EXPERIMENTAL INVESTIGATION OF THE ACOUSTIC PERFORMANCE OF LOW-ENVIRONMENTAL-IMPACT HEMP- AND MISCANTHUS-BASED COMPOSITE WALL ASSEMBLIES USING A SMALL-SCALE ACOUSTIC CHAMBER

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Abstract - The growing demand for sustainable construction has increased interest in bio-based building materials that combine low environmental impact with satisfactory functional performance. This study presents an experimental investigation of the acoustic performance of low-environmental-impact wall assemblies incorporating hemp- and miscanthus-based composite materials. The investigated assemblies were selected following a preliminary environmental assessment and consideration of their thermal performance, while the primary objective of the study was to evaluate their airborne sound insulation properties using a small-scale acoustic chamber. Composite specimens with different compositions and structural characteristics were experimentally tested over a limited frequency range using a small-scale acoustic chamber, providing a reliable basis for the comparative assessment of their airborne sound insulation performance. In addition to the individual bio-based composite materials, multilayer wall assemblies incorporating timber and gypsum plasterboard (GPB) were investigated to evaluate their airborne sound insulation performance under controlled laboratory conditions. The results demonstrate that hemp- and miscanthus-based composite wall assemblies exhibit promising sound insulation performance, highlighting their potential as sustainable alternatives to conventional building systems. The study also demonstrates the applicability of a small-scale acoustic chamber as an efficient experimental tool for the preliminary assessment and optimization of innovative bio-based wall assemblies.

Keywords - Acoustic performance; airborne sound insulation; bio-based composites; reduced-scale acoustic chamber; sustainable buildings.

I. INTRODUCTION

The transition towards more sustainable construction requires the development of building materials that reduce environmental impacts while maintaining the functional performance expected from contemporary building systems. Bio-based materials derived from renewable resources have received increasing attention because they offer opportunities for reducing the environmental footprint of construction products while potentially providing favourable thermal and hygrothermal properties. However, environmental sustainability cannot be considered independently from the functional performance of a building. A material with a low environmental impact must also provide adequate thermal, acoustic, moisture, fire, and durability performance if it is to become a viable component of building envelopes. Several studies have investigated the potential of eco-friendly materials for acoustic applications, such as wheat straw and hemp fibers, which can achieve high sound absorption coefficients (0.98–0.99), making them viable sustainable alternatives to traditional synthetic insulation materials such as mineral wool and fiberglass [1]. Within this broader context, the present study focuses specifically on the acoustic properties, particularly the sound insulation performance, of bio-based composite materials with low environmental impact. Particular attention is given to hemp- and miscanthus-based composites incorporated into lightweight wall assemblies consisting of timber, bio-based material, and gypsum plasterboard.

Acoustic characteristics are of particular importance in lightweight wall systems. Unlike massive masonry structures, lightweight walls rely on the interaction of multiple layers and specific physical mechanisms to achieve adequate airborne sound insulation. Their acoustic performance is therefore complex and depends not only on overall mass but also on factors such as material density, stiffness, porosity, damping properties, thickness, and internal structure. However, the acoustic properties of materials with a low environmental footprint remain insufficiently investigated, particularly with regard to their potential application in lightweight wall systems. This limited knowledge creates a need for reliable experimental approaches capable of providing meaningful acoustic data at an early stage of material development. Consequently, identifying a suitable and practical measurement method for obtaining preliminary sound insulation results is of particular importance. Such an approach would enable the acoustic performance of low-environmental-impact materials to be assessed during the early stages of their development and refinement, before their properties and potential applications are fully established, thereby supporting their optimization for use in sustainable lightweight wall systems. Bio-based composites are therefore of particular interest. Their relatively low density and heterogeneous fibrous structure can influence sound

propagation and energy dissipation in ways that differ from conventional insulation materials. Hemp and miscanthus, in particular, offer the possibility of combining thermal insulation and environmental benefits with potentially useful acoustic characteristics. The development of such materials can consequently benefit from a methodology in which environmental and thermal assessments are used to identify promising candidates, followed by targeted acoustic investigation. Such an approach avoids attempting to optimize all material properties simultaneously and instead allows the most promising material to be further developed according to its specific acoustic limitations and potential. The present research follows this concept. The investigated materials were selected following preliminary environmental and thermal assessments. Their acoustic properties were subsequently compared using a small-scale acoustic chamber developed and previously used at the University of Architecture, Civil Engineering and Geodesy (UACEG). Comparative measurements using this chamber have already been conducted in previous research, and corresponding results have been published [2], [3]. The present work builds on that experimental experience and applies the chamber specifically to the comparative evaluation of the investigated low-environmental-impact wall assemblies. An important feature of the present study is that the objective of the measurement differs from that of standardized laboratory sound insulation tests [4]. The aim is not to determine an absolute sound insulation index suitable for building design—a process requiring significant time and resources. Instead, the experiment seeks to quickly and easily establish, with reasonable accuracy, the amount of sound reaching the receiving room under various wall configurations; this allows for the comparison of different materials while keeping the source level and measurement conditions constant. The receiving room used in the present investigation has real-scale dimensions. For each tested configuration, the same sound source, source level, measurement procedure, and environmental conditions were maintained. Consequently, differences in the measured sound level in the receiving room can be directly used for comparative evaluation of the specimens. If necessary, other more detailed comparisons could be added, for example the in sound levels difference and the sound insulation index, as presented in this article. This approach is particularly valuable during material development. If one material exhibits better acoustic behaviour than another, the frequency-dependent results can indicate the frequency regions in which further improvement is desirable. The material can then be modified or optimized specifically for those frequency ranges. The main objectives of the study are therefore: to experimentally compare the acoustic behaviour of hemp- and miscanthus-based composite materials; to investigate their performance when incorporated into lightweight timber-based wall assemblies with gypsum plasterboard; to identify frequency ranges in which the investigated assemblies demonstrate favourable or unfavourable acoustic behaviour; to assess the suitability of the small-scale acoustic chamber for rapid comparative acoustic evaluation; and to establish a methodology for integrating acoustic optimization with prior thermal and environmental material assessment.

II. MATERIALS AND WALL ASSEMBLIES

A. Material Selection

The materials investigated in this study form part of a broader research effort aimed at developing low-environmental-impact wall systems. Hempcrete is a composite material consisting of shiv particles obtained from the stems of industrial hemp (Cannabis sativa L.), a binder, typically lime-based, and water. Figure 1 illustrates the production of hempcrete and its application as a thermal insulation material.

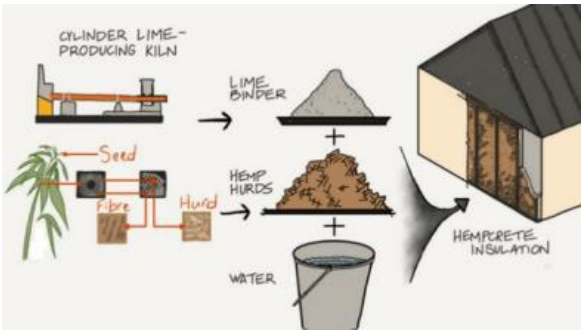


Figure 1. Production of hempcrete and its application as a thermal insulation material. [5]

Studies on hemp concrete have characterized it as a material with the potential for a negative carbon footprint [6], [7], [8]. Estimates of the net carbon emissions associated with the life cycle of hemp concrete for different samples range from -1.6 to -79 kg CO_2/m^2 [9], based on in situ carbonation assessment methods. This negative carbon balance is mainly due to the nature of the raw materials used and the processes involved in their production. Miscanthus, particularly Miscanthus × giganteus, has recently attracted increasing attention as a renewable lignocellulosic resource for the development of bio-based building materials. Its potential in the construction sector is primarily associated with its low density, porous cellular structure, fibrous morphology and relatively low thermal conductivity. These characteristics make miscanthus suitable for incorporation into lightweight composites intended primarily for thermal and acoustic insulation rather than for load-bearing applications. For the present study, materials under development based on hemp and miscanthus were selected, as shown in Fig. 2, with their main characteristics presented in Table 1.



Figure 2. Hemp- and miscanthus-based materials selected for the present study.

The initial selection of the materials was not based exclusively on their acoustic properties. Instead, environmental and thermal performance were considered first in order to identify materials with potential for sustainable building applications. Acoustic performance was then introduced as an additional criterion for material development.

parameter	hemp-composite	miscanthus-composite
ρ, kg/m^3	340	370
λ, W/mK	0,073	0,078
μ,	4,4	3,8
GWP*, CO_2	- 0,112	-0,229

*Global warming potential, total carbon footprint. Values are averaged

Table 1. Main characteristics of the hemp- and miscanthus-based materials selected for the study.

This sequence is important because it reflects the actual development strategy. The objective is not simply to identify the material with the best acoustic performance, but to identify a material that provides a favourable combination of environmental and thermal characteristics and can subsequently be improved from an acoustic perspective.

Hemp- and miscanthus-based composites were selected because both materials originate from renewable plant resources and can be incorporated into lightweight building components. Their physical structures also provide a potentially favourable basis for acoustic energy dissipation.

B. Wall Assembly Configurations

Comparative acoustic measurements were conducted on different wall assembly configurations combining:
timber structural elements;
bio-based composite materials;
gypsum plasterboard (GPB).
The principal configurations included assemblies incorporating hemp-based and miscanthus-based materials. The purpose of the comparison was not to determine a certified sound insulation value for each wall but to establish the relative acoustic behaviour of the different configurations under identical experimental conditions.
The use of timber and gypsum plasterboard is particularly relevant because the acoustic performance of a lightweight wall is determined by the combined behaviour of the entire assembly. Consequently, the measured results cannot be attributed exclusively to the bio-based filling material.

III. Experimental Setup

A. Small-Scale Acoustic Chamber at UACEG
The acoustic measurements were carried out using a small-scale acoustic chamber located at the University of Architecture, Civil Engineering and Geodesy (UACEG).
A particular feature of this method is the significant difference in volume between the source room, with a volume of 0.61 m³, and the receiving room, with a volume of 219 m³.



Figure 3. View of the Small-Size Acoustic Chamber and the measurement equipment

The main purpose of the chamber is to provide repeatable conditions for comparing different samples. The system allows the introduction of wall

samples or material configurations between the sound source and the receiving room, which allows the measurement of the resulting sound level in the receiving space.

B. Measurement Principle

The present investigation deliberately uses a simplified comparative measurement procedure. For each specimen, the sound source was operated under the same conditions. The sound level generated in the source room was kept constant, and the geometry, equipment, measurement procedure, and environmental conditions were maintained as consistently as possible.

The primary measured parameter was therefore the sound pressure level in the receiving room.

Because the source level and measurement conditions were kept constant, lower receiving-room sound levels indicate comparatively better sound insulation of the tested wall configuration. This approach provides a direct comparative measure of acoustic behaviour without attempting to assign a standardized sound reduction index to the individual specimens.

IV. RESULTS

A. Frequency-Dependent Acoustic Behaviour

The measured sound pressure levels in the receiving room are presented graphically for the investigated wall assemblies.

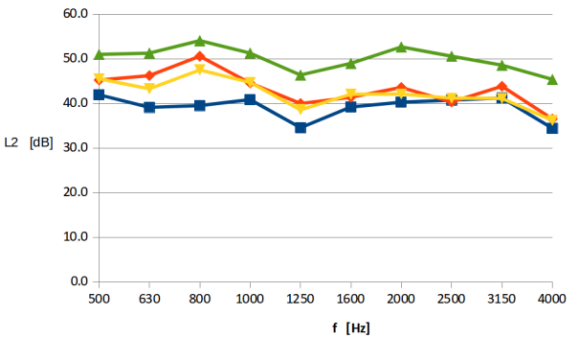


Figure 4 Frequency-dependent sound pressure levels measured in the receiving room for the investigated wall assemblies.(from bottom to top 1.Hemp-Based Composite, 2.Miscanthus-Based Composite 3.Composite textile-recycled material for comparison, 4. Single GPB)

Lower sound levels in the receiving room indicate relatively better sound insulation of the tested wall configuration.

The results demonstrate clear differences between the tested configurations. Although the general shape of the frequency response is similar, the magnitude of the transmitted sound varies depending on the material and wall configuration. These differences confirm that the bio-based material contributes measurably to the acoustic behaviour of the complete wall assembly. Consequently, the relative differences in receiving-room sound levels can be attributed primarily to differences in the acoustic behaviour of the wall assemblies.

B. Hemp-Based Composite

Among the investigated bio-based materials, the hemp-based configuration demonstrated the most favourable acoustic response over significant portions of the measured frequency range.

The receiving-room sound levels associated with the hemp-based assembly were generally lower than those obtained for the corresponding alternative configurations.

This result is particularly important because the hemp-based material was not selected solely for its acoustic performance. Its initial selection was related to its overall potential as a low-environmental-impact construction material, including thermal and environmental considerations.

The measured frequency-dependent response also provides information that can be used for subsequent material optimization. Rather than simply seeking a general increase in acoustic performance, the material development process can focus on the frequency ranges where the hemp-based assembly shows relatively higher sound transmission.

C. Miscanthus-Based Composite

The miscanthus-based configurations also demonstrated measurable acoustic performance, although the receiving-room sound levels were generally higher than those obtained for the hemp-based configuration in the most relevant parts of the investigated frequency range.

The difference indicates that the two bio-based materials cannot be considered acoustically equivalent, even when they are incorporated into similar lightweight wall configurations.

The result may be associated with differences in density, porosity, internal morphology, stiffness, damping, or binder characteristics.

However, because several material parameters may differ simultaneously, the present results should be interpreted as a comparison of the complete tested assemblies rather than as an isolated determination of the acoustic properties of the plant fibres themselves.

D. Comparison of Wall Assemblies

The hemp-based wall assembly produced the lowest receiving-room levels over the most significant part

of the measured frequency range.The comparative results are shown in Fig. 2.

These results suggest that the hemp composite holds significant potential for further development as an acoustic element in low-environmental-impact wall systems. A similar conclusion can be drawn based on the analysis of in the sound levels difference, however, the relationship is inverse: the greater the difference, the better the insulation (Fig. 5).

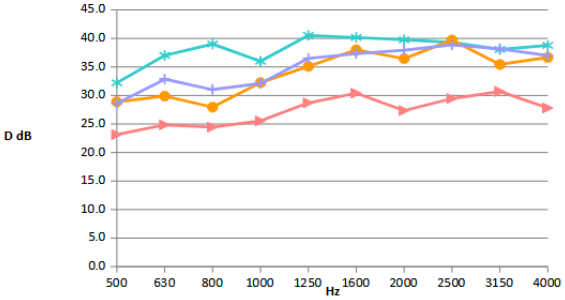


Figure 5 Sound levels difference (from top to bottom 1.Hemp-Based Composite, 2.Miscanthus-Based Composite 3.Composite textile-recycled material for comparison, 4. Single plane GKB)

Sound levels difference D is $D=L_1-L_2$
Irborne sound insulation is calculated using the formula
$R = L_1 – L_2 + 10 \log(S/A)$,
where:
L_1 is the average sound pressure level in the source room, dB
L_2 – average sound pressure level in the receiving room, dB
S – area of the test specimen, m^2
A – equivalent sound absorption area of the receiving room, m^2
To obtain sound insulation index results and gain a realistic understanding of the assembly's capabilities, calculations accounting for the specimen area and the reverberation time in the receiving room wereperformed; the results are presented in Table 2.

Frequency	Level in the source room	Level in the receiving room	Reverberation time (Reseiving room)	A	Sound insulation
[Hz]	[dB]	[dB]	[s]	m²	[dB]
500	74,15	41,9	1,63	21.30	30.4
630	76,15	39,1	1,47	23.62	35.15
800	78,55	39,5	1,58	21.97	31.19
1000	76,85	40,9	1,56	22.26	34.08
1250	75,1	34,6	1,55	22.40	38.62
1600	79,4	39,2	1,47	23.62	38.3
2000	80,05	40,3	1,48	23.46	37.86
2500	80,05	40,8	1,46	23.78	37.35
3150	79,3	41,2	1,28	27.12	36.14

Table 2. Main characteristics of the hemp- and miscanthus-based materials selected for the study.

V. DISCUSSION

Acoustic Properties as a Development Criterion
This study demonstrates the potential of the proposed method for assessing the sound insulation performance of novel eco-friendly materials during their development and optimization stages. A preliminary assessment can be performed by comparing the sound pressure level in the receiving room (Fig. 4), or by evaluating the difference between the sound levels (Fig. 5). Alternatively, by taking into account the dimensions of the test specimen and the reverberation time in the receiving room, a sound insulation index can be determined (Tabl.2). This index can then be used for comparative assessment against materials with established sound insulation properties.The central finding of the investigation is that the acoustic behaviour of bio-based materials can be used not only as a criterion for evaluating an already developed wall system but also as a design parameter for further material development.

In conventional building design, the acoustic performance of a wall is generally evaluated after its composition has been established. In the development of innovative bio-based materials, however, acoustic measurements can be incorporated much earlier in the process.

The proposed methodology allows the development process to follow a sequence such as:

Environmental assessment → Thermal assessment → Material selection → Acoustic screening → Identification of critical frequencies → Acoustic material optimization → Full-scale validation.
This approach can significantly reduce the number of full-scale specimens that need to be constructed and tested.

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