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Sustainable Natural-Fibre Nonwovens and Pith-Based Composites for Acoustic and Thermal Building Applications: Integrated Characterization, Mechanisms, and Design Principles

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ABSTRACT

This paper presents an integrative and comprehensive examination of sustainable natural-fibre nonwovens and pith-based lightweight bio-composites for acoustic and thermal building applications. The research synthesizes morphological, chemical, mechanical, hygrothermal, and acoustical findings from contemporary experimental and theoretical studies to build a coherent framework for material selection, processing, and application. Key material classes considered include pith-derived mortars and composites, cellulose-based nonwovens (including barkcloth), agricultural residues such as sugarcane bagasse, oil palm empty fruit bunch (OPEFB), almond skins, sheep wool, date palm fibres, and chemically treated wood fibres integrated into flexible polyurethane matrices. The exposition develops causally linked explanations for acoustic absorption, sound insulation, thermal conductivity, moisture interaction, and long-term hygrothermal stability, drawing on microstructural phenomena (porosity, pore size distribution, fibre morphology, cell wall chemistry) and macroscopic performance metrics (sound absorption coefficient, transmission loss, thermal resistance). Theoretical mechanisms are elaborated with attention to viscous and thermal boundary-layer effects in porous absorbers, frame-structure coupling in sandwich panels, and the role of fibre-hydrophilicity and bound water in heat and mass transport. Practical design principles and manufacturing recommendations are given, covering nonwoven web formation, binder selection, density control, surface treatments, and hybridization strategies for simultaneous acoustic and thermal performance. Limitations in current evidence are critically appraised, including variability due to botanical origin and harvest year, measurement standardization challenges, durability under cyclic moisture and temperature loading, and scale-up constraints. The paper concludes with prioritized research directions to advance the deployment of bio-based acoustic-thermal materials in buildings: standardized characterization protocols, predictive multiscale models, life-cycle assessment aligned with performance outcomes, reproducible processing routes, and pilot-scale field demonstrations. The integrated perspective offered here aims to help researchers and practitioners move from promising laboratory-scale materials to robust, certified building products that contribute to circular material flows and improved indoor environmental quality.

KEYWORDS

natural fibres, pith composites, nonwovens, sound absorption, thermal insulation, hygrothermal performance

INTRODUCTION

Modern The global drive toward sustainable construction and circular material systems has focused renewed attention on bio-based materials for building envelopes, acoustic finishes, and insulation layers. Traditional mineral-based insulations and synthetic acoustic absorbers are energy and carbon intensive in manufacture and can present end-of-life challenges; by contrast, agricultural residues and natural fibres promise low embodied energy, renewability, and the potential for biodegradable end-of-life streams (Gurunathan et al., 2015; Oldham et al., 2011). However, realizing these promises requires a detailed understanding of how microstructure, chemistry, and processing determine the coupled acoustic and thermal performance of materials manufactured from plant piths, cellulose nonwovens, and fibre-based mats.

Recent studies demonstrate that pith — an internal, lightweight tissue present in many stems and stalks — can be formulated into lightweight mortars and composites with attractive thermal and mechanical properties (Abbas et al., 2020; Abbas et al., 2019). Pith offers a low-density core material that can substantially reduce composite weight while contributing to thermal resistance. At the same time, nonwoven assemblies of natural fibres — whether harvested as wool, barkcloth, sugarcane bagasse fibres, or processed almond skins — have been shown to provide effective broadband sound absorption through viscous and thermal dissipation mechanisms within porous networks (Zhu et al., 2013; Liuzzi et al., 2020; Rey et al., 2017). These disparate material classes share common governing principles: porosity distribution, tortuosity, fibre morphology, and moisture-related phenomena control both heat and sound propagation.

Even as experimental reports proliferate, two transdisciplinary gaps impede wider application. First, the literature often treats thermal and acoustic properties separately, with limited integrated frameworks that explain trade-offs and synergies between sound absorption, insulation, and hygrothermal durability (Ramlee et al., 2021; Tămaş-Gavrea et al., 2020). Second, material variability arising from botanical origin, harvest year, and pre-treatment introduces performance uncertainty that is inadequately characterized for design and certification (Abbas et al., 2019; Sanjuán et al., 2001). This paper seeks to bridge these gaps by synthesizing mechanistic knowledge across studies, proposing unified design heuristics and practical processing pathways, and identifying critical research priorities to accelerate reliable deployment of bio-based acoustic-thermal building components.

The following sections will lay out methodology for integrating published experimental findings, present a descriptive analysis of how microstructure governs macro-performance, critically discuss processing and durability, and conclude with actionable recommendations for researchers and industry.

METHODOLOGY

This work is a synthesis-driven research article: it does not report new experimental measurements but instead constructs a rigorous, theory-informed integration of experimental and modeling studies from the provided reference corpus. The methodology follows three interconnected strands: (1) systematic thematic synthesis of experimental findings; (2) mechanistic mapping from microstructure to thermal and acoustic response; and (3) design translation into manufacturing recommendations and research priorities.

Thematic synthesis: Each primary source was analyzed for reported material types, processing methods, physical and chemical characterization, and measured performance metrics (sound absorption coefficient, transmission loss, thermal conductivity, specific heat, moisture uptake, mechanical strength). Emphasis was placed on studies which reported broadband acoustic data, porosity characterization, hygrothermal behavior, and interfacial chemistry between fibre and binder (Zhu et al., 2013; Liuzzi et al., 2020; Abbas et al., 2020; Rwawiire et al., 2017). Where studies compared untreated and chemically treated fibres, the chemical pathways and resultant changes in absorption and thermal properties were catalogued (Choe et al., 2018).

Mechanistic mapping: Using established porous-media acoustics and heat-transfer theories from the textile and acoustic materials literature, causal linkages between measurable microstructural attributes (e.g., fibre diameter distribution, cell wall porosity, mean pore radius, and overall matrix density) and macroscopic performance were developed (Morton & Hearle, 2008; Shoshani & Yakubov, 2001). The mapping pays particular attention to viscous and thermal boundary layer dissipation at pore walls, frame stiffness effects relevant to sandwich panel designs, and the influence of hygroscopic bound water on thermal conductivity and internal damping (Tsuchida et al., 2014; Zach et al., 2012).

Design translation: The mechanistic mapping was used to derive specific material and processing recommendations: nonwoven web architecture (needling vs. wet-laid), binder choices (bio-based vs. synthetic), density and compression targets for simultaneous acoustic and thermal optimization, and surface treatments to mitigate moisture sensitivity without compromising acoustic porosity (Thilagavathi et al., 2010; Choe et al., 2018). Evidence of performance variability due to botanical origin and harvest year was incorporated into guidelines for quality control and material specification (Abbas et al., 2019; Sanjuán et al., 2001).

Limitations of the synthesis approach are acknowledged: the heterogeneity of testing standards, variations in sample geometry, and inconsistent reporting of porosity metrics across the literature reduce the ability to generate universal quantitative models. Nonetheless, qualitative and semi-quantitative insights derived here are robust and directly actionable for material developers and applied acousticians.

RESULTS

This section presents descriptive integration of the principal findings from the literature and translates them into performance-relevant statements. Results are organized around material families and the dominant mechanisms that link their microstructure and chemistry to acoustic and thermal behavior.

Pith-based composites: Pith, the lightweight central tissue of many plant stems, has been incorporated into mortar and composite matrices to produce lightweight panels and blocks with enhanced thermal resistance and reduced density (Abbas et al., 2020; Abbas et al., 2019). The key observed outcomes are (a) marked reduction in composite density with modest impact on compressive strength when pith is used as an aggregate; (b) reduced thermal conductivity compared with dense mineral-based matrices due to internal air-filled cellular structure; and (c) sensitivity of mechanical and hygrothermal behavior to the pith's botanical origin and the harvest year, which influence cell wall thickness and soluble extractives content (Abbas et al., 2020; Sanjuán et al., 2001). The literature demonstrates that with appropriate binder selection and controlled porosity, pith-containing composites can achieve thermal resistances suitable for non-load-bearing insulation panels while remaining compatible with standard construction adhesives and fasteners (Abbas et al., 2020).

Cellulose nonwovens and barkcloth: Cellulose-based nonwovens, including traditional barkcloth and modern wet-laid or spunbonded webs, show excellent broadband acoustic absorption when fabricated with open, interconnected porosity and moderate thickness (Rwawiire et al., 2017; Oldham et al., 2011). The primary mechanism is viscous dissipation within the pore network: incoming acoustic energy drives air motion through narrow channels where viscous shear at fibre and pore walls converts kinetic energy to heat. Barkcloth nonwovens also exhibit favorable thermal behavior due to tortuous pathways that reduce conductive heat transfer and trap air pockets (Rwawiire et al., 2017; Zhu et al., 2013).

Agricultural residues: Sugarcane bagasse, almond skins, and oil palm empty fruit bunch (OPEFB) have each been investigated as feedstocks for absorptive panels and insulating composites (Othmani et al., 2016; Liuzzi et al., 2020; Ramlee et al., 2021). Experimental studies consistently report that fibrous residues with high fibre fines content and irregular particle geometry contribute to absorption across a broad frequency range by creating multiscale porosity and increasing viscous interactions (Othmani et al., 2016; Liuzzi et al., 2020). Moreover, when these residues are combined into hybrid panels, synergies emerge: coarse fibrous layers provide structural integrity and low-frequency absorption via frame resonances, while fine particulate layers provide effective high-frequency absorption (Ramlee et al., 2021).

Sheep wool and animal fibres: Sheep wool uniquely combines intrinsic crimped morphology, natural hydrophobic-hydrophilic balance, and high internal porosity to produce materials with simultaneous sound absorption and thermal insulation properties (Rey et al., 2017; Tămaş-Gavrea et al., 2020). Wool fibers' complex surface scales and porosity increase internal friction and scattering, while the fibres trap air effectively, lowering bulk thermal conductivity. Studies show wool-based sandwich panels and felted mats achieve excellent acoustic performance and thermal R-values comparable to commonly used mineral insulations when conditioned properly (Rey et al., 2017; Tămaş-Gavrea et al., 2020).

Chemical treatments and composite foams: Chemical modification of wood fibres and incorporation into polyurethane foams are reported to enhance sound absorption by increasing fibre-matrix interfacial friction and by tuning the foam's cell openness (Choe et al., 2018). Chemical treatments that increase surface roughness or introduce polar functional groups can raise viscous losses and broaden absorption bands. However, trade-offs exist: crosslinking that stiffens the matrix can decrease low-frequency absorption unless compensated by increased thickness or backing cavity depth (Choe et al., 2018).

Nonwoven porosity control and nonwoven mechanics: Studies of variable porosity nonwovens indicate that graded porosity — where surface layers are more open than core layers — creates a favorable impedance gradient that reduces reflection and increases absorption across frequencies (Shoshani & Yakubov, 2001; Thilagavathi et al., 2010). Needling density, fibre orientation, and mass per unit area were shown to be effective process levers for tailoring the characteristic flow resistivity and resulting acoustic impedance, which are primary determinants of absorption spectra (Shoshani & Yakubov, 2001; Morton & Hearle, 2008).

Hygrothermal interactions: Natural fibres' hygroscopic nature impacts both thermal and acoustic performance. Adsorbed and bound water increases thermal conductivity (through conduction pathways and higher heat capacity) and modifies acoustic absorption by changing viscous damping and internal friction (Tsuchida et al., 2014; Zach et al., 2012). Experimental reports emphasize the necessity of moisture management — through hydrophobic treatments, vapor-control layers, or composite encapsulation — to maintain predictable long-term performance in building environments (Zach et al., 2012; Tsuchida et al., 2014).

Variability due to origin and processing: Multiple studies emphasize that botanical origin, harvest timing, and pre-processing (drying, milling, defibration) produce statistically significant variability in mechanical, thermal, and acoustic outcomes (Abbas et al., 2019; Sanjuán et al., 2001). This variability necessitates specification ranges rather than single-point material properties for design, and calls for quality assurance measures such as standardized moisture conditioning, density targets, and flow resistivity testing before approval for construction use (Abbas et al., 2019).

DISCUSSION

The integrated findings yield a comprehensive set of mechanistic insights, design trade-offs, and practical pathways to convert laboratory-scale bio-based materials into robust building components. The discussion explores four key themes in depth: (1) governing mechanisms linking microstructure to macro-performance; (2) trade-offs and hybridization strategies for simultaneous acoustic and thermal optimization; (3) moisture, durability and lifecycle considerations; and (4) measurement, standardization and scalability barriers.

Governing mechanisms: Acoustic absorption in porous, fibrous absorbers is dominated by viscous and thermal dissipation occurring within narrow pores and along fibre surfaces. The magnitude and frequency dependence of absorption are primarily determined by flow resistivity — which encapsulates how easily air flows through the material — and by tortuosity, the effective path length of flow relative to straight-line thickness (Shoshani & Yakubov, 2001; Morton & Hearle, 2008). Materials with low flow resistivity (very open pores) tend to perform poorly at high frequencies because insufficient viscous interaction occurs; conversely, materials with overly high flow resistivity reflect sound rather than absorbing it. The target for broadband absorption is an intermediate flow resistivity that matches the characteristic acoustic impedance of air at the frequencies of interest (Morton & Hearle, 2008; Zhu et al., 2013).

Thermal behavior is governed by the same microstructural features but manifests differently. Thermal conductivity in low-density bio-based mats is reduced primarily by trapped air; thus porosity and pore connectivity strongly influence heat conduction. However, the presence of moisture — both adsorbed and bound — raises effective conductivity because water has higher thermal conductivity than air and because water bridges between fibres create conduction pathways (Tsuchida et al., 2014; Zach et al., 2012). Consequently, design approaches that increase porosity for acoustic reasons must account for moisture control to maintain thermal insulation performance.

Trade-offs and hybridization: The dual goals of sound absorption and thermal insulation can be synergistic when design exploits multiscale porosity: coarser pores and stiffer layers can address low-frequency absorption and structural requirements, while fine porosity and soft fibres absorb higher frequencies and trap air for thermal resistance (Ramlee et al., 2021; Liuzzi et al., 2020). Hybrid panels that layer materials with differing porosities or that combine stiff faces with soft cores (sandwich construction) can target a wider frequency band without sacrificing thermal R-value (Tămaş-Gavrea et al., 2020). Yet stiffness and frame coupling must be controlled: overly stiff faces lead to panel resonances and transmission loss peaks that can undermine absorption at target frequencies unless decoupling strategies (e.g., constrained layer damping, porous interlayers) are introduced (Tămaş-Gavrea et al., 2020).

Moisture and durability: Hygroscopic uptake of moisture is a defining challenge for natural-fibre insulations and absorbers. Water uptake modifies both thermal and acoustic responses and accelerates biological degradation if not controlled (Tsuchida et al., 2014; Zach et al., 2012). Several mitigation strategies are described in the literature and synthesized here: (a) hydrophobic surface treatments that preserve fibre-level porosity while reducing equilibrium moisture content; (b) composite encapsulation using breathable membranes that prevent liquid ingress but permit vapor diffusion; and (c) formulation with integrated biocidal additives where appropriate to prevent fungal growth. However, treatments introduce trade-offs: hydrophobic coatings may reduce surface friction and slightly lower viscous damping, and certain preservatives raise environmental concerns. Therefore, design decisions must balance moisture protection with acoustic and environmental performance goals (Choe et al., 2018; Rey et al., 2017).

Measurement and standardization barriers: The literature reveals inconsistent reporting conventions. Studies use different sample thicknesses, backing conditions, porosity metrics, and acoustic measurement setups (impedance tube vs. reverberation chamber), making direct comparison challenging (Zhu et al., 2013; Oldham et al., 2011). To overcome this, the field needs standardized reporting templates that include: density, mass per unit area, open porosity fraction, mean pore size, flow resistivity, sample conditioning history (relative humidity and temperature), and both normal-incidence and diffuse-field acoustic metrics. Adoption of such standards will enable meta-analyses and predictive modeling essential to scale-up and certification (Euronoise, 2006; Zhu et al., 2013).

Processing and manufacturing recommendations: Several process variables emerge as decisive for final performance:

• **Web formation and fibre orientation:** Wet-laid and carding/needling processes yield different fibre alignments and porosity distributions. Wet-laid processes produce more isotropic, fine-porosity mats suitable for high-frequency absorption, while needlepunching can create inhomogeneous density profiles with enhanced low-frequency behavior (Thilagavathi et al., 2010; Shoshani & Yakubov, 2001).

• **Binder selection:** Binders must provide mechanical cohesion without clogging pore spaces. Low-addition, thermoset or bio-based polymeric binders that form thin films at fibre cross points are preferred. Waterborne binders applied minimally preserve open porosity (Thilagavathi et al., 2010; Choe et al., 2018).

• **Density control:** Target bulk densities should be specified based on flow resistivity targets. For many natural fibre absorbers, densities in the range of 20–80 kg/m³ produce favorable trade-offs, but precise targets depend on fibre stiffness and diameter distribution (Morton & Hearle, 2008; Liuzzi et al., 2020).

• **Surface treatments:** Silane-based, polymeric, or wax-based hydrophobisation can stabilize moisture uptake. Treatments should be validated to ensure the retained absorption performance and minimal environmental impact (Choe et al., 2018; Zach et al., 2012).

Environmental and lifecycle considerations: Beyond in-use performance, bio-based materials must be evaluated in life-cycle terms. The embodied energy and greenhouse gas intensity of processing steps, treatments, and binders can erode the environmental advantage of raw biomasses if not chosen carefully (Gurunathan et al., 2015). Therefore, life cycle assessment (LCA) tied to actual performance (e.g., R-value per kilogram of CO_2 embodied) should be integrated into material selection and optimization. Papers emphasize that low-tech processing pathways and minimal chemical modification tend to produce the most favorable LCA outcomes, provided durability in the field is assured (Gurunathan et al., 2015; Ramlee et al., 2021).

Limitations and uncertainties: The evidence base, while rich, has limitations that constrain prescriptive claims. Primary among these are variability due to botanical source and harvest conditions (Abbas et al., 2019; Sanjuán et al., 2001), inconsistent measurement protocols (Zhu et al., 2013), and a scarcity of long-term field performance data that accounts for cyclic moisture and temperature loads (Tsuchida et al., 2014). Addressing these limitations requires coordinated research programs that couple standardized laboratory testing with long-term in-situ monitoring.

CONCLUSION

This synthesis highlights the substantial potential of pith-based composites, cellulose nonwovens, and agricultural-residue-derived panels for delivering combined acoustic absorption and thermal insulation in sustainable buildings. Mechanistic understanding indicates clear levers — porosity architecture, flow resistivity, hybrid layering, moisture management, and binder strategy — that can be tuned to achieve desired multifunctional performance. To translate these materials from laboratory proof-of-concept to reliable building products, the community must prioritize:

1. Standardized measurement and reporting to enable reproducible comparisons and meta-analyses (Euronoise, 2006; Zhu et al., 2013).

2. Predictive, multiscale models that connect botanical microstructure to macroscopic flow resistivity and thermal conductivity (Morton & Hearle, 2008; Tsuchida et al., 2014).

3. Life-cycle assessments integrated with performance metrics to ensure environmental advantage is real and not offset by energy- or chemical-intensive processing (Gurunathan et al., 2015).

4. Field-scale pilot demonstrations with in-service monitoring of moisture, thermal performance, and acoustic behavior to validate durability and maintenance needs (Zach et al., 2012; Tămaş-Gavrea et al., 2020).

5. Quality assurance frameworks to manage botanical variability through specification ranges and standardized conditioning (Abbas et al., 2019; Sanjuán et al., 2001).

The convergence of mechanistic insight and practical processing recommendations presented here provides a roadmap for material scientists, acousticians, and building engineers to exploit the unique attributes of natural fibres and piths. With disciplined attention to measurement rigor, moisture control, and lifecycle thinking, bio-based acoustic-thermal materials can become mainstream contributors to healthier, lower-carbon buildings.

REFERENCES

1. Abbas, M.S.; Mcgregor, F.; Fabbri, A.; Ferroukhi, M.Y. The Use of Pith in the Formulation of Lightweight Bio-Based Composites: Impact on Mechanical and Hygrothermal Properties. Construction and Building Materials. 2020, 259, 120573.
2. Abbas, M.S.; Mcgregor, F.; Fabbri, A.; Ferroukhi, Y.M. Influence of origin and year of harvest on the performance of pith mortars. Acad. J. Civ. Eng. 2019, 37, 42–48.
3. Zhu, X.; Kim, B.-J.; Wang, Q.; Wu, Q. Recent Advances in the Sound Insulation Properties of Bio-Based Materials. Bioresources. 2013, 9, 1764–1786.
4. Liuzzi, S.; Rubino, C.; Stefanizzi, P.; Materials, F.M. Performance Characterization of Broad Band Sustainable Sound Absorbers Made of Almond Skins. Materials. 2020, 13, 5474.
5. Shoshani, Y.; Yakubov, Y. Use of Nonwovens of Variable Porosity as Noise Control Elements. Int. Nonwovens J. 2001, 10, 1558925001os–155892500110.
6. Thilagavathi, G.; Pradeep, Ã.E.; Kannaian, T.; Sasikala, L. Development of Natural Fiber Nonwovens for Application as Car Interiors for Noise Control. Journal of Industrial Textiles. 2010, 39, 267–278.
7. Lulla, K.; Chandra, R.; Sirigiri, K. Proxy-based thermal and acoustic evaluation of cloud GPUs for AI training workloads. Emerging Frontiers Library for The American Journal of Applied Sciences. 2025, 7(07), 111-127.
8. Euronoise, F.A.-P. Survey on the Acoustical Properties of New Sustainable Materials for Noise Control. Proceedings of the Euronoise, Tampere, Finland, 30 May–1 June 2006.
9. Rwawiire, S.; Tomkova, B.; Militky, J.; Hes, L. Acoustic and Thermal Properties of a Cellulose Nonwoven Natural Fabric (Barkcloth). Applied Acoustics. 2017, 116, 177–183.
10. Gurunathan, T.; Mohanty, S.; Nayak, S.K. A Review of the Recent Developments in Biocomposites Based on Natural Fibres and Their Application Perspectives. Composites Part A: Applied Science and Manufacturing. 2015, 77, 1–25.
11. Choe, H.; Sung, G.; Kim, J.H. Chemical Treatment of Wood Fibers to Enhance the Sound Absorption Coefficient of Flexible Polyurethane Composite Foams. Composites Science and Technology. 2018, 156, 19–27.
12. Morton, W.E.; Hearle, J.W.S. An Introduction to Fibre Structure. In Physical Properties of Textile Fibres, 4th ed.; Woodhead Publishing Series in Textiles. 2008, 1–81.
13. Oldham, D.J.; Egan, C.A.; Cookson, R.D. Sustainable Acoustic Absorbers from the Biomass. Applied Acoustics. 2011, 72(6), 350–363.
14. Othmani, C.; Taktak, M.; Zein, A.; Hentati, T.; Elnady, T.; Fakhfakh, T.; Haddar, M. Experimental and Theoretical Investigation of the Acoustic Performance of Sugarcane Wastes Based Material. Applied Acoustics. 2016, 109, 90–96.

15. Ramlee, N.A.; Jawaid, M.; Safwan Ismail, A.; Syams Zainudin, E.; Abdul Karim Yamani, S. Evaluation of Thermal and Acoustic Properties of Oil Palm Empty Fruit Bunch/Sugarcane Bagasse Fibres Based Hybrid Composites for Wall Buildings Thermal Insulation. Fibers and Polymers. 2021, 22(9), 2563–2571.

16. Ramlee, N.A.; Naveen, J.; Jawaid, M. Potential of Oil Palm Empty Fruit Bunch (OPEFB) and Sugarcane Bagasse Fibres for Thermal Insulation Application – A Review. Construction and Building Materials. 2021, 271, 121519.

17. Rey, R.D.; Uris, A.; Alba, J.; Candelas, P. Characterization of Sheep Wool as a Sustainable Material for Acoustic Applications. Materials. 2017, 10(11), 1277.

18. Sanjuán, R.; Anzaldo, J.; Vargas, J.; Turrado, J.; Patt, R. Morphological and Chemical Composition of Pith and Fibers from Mexican Sugarcane Bagasse. Holz als Roh- und Werkstoff. 2001, 59(6), 447–450.

19. Taban, E.; Khavanin, A.; Ohadi, A.; Putra, A.; Jonidi Jafari, A.; Faridan, M.; Soleimanian, A. Study on the Acoustic Characteristics of Natural Date Palm Fibres: Experimental and Theoretical Approaches. Building and Environment. 2019, 161, 106274.

20. Tămaş-Gavrea, D.-R.; Dénes, T.-O. Mechanical, Thermal and Acoustical Properties of an Innovative Lime-Wool Composite. Procedia Manufacturing. 2020, 46, 402–409.

21. Tămaş-Gavrea, D.-R.; Dénes, T.-O.; Iştoan, R.; Elena Tiuc, A.; Lucia Manea, D.; Vasile, O. A Novel Acoustics Sandwich Panel Based on Sheep Wool. Coatings. 2020, 10(2), 148.

22. Tsuchida, J.E.; Alves Rezende, C.; De Oliveira-Silva, R.; Aparecida Lima, M.; Nogueira D'Eurydice, M.; Polikarpov, I.; José Bonagamba, T. Nuclear Magnetic Resonance Investigation of Water Accessibility in Cellulose of Pretreated Sugarcane Bagasse. Biotechnology for Biofuels. 2014, 7(1), 1–13.

23. Zach, J.; Korjenic, A.; Petránek, V.; Hroudová, J.; Bednar, T. Performance Evaluation and Research of Alternative Thermal Insulations Based on Sheep Wool. Energy and Buildings. 2012, 49, 246–253.

24. Zhu, Y.; Jiang, Y.; Zhu, Z.; Deng, H.; Ding, H.; Yanhong, L.; Zhang, L.; Lin, J. Preparation of a Porous Hydroxyapatite-Carbon Composite with the Bio-Template of Sugarcane Top Stems and Its Use for the Pb(II) Removal. Journal of Cleaner Production. 2018, 187, 650–661.