$ one-third octave band and up to $36\,\mathrm{dB}$ in the $3150\,\mathrm{Hz}$ one-third octave band. At the cold welded junction (shown with a gray line in Figure 3), there is no significant drop in velocity level due to the continuous adhesive bonding. It is therefore assumed, that the receiving plate, consisting of three bonded elements, can be considered as a homogeneous structure up to approximately $3150\,\mathrm{Hz}$.

## 5. CONCLUSION

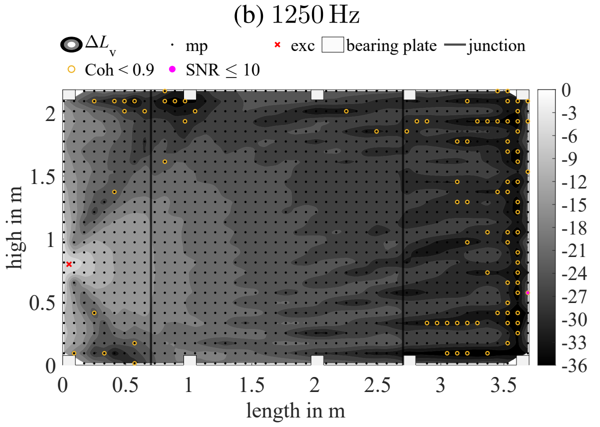
The project will be conducted over the next three years. It will generate further insights and identify optimisation potentials specifically in the area of wastewater noise in




(a) 31.5 Hz




(b) 1250 Hz




(c) 3150 Hz

**Figure 3**: Contour plot of velocity level across the perspex plate for selected one-third-octave bands. Levels are normalized to the velocity at the excitation point. Legend entries: $\Delta L_\mathrm{v} = L_{\mathrm{v,mp}} - L_{\mathrm{v,exc}}$, shading in 3 dB steps; mp: measuring point; exc: excitation point.

timber buildings. At the start of the project, fundamental investigations to characterise the idealised reception plate as a substitute for timber frame constructions are carried out. The results obtained so far are promising and indicate that the selected perspex receiving structure is suitable. It exhibits similar and more homogeneous properties compared to conventional timber stud wall constructions.

## 6. OUTLOOK

Further measurements and evaluations will be carried out to characterise the reception plate in more detail. The determination of the loss factor will be extended by additional methods, such as the power injection method, in order to investigate the influence of boundary conditions on the dynamic behaviour of the plate. In addition, suitable buildings for acoustic measurements and binaural recordings for listening tests will be selected and carried out in cooperation with industry partners. Surveys conducted in collaboration with timber construction associations will provide an overview of the currently prevailing installation conditions for wastewater systems in timber buildings.

## 7. ACKNOWLEDGMENT

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