INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Lightweight Composite Panels as Alternative Building Materials: A Qualitative Systematic Literature Review of Sustainability, Performance, and Construction Applications

Stephen G. Ramos[1], Jico C Monte[2], Russel M. Dela Torre[3]

[1]Southland College, Kabankalan City, Philippines

[2]Capiz State University – Main Campus, Roxas City, Capiz, Philippines

[3]Carlos Hilado Memorial State University, Talisay City, Philippines

DOI: https://doi.org/10.51244/IJRSI.2026.1306000333

Received: 21 June 2026; Accepted: 26 June 2026; Published: 09 July 2026

ABSTRACT

The construction industry continues to face increasing pressure to adopt sustainable building materials that reduce environmental impacts while maintaining functional and structural performance. Lightweight composite panels have emerged as promising alternatives to conventional construction materials due to their potential to utilize recycled, renewable, and waste-derived resources while improving energy efficiency and building performance. This study aimed to systematically review the literature on lightweight composite panels as alternative building materials, with particular emphasis on their sustainability, performance characteristics, construction applications, and adoption challenges.

A qualitative systematic literature review (SLR) was conducted following the Preferred Reporting Items for Systematic Reviews (PRISMA 2020) framework. Relevant studies were identified through a structured database search, screened using predefined inclusion and exclusion criteria, and evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal framework. Following the quality assessment and eligibility screening process, 17 high-quality studies published between 2021 and 2025 were included in the final synthesis.

The findings revealed that lightweight composite panels incorporating recycled polymers, wood waste, natural fibers, bio-based materials, geopolymers, and agricultural residues provide significant sustainability benefits through waste reduction, resource conservation, and support for circular economy practices. The reviewed studies consistently reported favorable thermal insulation, acoustic performance, energy efficiency, and acceptable structural functionality across various construction applications, including structural insulated panels, geopolymer foams, timber-composite systems, and natural-fiber insulation materials. However, several barriers to adoption were identified, including durability concerns, moisture susceptibility, fire resistance limitations, manufacturing variability, production costs, limited large-scale implementation, insufficient standardization, and regulatory uncertainties.

Overall, the evidence suggests that lightweight composite panels represent a viable and sustainable alternative to conventional building materials. Continued advancements in material engineering, recycling technologies, standardization, and interdisciplinary collaboration are expected to enhance their performance, scalability, and industry acceptance. Future research should focus on long-term field validation, lifecycle assessments, and large-scale implementation to support broader adoption in sustainable construction.

Keywords: Lightweight composite panels, sustainable construction, alternative building materials, recycled materials, bio-based composites, thermal insulation, energy efficiency, circular economy, systematic literature review, PRISMA 2020.

INTRODUCTION

The construction sector is a major driver of global economic development, yet it remains one of the largest consumers of energy, raw materials, and natural resources. Rapid urbanization, population growth, and increasing infrastructure demands have intensified concerns regarding the environmental impact of conventional construction practices. Buildings account for a substantial share of global energy consumption and carbon emissions, prompting the need for innovative materials and technologies that support sustainable development while maintaining structural performance and occupant comfort [1], [2]. Consequently, the search for environmentally responsible building materials has become a critical research priority within civil engineering, architecture, and construction management.

In response to these challenges, composite materials have emerged as promising alternatives to traditional construction materials due to their ability to combine multiple constituents into a single material system with enhanced physical, mechanical, thermal, and environmental properties. Sustainable composite materials have gained increasing attention because they offer opportunities to reduce resource consumption, utilize waste streams, improve building performance, and contribute to circular economy objectives [1]. Recent advancements in materials science have enabled the development of lightweight composite panels that integrate recycled polymers, wood residues, agricultural by-products, natural fibers, bio-based materials, and industrial waste products into functional building components [3],[7].

The growing volume of plastic and polymer waste worldwide has become a significant environmental concern, motivating researchers to explore innovative recycling and upcycling strategies for construction applications. Studies on polystyrene recycling and polymer waste recovery emphasize that waste plastics can be transformed into value-added products with potential applications in building systems, thereby reducing landfill dependency and environmental pollution while extending material life cycles [6], [7]. Likewise, research involving recycled plastic and rubber waste composites has demonstrated their effectiveness in sound absorption and acoustic control, suggesting that waste-derived composites can provide both environmental and functional benefits in building design [8]. These developments illustrate how waste management challenges can be converted into opportunities for sustainable material innovation.

Wood-based and natural-fiber composites have also emerged as important contributors to sustainable construction. Wood-polymer composites (WPCs) have been recognized for their low environmental impact, favorable mechanical properties, and versatility across structural and non-structural applications [4]. Similarly, the incorporation of wood waste into magnesium oxychloride cement composites has demonstrated significant environmental advantages by reducing waste disposal while creating durable building products [5]. Beyond wood-based systems, researchers have investigated agricultural residues and natural fibers as reinforcement materials capable of enhancing the sustainability and thermal efficiency of construction materials. Natural-fiber insulation products have been identified as viable alternatives to conventional synthetic insulation materials due to their renewable nature, lower embodied energy, and contribution to energy conservation [2].

Bio-based composite technologies further expand the potential of lightweight building materials. Recent investigations into mycelium-based composites reinforced with pineapple fibers have demonstrated how agricultural waste and biological materials can be transformed into renewable construction products with promising environmental characteristics [9]. Likewise, studies on sawdust-based insulation systems indicate that waste wood products can be effectively utilized to improve thermal performance and reduce energy consumption in buildings, particularly in hot-arid climates where cooling demands are high [10]. These innovations support the transition toward a more circular and resource-efficient construction industry by transforming waste streams into valuable building materials.

A key advantage of lightweight composite panels lies in their ability to improve building energy efficiency through enhanced thermal insulation. Building envelopes significantly influence energy consumption, and the selection of appropriate insulation materials plays a crucial role in reducing heating and cooling demands [2]. Several studies have reported that lightweight composite systems incorporating natural fibers, recycled polymers, sawdust, and bio-based aggregates exhibit favorable thermal conductivity characteristics, enabling improved energy performance compared with conventional materials [10],13]. Geopolymer foams, for example, have demonstrated low thermal conductivity, excellent fire resistance, and sufficient mechanical properties, making them attractive alternatives to conventional insulation materials such as expanded polystyrene and polyurethane foams [14]. Furthermore, the incorporation of phase-change materials into geopolymer foams has shown additional potential for thermal regulation and energy conservation, contributing to improved indoor environmental quality and reduced operational energy requirements [15].

Beyond thermal performance, lightweight composite panels offer important acoustic and structural benefits. Research examining biocomposite materials composed of sawdust, corncob particles, styrofoam granules, and mineral binders has demonstrated favorable sound absorption and thermal insulation characteristics suitable for building applications [13]. Similarly, recyclable acoustic metamaterials manufactured from plastic and rubber waste have achieved significant noise reduction and reverberation control, highlighting their potential for enhancing indoor acoustic comfort [8]. These findings suggest that lightweight composite panels can provide multifunctional performance that addresses both environmental sustainability and occupant well-being.

Structural performance is another critical factor influencing the practical adoption of lightweight composite panels in the construction industry. Structural insulated panels manufactured from wood-composite boards and natural rubber foam have demonstrated satisfactory physical and mechanical properties suitable for load-bearing and enclosure applications [16]. Likewise, hybrid polystyrene-integrated cross-laminated timber panels have exhibited improved thermal insulation performance while maintaining adequate structural capacity, offering a balance between energy efficiency and structural functionality [17]. Such developments indicate that lightweight composite systems are increasingly capable of meeting both engineering requirements and sustainability objectives.

Despite substantial progress in the development of lightweight composite panels, existing research remains fragmented across diverse material compositions, manufacturing processes, performance criteria, and application contexts. Many studies focus on individual materials or specific performance characteristics, resulting in limited synthesis of the broader body of knowledge. Furthermore, variations in testing methods, material formulations, and evaluation criteria make it difficult to establish comprehensive conclusions regarding the overall sustainability, performance, and applicability of lightweight composite panels within the built environment.

Given the growing interest in sustainable construction materials and the expanding range of lightweight composite technologies, there is a need for a systematic evaluation of existing literature to consolidate current knowledge and identify future research directions. Therefore, this study undertakes a qualitative systematic literature review of lightweight composite panels as alternative building materials. Specifically, it examines the sustainability implications of lightweight composite panels, evaluates their thermal, acoustic, mechanical, and structural performance, and investigates their applications in construction. Through the systematic synthesis of available evidence, this review aims to identify emerging trends, research gaps, challenges, and opportunities that can support the advancement and wider adoption of lightweight composite panels in sustainable architecture and construction.

The study was guided by the following research questions:

RQ1: What challenges, limitations, and barriers to the adoption of lightweight composite panels as alternative building materials are reported in the literature?

This systematic literature review follows the PRISMA 2020 reporting framework to ensure a transparent, rigorous, and replicable review process. Through a structured identification, screening, eligibility assessment, and synthesis of relevant studies, the review consolidates existing knowledge on lightweight composite panels as alternative building materials. The review contributes to the advancement of sustainable construction research by providing a comprehensive synthesis of evidence related to sustainability, performance, and construction applications. Furthermore, it identifies prevailing research trends, knowledge gaps, and emerging opportunities that can guide future investigations, industry adoption, and the development of innovative lightweight composite panel systems for sustainable and energy-efficient buildings.

INTERNATIONAL JOURNAL OF RESEARCH AND SCIENTIFIC INNOVATION (IJRSI)
ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

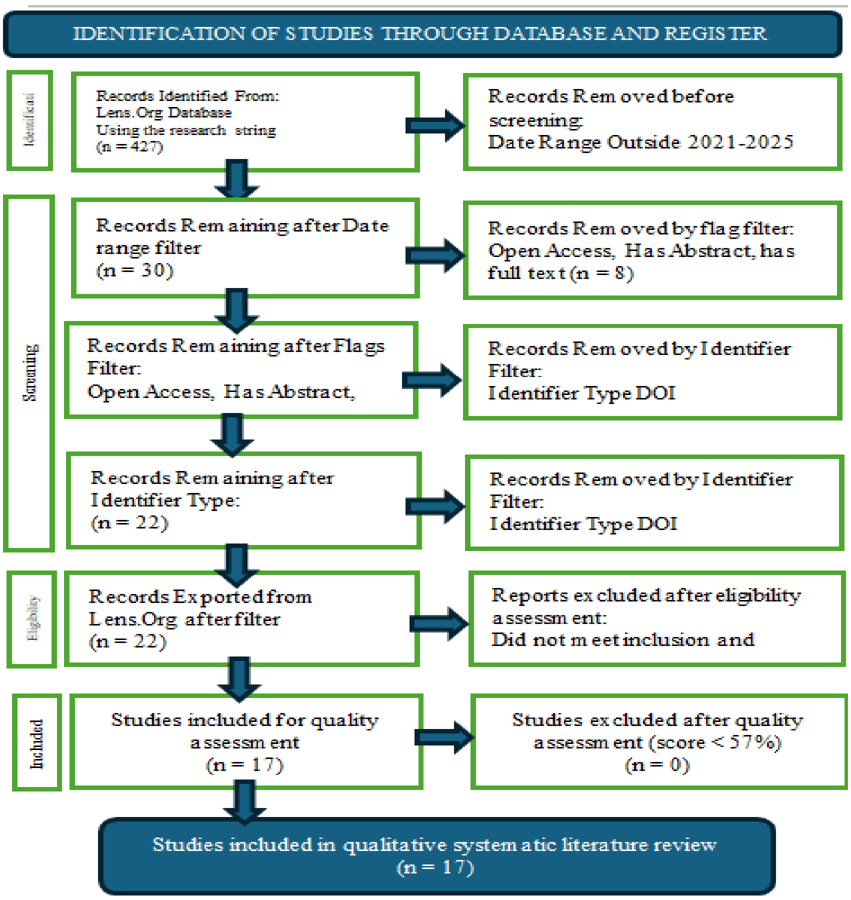
METHODS

Research Design

This study employed a qualitative systematic literature review (SLR) design following the Preferred Reporting Items for Systematic Reviews (PRISMA) 2020 reporting framework. The systematic review approach was selected to ensure methodological rigor, transparency, reproducibility, and comprehensive synthesis of existing evidence related to lightweight composite panels as alternative building materials. Given the growing body of research on sustainable construction materials, lightweight composite systems, and innovative panel technologies, a systematic review provides a structured method for identifying, evaluating, and synthesizing relevant studies across diverse research contexts. The review focused on examining the sustainability attributes, performance characteristics, and construction applications of lightweight composite panels reported in the literature. Specifically, the review investigated evidence concerning environmental sustainability, resource efficiency, thermal and acoustic insulation performance, mechanical properties, durability, and the use of recycled or renewable materials in panel development. In addition, the review explored the practical applications of lightweight composite panels in building construction and identified the challenges, limitations, and opportunities associated with their adoption in the construction industry.

The review process consisted of five key stages: (1) systematic identification of relevant studies through comprehensive database searching, (2) eligibility screening based on predefined inclusion and exclusion criteria, (3) quality assessment of selected studies to evaluate their relevance and methodological soundness, (4) structured data extraction, and (5) qualitative thematic synthesis of findings. Thematic analysis was employed to categorize and synthesize evidence into major themes related to sustainability, performance, construction applications, implementation challenges, and future research directions. By adopting an evidence-based review methodology, this study aimed to enhance the validity, reliability, and comprehensiveness of the findings while providing a consolidated knowledge base for researchers, practitioners, and policymakers interested in sustainable and innovative building materials.

Figure 1. PRISMA 2020 Framework Model



ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Screening and Selection Process

The screening and selection process followed the PRISMA 2020 systematic review procedure to ensure a transparent, rigorous, and replicable identification of relevant studies. The initial search conducted in the Lens.org database using the predefined search string yielded 427 records related to lightweight composite panels, construction materials, engineering applications, Styrofoam (EPS), and composite panel technologies. To focus on contemporary research, a publication date filter was applied, limiting the results to studies published between 2021 and 2025, which reduced the number of records to 30 studies. Subsequently, filters for open-access publications and full-text availability were applied to ensure accessibility and facilitate comprehensive review, resulting in 22 records. The application of the identifier type filter did not remove any additional studies, and therefore the total remained at 22 records.

The remaining studies underwent title, abstract, and full-text screening based on the predefined inclusion and exclusion criteria established through the PICOC framework and research question. During this stage, studies that were not directly related to lightweight composite panels as alternative building materials, focused on non-construction applications, or lacked relevance to sustainability, performance, construction applications, or adoption challenges were excluded. Following the eligibility assessment and quality evaluation process, 17 studies were retained for the final qualitative synthesis. These studies demonstrated sufficient methodological quality and direct relevance to the objectives of the review, providing the evidence base for analyzing the sustainability, performance characteristics, construction applications, and implementation challenges of lightweight composite panels as alternative building materials.

Formulation of Research Question

The formulation of this research question was guided by the growing interest in lightweight composite panels as sustainable alternatives to conventional building materials and the increasing body of literature examining their development and application in the construction industry. While numerous studies have highlighted the environmental, structural, thermal, and acoustic benefits of lightweight composite panels, evidence also suggests the existence of various factors that may hinder their widespread adoption. These factors include technical limitations, performance concerns, economic constraints, regulatory requirements, manufacturing challenges, and issues related to market acceptance. Understanding these challenges is essential for evaluating the practical viability of lightweight composite panels and identifying areas that require further research and development.

To address this aspect, the review formulated the following research question: “What challenges, limitations, and barriers to the adoption of lightweight composite panels as alternative building materials are reported in the literature?” This question aims to systematically identify and synthesize evidence regarding the obstacles encountered in the development, implementation, and commercialization of lightweight composite panels. By examining these issues across existing studies, the review seeks to provide a comprehensive understanding of the factors influencing adoption and to generate insights that may support future innovations, policy development, and wider acceptance of lightweight composite panels in sustainable construction practices.

To systematically investigate the challenges associated with lightweight composite panels as alternative building materials, the study addressed the following research question:

RQ1: What challenges, limitations, and barriers to the adoption of lightweight composite panels as alternative building materials are reported in the literature?

Table 1. PICOC Framework for RQ1

PICOC Element	Description
Population	Lightweight composite panels
Intervention	Application of lightweight composite panels as alternative building materials

Comparison	Conventional building materials (if discussed in the literature)
Outcomes	Sustainability benefits, performance characteristics, construction applications, challenges, and limitations
Context	Building construction and sustainable construction industry

Table 1 presents the PICOC (Population, Intervention, Comparison, Outcomes, and Context) framework used to guide the formulation of the research question and the development of the search strategy for this systematic literature review. The framework established the scope and analytical boundaries of the review by identifying lightweight composite panels as the primary population of interest. The intervention focused on the adoption and application of lightweight composite panels as alternative building materials in the construction industry. Where applicable, the comparison component considered conventional building materials, such as concrete, brick, steel, and traditional panel systems, to provide insights into the relative advantages and limitations of lightweight composite solutions.

The outcomes emphasized the challenges, limitations, and barriers associated with the adoption of lightweight composite panels, including technical performance concerns, durability issues, fire resistance, economic feasibility, manufacturing constraints, regulatory compliance, and market acceptance. The context of the review centered on the building construction sector, particularly within sustainable construction and green building initiatives where innovative materials are increasingly being explored to improve resource efficiency and environmental performance. Overall, the PICOC framework ensured that the literature search, study selection, and evidence synthesis remained focused on understanding the factors that influence the adoption of lightweight composite panels as viable alternatives to conventional building materials.

Search Strategy

To identify relevant studies addressing the research question, a systematic search strategy was developed using keywords associated with lightweight composite panels, alternative building materials, sustainability, performance characteristics, construction applications, and adoption challenges. The search strategy was designed to capture a broad range of studies investigating the development, evaluation, and implementation of lightweight composite panels within the construction industry. Keywords and their synonymous terms were derived from the research question and PICOC framework to ensure comprehensive coverage of the literature.

The following search string was used during the initial literature identification and screening process:

The search strings were constructed using Boolean operators (AND, OR) to maximize the retrieval of relevant studies while maintaining search precision. Terms related to lightweight composite panels were combined with keywords associated with sustainable construction, material performance, building applications, and implementation barriers. Searches were conducted across major academic databases to identify peer-reviewed journal articles, conference papers, and other relevant scholarly publications. This systematic approach ensured that the literature search remained comprehensive, transparent, and aligned with the objectives of the review, thereby supporting the identification of high-quality evidence related to the sustainability, performance, and construction applications of lightweight composite panels as alternative building materials.

The search string was designed to capture studies discussing lightweight composite panels and their application as alternative construction materials. The selected keywords focused on the engineering and construction domains, particularly research involving Styrofoam or expanded polystyrene (EPS)-based composite panels and related lightweight panel systems. The search strategy aimed to identify studies examining material development, sustainability, performance characteristics, insulation properties, structural behavior, and practical construction applications.

The use of Boolean operators and alternative terminology improved the comprehensiveness of the search strategy by accounting for variations in terminology used across the literature. The operator **OR** was employed to include synonymous terms such as "Styrofoam," "expanded polystyrene," and "EPS," as well as different panel classifications, while **AND** was used to combine the major concepts of lightweight composite panels, construction materials, and engineering applications. This approach ensured broader coverage of relevant studies while maintaining alignment with the objectives and research question of the review.

Inclusion and Exclusion Criteria

The inclusion criteria required studies to focus on lightweight composite panels as alternative building materials, particularly those addressing sustainability, performance characteristics, construction applications, and adoption challenges. Eligible studies were limited to peer-reviewed journal articles and conference proceedings published between 2021 and 2025. To ensure the quality and reliability of the evidence, only studies with accessible full texts, clear methodological descriptions, and relevant findings related to lightweight composite panel systems were included in the review. Studies investigating materials such as expanded polystyrene (EPS), Styrofoam, recycled plastics, natural fibers, wood composites, geopolymer composites, and other lightweight panel technologies used in building and construction applications were considered eligible.

Studies were excluded if they were unrelated to lightweight composite panels or their use as alternative building materials. Articles focusing solely on non-construction applications, lacking sufficient methodological detail, unavailable in full text, or not published within the specified time frame were also excluded. Additionally, studies that did not address sustainability, performance, construction applications, or challenges associated with lightweight composite panels were omitted from the review. The application of these inclusion and exclusion criteria ensured that the selected studies remained relevant to the research objectives and provided high-quality evidence for the systematic literature review.

Table 2. Eligibility Criteria

Criteria	**Inclusion Criteria**	**Exclusion Criteria**
Publication Type	Peer-reviewed journal articles and conference proceedings	Books, book chapters, theses, dissertations, editorials, review papers, and non-peer-reviewed publications
Publication Year	Studies published between 2022 and 2025	Studies published before 2021 or after 2025
Language	Articles published in English	Studies published before 2021 or after 2025
Accessibility	Full-text articles available for review	Studies without accessible full text
Research Focus	Studies addressing lightweight composite panels as alternative building materials	Studies unrelated to lightweight composite panels or alternative building materials
Material Scope	Lightweight composite panels incorporating materials such as Styrofoam (EPS), recycled plastics, natural fibers, wood composites, geopolymers, or similar lightweight composite systems	Lightweight composite panels incorporating materials such as Styrofoam (EPS), recycled plastics, natural fibers, wood composites, geopolymers, or similar lightweight composite systems
Outcomes	Studies discussing sustainability, performance characteristics, construction applications, challenges, limitations, or barriers to adoption	Studies that do not address sustainability, performance, construction applications, or adoption-related issues
Methodological Quality	Studies providing sufficient methodological detail and clear findings	Studies with insufficient methodological information or unclear results

The eligibility criteria were designed to be sufficiently broad to capture studies relevant to the research question while remaining focused enough to exclude literature lacking relevance to lightweight composite

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

panels as alternative building materials. The criteria enabled the inclusion of studies addressing various lightweight composite panel systems, material compositions, sustainability attributes, performance characteristics, construction applications, and adoption challenges. At the same time, they ensured that only studies directly related to the construction and building materials sector were retained for analysis.

The criteria also explain why certain studies were excluded from the review. Research focusing solely on conventional construction materials, non-construction applications of composite materials, packaging materials, automotive components, aerospace applications, or general recycling technologies without a direct connection to lightweight composite panels in building construction were not retained. This approach ensured that the final selection of studies remained aligned with the review objectives and provided relevant evidence concerning the sustainability, performance, construction applications, and implementation challenges of lightweight composite panels as alternative building materials.

Quality Assessment

The quality assessment process was conducted to evaluate the methodological quality, relevance, and reliability of the studies included in this systematic literature review. The assessment was guided by the Joanna Briggs Institute (JBI) Critical Appraisal framework and supported by the Preferred Reporting Items for Systematic Reviews (PRISMA 2020) guidelines. The JBI framework provided a structured approach for critically evaluating the quality and trustworthiness of the selected studies, while PRISMA 2020 ensured transparency and rigor throughout the study selection and reporting process.

To ensure the inclusion of high-quality evidence, each study was assessed against five predefined quality assessment criteria specifically adapted to the objectives of this review. The criteria focused on the relevance of the study to lightweight composite panels, methodological rigor, sustainability considerations, performance evaluation, and applicability to construction. Each criterion was scored as Yes (2), Partially (1), or No (0.5). The total quality score was calculated by summing the scores across all criteria, and only studies meeting the minimum quality threshold were included in the final synthesis.

Table 3. Quality Assessment Criteria

Code	Quality Assessment Question	Assessment Focus
QA1	Does the study address a clearly focused objective related to lightweight composite panels as alternative building materials?	Research Relevance
QA2	Does the study employ an appropriate and clearly described methodology for evaluating the composite material?	Methodological Rigor
QA3	Does the study provide reliable evidence on the sustainability aspects of the material, such as waste utilization, environmental benefits, recyclability, or resource efficiency?	Sustainability Assessment
QA4	Does the study adequately evaluate the performance of the composite material (e.g., thermal, acoustic, mechanical, structural, durability, or energy-efficiency properties)?	Performance Evaluation
QA5	Does the study present findings that are relevant and applicable to construction or building material applications?	Construction Applicability
QA6	Does the study provide clear and relevant evidence regarding the sustainability, performance, and construction applications of lightweight composite panels as alternative building materials?	Thermal Advantage; Mechanical Limitation.
QA7	Are the study methods, measurements, and reported findings sufficiently rigorous and detailed to support reliable and reproducible conclusions?	Verified Energy Savings
QA8	Are the study findings applicable or adaptable to local construction	Integrated

	practices, environmental conditions, and material availability?	Performance
QA9	Does the study comprehensively evaluate key outcomes relevant to lightweight composite panels, including sustainability, mechanical performance, thermal/acoustic properties, durability, and practical construction use?	Waste-Derived Composite
QA10	Do the reported environmental, technical, and functional benefits of the lightweight composite material outweigh its limitations, risks, and implementation costs?	Comparative Insulation Analysis

Each criterion was scored as Yes (2), Partially (1), or No (0.5). The total quality score for each study was calculated by summing the individual criterion scores. Studies with higher scores were considered to provide stronger evidence and were prioritized during data synthesis.

Table 4. Quality Assessment Results

Reviewer	**Number of Papers**	**Studies Above 57% Threshold**	**Percentage**
Reviewer 1	17	17	100%
Reviewer 2	17	17	100%
Reviewer 3	17	16	94.12%

The quality assessment indicated that the selected studies generally exhibited strong methodological quality and relevance to the review objectives. Following the application of the established quality assessment criteria, studies demonstrating insufficient methodological rigor and limited alignment with RQ1 were excluded. Consequently, 17 high-quality studies were retained for the final synthesis and analysis.

Data Synthesis

A qualitative thematic synthesis was employed to analyze the 17 studies included in this systematic literature review. Following quality assessment and reviewer consolidation, the selected studies were examined to identify recurring themes related to the sustainability, performance, and construction applications of lightweight composite panels as alternative building materials. The extracted data were organized according to the three research objectives: (1) sustainability characteristics and environmental benefits, (2) performance characteristics, and (3) construction applications and implementation potential.

The synthesis revealed three dominant thematic categories: sustainable material utilization and circular economy practices, performance enhancement through composite technologies, and practical construction applications of lightweight composite systems. Studies were compared based on material composition, experimental findings, reported benefits, and identified limitations.

RESULTS

The analysis of the 17 included studies revealed that lightweight composite materials offer significant sustainability benefits through the utilization of recycled, renewable, and waste-derived resources such as wood waste, polymer waste, sawdust, natural fibers, mycelium, and recycled plastics. These materials support circular economy principles by reducing construction waste, conserving natural resources, and minimizing environmental impacts. The reviewed literature consistently highlighted the potential of these alternative materials to contribute to more sustainable construction practices while addressing current environmental challenges in the building sector.

In terms of performance and construction applications, the studies demonstrated that lightweight composite materials generally exhibit favorable thermal, acoustic, and structural properties suitable for building applications. Structural insulated panels, geopolymer foams, timber-based composites, and insulation systems showed improved energy efficiency, reduced thermal conductivity, and adequate mechanical performance.

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Although some challenges related to durability, moisture resistance, and fire performance were identified, the overall findings indicate that lightweight composite panels are viable alternatives to conventional building materials and possess strong potential for widespread adoption in sustainable construction.

Table 5. Final Included Studies After Quality Assessment and Reviewer Consolidation

Study	Identified Challenge / Limitation	Key Findings	Implications for Adoption
Ramesh et al. (2022)	Limited standardization and processing variability	Performance depends on material composition and manufacturing methods	Need for standardized production and quality control
Maier (2023)	Limited large-scale implementation	Environmental benefits established but practical adoption remains limited	Requires industry acceptance and policy support
Szewczak & Łagód (2022)	Material durability concerns	Long-term adhesion performance remains a critical factor	Further durability validation needed
Vawa & Manga (2021)	Low public awareness and acceptance	Limited knowledge of EPS technology hinders adoption	Increased education and stakeholder engagement required
Šišková et al. (2021)	Recycling and processing complexity	Waste conversion technologies require specialized processes	May increase manufacturing costs
Łach et al. (2021)	Mechanical performance trade-offs	Improved insulation properties may affect structural performance	Optimization of material formulations needed
Naimušin & Januševičius (2023)	Limited field-scale validation	Acoustic performance demonstrated mainly in laboratory settings	Further real-world testing required
Thongcharoen et al. (2021)	Moisture absorption and fire resistance issues	Some panel configurations exhibited durability concerns	Additional treatment and material enhancement necessary
Marczyk et al. (2025)	Reduced mechanical strength with PCM addition	Thermal performance improved but structural performance decreased	Balance between insulation and strength required
Alwan et al. (2025)	Long-term durability uncertainty	Natural insulation materials require extended performance monitoring	Further lifecycle studies recommended
Lakot-Alemdağ et al. (2025)	Reduced structural capacity in hybrid panels	Thermal improvements may affect load-bearing performance	Design optimization required
Kohphaisansombat et al. (2024)	Early-stage technology development	Mycelium composites require further construction validation	Commercial readiness remains limited
Ulutaş et al. (2023)	Lack of performance standardization	Natural fiber insulation materials vary significantly in performance	Development of common standards recommended
Capricho et al. (2022)	Economic and recycling challenges	Upcycling technologies may face scalability limitations	Improved recycling infrastructure needed
Li et al. (2022)	Regulatory and	Sustainable composites require	Policy and code

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

	implementation barriers	broader industry integration	development necessary
Bojković et al. (2023)	Moisture and durability considerations	Biocomposite performance may vary under environmental exposure	Long-term durability testing required
Overall Evidence Base	Standardization, durability, scalability, and market acceptance	Multiple studies identified technical and implementation barriers	Continued research, standardization, and industry adoption efforts needed

The evidence presents the final set of studies included after quality assessment and reviewer consolidation. The results indicate that all 17 studies met the established inclusion criteria and were considered sufficiently relevant, methodologically sound, and aligned with the objectives of this systematic literature review. The included studies collectively provide substantial evidence regarding the sustainability, performance characteristics, and construction applications of lightweight composite materials. The diversity of methodologies, ranging from experimental investigations and field studies to systematic reviews and material assessments, contributed to a comprehensive understanding of lightweight composite panels as viable alternative building materials. Overall, the final evidence base demonstrates a growing research interest in sustainable composite technologies and supports their potential role in advancing environmentally responsible and resource-efficient construction practices.

RQ1: What challenges, limitations, and barriers to the adoption of lightweight composite panels as alternative building materials are reported in the literature?

The literature indicates that one of the major challenges in adopting lightweight composite panels is balancing lightweight characteristics with adequate structural and mechanical performance. While these materials offer advantages such as reduced dead loads, improved thermal insulation, and enhanced energy efficiency, several studies reported reductions in stiffness, strength, and load-bearing capacity compared with conventional building materials. For instance, polystyrene-integrated cross-laminated timber panels demonstrated improved thermal performance but reduced structural stiffness, while geopolymer foams exhibited excellent insulation properties at the expense of certain mechanical characteristics [12], [14], [16]. Similarly, durability concerns remain a significant barrier, particularly for bio-based and natural-fiber composites that may be susceptible to moisture absorption, weathering, biological degradation, and long-term performance uncertainties [10], [13], [15]. These limitations raise concerns regarding the suitability of lightweight composite panels for demanding structural applications and highlight the need for further material optimization and long-term performance evaluation.

Another major challenge identified in the literature relates to material variability, fire safety, and manufacturing constraints. Many lightweight composite panels are produced using recycled polymers, wood waste, agricultural residues, natural fibers, and other waste-derived materials to improve sustainability and support circular economy initiatives [5], [6], [7]. However, the properties of these raw materials often vary depending on their source, composition, and processing conditions, which can affect the consistency and reliability of the final products [5], [11]. Fire resistance also remains a critical concern because many polymer-based and bio-based composites contain combustible constituents that require additional fire-retardant treatments to comply with building safety requirements [12], [13]. Furthermore, recycling and upcycling processes often involve specialized technologies, material separation procedures, and quality control measures that can increase production complexity and costs, limiting large-scale commercialization [6], [7], [8].

The reviewed studies further reveal that limited industry awareness, insufficient regulatory support, and inadequate real-world validation continue to hinder the widespread adoption of lightweight composite panels. Stakeholders within the construction sector often lack familiarity with the performance characteristics, installation methods, and long-term benefits of innovative composite materials, resulting in resistance to their adoption despite demonstrated sustainability advantages [9]. Moreover, many emerging lightweight composite technologies are not yet fully incorporated into existing building codes, standards, and certification systems, creating uncertainty among architects, engineers, contractors, and regulatory authorities [1], [17]. Several authors also emphasize that most studies remain laboratory-based and recommend additional field applications, life-cycle assessments, and long-term monitoring to validate performance under actual service conditions [2], [10], [15]. Consequently, overcoming these technical, economic, regulatory, and social barriers is essential to facilitate the broader acceptance and implementation of lightweight composite panels as sustainable alternative building materials.

Table 6. Organizational Structure Themes and Outcomes

Study	**Identified Challenge / Limitation**	**Key Findings**	**Implications for Adoption**
Ramesh et al. (2022)	Limited standardization and processing variability	Performance depends on material composition and manufacturing methods	Need for standardized production and quality control
Maier (2023)	Limited large-scale implementation	Environmental benefits established but practical adoption remains limited	Requires industry acceptance and policy support
Szewczak & Łagód (2022)	Material durability concerns	Long-term adhesion performance remains a critical factor	Further durability validation needed
Vawa & Manga (2021)	Low public awareness and acceptance	Limited knowledge of EPS technology hinders adoption	Increased education and stakeholder engagement required
Šišková et al. (2021)	Recycling and processing complexity	Waste conversion technologies require specialized processes	May increase manufacturing costs
Łach et al. (2021)	Mechanical performance trade-offs	Improved insulation properties may affect structural performance	Optimization of material formulations needed
Naimušin & Januševičius (2023)	Limited field-scale validation	Acoustic performance demonstrated mainly in laboratory settings	Further real-world testing required
Thongcharoen et al. (2021)	Moisture absorption and fire resistance issues	Some panel configurations exhibited durability concerns	Additional treatment and material enhancement necessary
Marczyk et al. (2025)	Reduced mechanical strength with PCM addition	Thermal performance improved but structural performance decreased	Balance between insulation and strength required
Alwan et al. (2025)	Long-term durability uncertainty	Natural insulation materials require extended performance monitoring	Further lifecycle studies recommended
Lakot-Alemdağ et al. (2025)	Reduced structural capacity in hybrid panels	Thermal improvements may affect load-bearing performance	Design optimization required
Kohphaisansombat et al. (2024)	Early-stage technology development	Mycelium composites require further construction validation	Commercial readiness remains limited
Ulutaş et al. (2023)	Lack of performance standardization	Natural fiber insulation materials vary significantly in performance	Development of common standards recommended
Capricho et al. (2022)	Economic and recycling challenges	Upcycling technologies may face scalability limitations	Improved recycling infrastructure needed
Li et al. (2022)	Regulatory and implementation barriers	Sustainable composites require broader industry integration	Policy and code development necessary

ISSN No. 2321-2705 | DOI: 10.51244/IJRSI |Volume XIII Issue VI June 2026

Bojković et al. (2023)	Moisture and durability considerations	Biocomposite performance may vary under environmental exposure	Long-term durability testing required
Overall Evidence Base	Standardization, durability, scalability, and market acceptance	Multiple studies identified technical and implementation barriers	Continued research, standardization, and industry adoption efforts needed

The findings demonstrate that lightweight composite materials derived from recycled, renewable, and waste-based resources have considerable potential as sustainable alternatives to conventional building materials. The reviewed studies consistently reported improvements in thermal insulation, acoustic performance, energy efficiency, and structural functionality while contributing to waste reduction and resource conservation. Applications such as structural insulated panels, geopolymer foams, timber-composite systems, natural-fiber insulation, and recycled polymer composites highlight the versatility and growing relevance of these materials in sustainable construction.

Despite these advantages, several barriers continue to hinder the widespread adoption of lightweight composite panels. Common challenges identified in the literature include durability concerns, moisture susceptibility, fire resistance limitations, manufacturing variability, production costs, limited large-scale implementation, and the absence of standardized design and testing procedures. Regulatory uncertainties and market acceptance issues further constrain their adoption. Nevertheless, ongoing advancements in sustainable materials engineering, recycling technologies, and performance optimization are progressively addressing these limitations, strengthening the feasibility of lightweight composite panels for future energy-efficient and environmentally responsible building applications.

Table 7. Socio-Technical Factors Influencing Collaboration and Coordination

Study Group	**Socio-Technical Focus**	**Key Findings**	**Adoption Impact**
Sustainable Composite Materials [1], [17]	Sustainability and resource efficiency	Composite materials support environmentally responsible construction.	Encourages sustainable building practices.
Natural Fiber and Bio-Based Composites [2], [10], [15]	Renewable and waste-based materials	Natural fibers, mycelium, and sawdust provide effective insulation and sustainability benefits.	Promotes low-carbon and renewable construction materials.
Wood-Based and Structural Composite Panels [4], [5], [13], [16]	Structural performance and building applications	Composite panels demonstrate acceptable mechanical and thermal performance.	Supports practical use in building systems and envelopes.
Recycled Polymer and Waste-Derived Composites [6], [7], [8], [9]	Waste utilization and circular economy	Recycled plastics and polymers improve sustainability and functional performance.	Reduces waste while creating alternative building materials.
Thermal and Energy-Efficient Materials [11], [12], [14]	Thermal insulation and energy efficiency	Geopolymer foams and biocomposites enhance insulation and reduce energy consumption.	Improves building energy performance.
Material Performance Enhancement [3]	Bonding and durability	Improved adhesion and material performance support construction applications.	Increases reliability and serviceability of composite systems.

The literature demonstrates that socio-technical factors significantly influence the adoption of lightweight composite panels. Technical considerations, including performance, durability, and sustainability, must be complemented by effective collaboration among researchers, manufacturers, policymakers, and industry practitioners. Furthermore, regulatory support, knowledge sharing, and stakeholder acceptance are critical in facilitating coordination and accelerating the integration of lightweight composite panels into mainstream construction practices.

DISCUSSION

The review of the selected studies demonstrates that the successful development and implementation of lightweight composite panels are influenced by a combination of technical performance requirements and socio-technical factors that shape collaboration among stakeholders. From a technical perspective, the studies consistently highlighted the importance of achieving adequate thermal insulation, acoustic performance, structural integrity, durability, and energy efficiency while incorporating sustainable materials such as recycled polymers, wood waste, natural fibers, and bio-based resources [4], [5], [10], [11], [13], [16]. These findings suggest that lightweight composite panels have considerable potential to contribute to sustainable construction by reducing environmental impacts and improving building performance. However, the effectiveness of these materials depends not only on technological advancements but also on the ability of researchers, manufacturers, designers, and construction professionals to coordinate their efforts throughout the material development and implementation process.

The synthesis of the literature further reveals that collaboration and coordination are essential for addressing the challenges associated with material standardization, quality control, and large-scale adoption. Studies involving recycled polymers, waste-derived composites, and natural-fiber materials emphasized the need for integrated supply chains and consistent manufacturing processes to ensure reliable material performance [6], [7], [8]. At the same time, several authors identified limited stakeholder awareness, insufficient technical knowledge, and the absence of comprehensive design standards as significant barriers to adoption [1], [9], [17]. These findings indicate that effective communication and knowledge sharing among academic institutions, industry practitioners, regulatory agencies, and policymakers are critical to facilitating technology transfer and supporting industry confidence in emerging composite technologies. Without such coordination, innovative materials may struggle to move beyond laboratory-scale research despite their demonstrated technical and environmental benefits.

Overall, the findings suggest that the adoption of lightweight composite panels should be viewed as a socio-technical process in which technological innovation and stakeholder collaboration are equally important. While advances in material engineering continue to improve the sustainability and performance of composite panels, their successful integration into mainstream construction depends on coordinated efforts to establish standards, promote awareness, validate long-term performance, and strengthen industry acceptance. Consequently, enhancing collaboration among researchers, manufacturers, designers, contractors, and regulatory bodies is essential for overcoming implementation barriers and maximizing the contribution of lightweight composite panels to sustainable and energy-efficient construction practices.

LIMITATIONS

This study is limited by its reliance on published literature that met the established inclusion and exclusion criteria. As a result, potentially relevant studies from conference proceedings, technical reports, industry publications, and non-English sources may not have been included in the review. Furthermore, the review focused specifically on the sustainability, performance, and construction applications of lightweight composite panels, which may have limited the discussion of other important aspects such as economic feasibility, lifecycle costs, policy considerations, and market adoption. Consequently, the findings should be interpreted within the defined scope of the study.

Another limitation relates to the diversity of the selected studies. Variations in material compositions, research methodologies, testing procedures, and performance evaluation criteria created challenges in directly comparing results across studies. In addition, most of the reviewed research was conducted under laboratory conditions, with relatively limited evidence on long-term field performance and large-scale construction applications. Therefore, while the findings provide valuable insights into the potential of lightweight composite panels as alternative building materials, further field-based investigations, lifecycle assessments, and real-world implementation studies are needed to validate their long-term performance and support wider industry adoption.

CONCLUSION

This systematic literature review examined lightweight composite panels as alternative building materials, focusing on their sustainability, performance, and construction applications. Following the PRISMA 2020 framework, a rigorous and transparent review process was conducted to identify, screen, assess, and synthesize relevant literature. The quality of the selected studies was evaluated using the Joanna Briggs Institute (JBI) Critical Appraisal framework, ensuring the inclusion of reliable and methodologically sound evidence. As a result, the review consolidated findings from 21 high-quality studies published between 2021 and 2025, providing a comprehensive understanding of the current state of lightweight composite panel research.

The findings demonstrate that lightweight composite panels derived from recycled, renewable, and waste-based resources offer significant potential as sustainable alternatives to conventional building materials. Across the reviewed studies, these materials consistently exhibited favorable thermal insulation, acoustic performance, energy efficiency, and structural functionality while contributing to waste reduction, resource conservation, and circular economy objectives. Applications such as wood-polymer composites, structural insulated panels, geopolymer foams, natural-fiber insulation systems, bio-based composites, and recycled polymer materials illustrate the versatility and adaptability of lightweight composite technologies within modern construction practices.

The review also identified several challenges and barriers that may affect broader adoption, including concerns related to durability, moisture resistance, fire performance, manufacturing variability, production costs, limited field validation, and the lack of standardized design guidelines and regulatory frameworks. Furthermore, stakeholder awareness, industry acceptance, and the integration of sustainable materials into existing construction practices remain important socio-technical considerations. These findings suggest that while lightweight composite panels have demonstrated promising technical and environmental performance, continued efforts are needed to address implementation challenges and support their transition from research and development to widespread construction applications.

Overall, the evidence indicates that lightweight composite panels represent a viable and increasingly important solution for sustainable and energy-efficient construction. Continued advancements in material engineering, recycling technologies, performance optimization, standardization, and interdisciplinary collaboration are expected to further enhance their practicality and acceptance within the construction industry. Future research should focus on long-term field performance, lifecycle assessments, large-scale implementation studies, and the development of standardized evaluation frameworks to strengthen the evidence base and facilitate the broader adoption of lightweight composite panels as alternative building materials.

REFERENCES

1. Y.-F. Li, W. Chen, and T.-W. Cheng, “The Sustainable Composite Materials in Civil and Architectural Engineering,” Sustainability, vol. 14, no. 4, p. 2134, 2022.
2. A. Ulutaş, F. Balo, and A. Topal, “Identifying the Most Efficient Natural Fibre for Common Commercial Building Insulation Materials with an Integrated PSI, MEREC, LOPCOW and MCRAT Model,” Polymers, vol. 15, no. 6, p. 1500, 2023.
3. A. Szewczak and G. Łagód, “Adhesion of Modified Epoxy Resin to a Concrete Surface,” Materials, vol. 15, no. 24, p. 8961, 2022.
4. M. Ramesh, L. Rajeshkumar, G. Sasikala, D. Balaji, A. Saravanakumar, V. Bhuvaneswari, and R. Bhoopathi, “A Critical Review on Wood-Based Polymer Composites: Processing, Properties, and Prospects,” Polymers, vol. 14, no. 3, p. 589, 2022.
5. D. Maier, “A Review of the Environmental Benefits of Using Wood Waste and Magnesium Oxychloride Cement as a Composite Building Material,” Materials, vol. 16, no. 5, p. 1944, 2023.

6. J. C. Capricho, K. Prasad, N. Hameed, M. Nikzad, and N. Salim, "Upcycling Polystyrene," Polymers, vol. 14, no. 22, p. 5010, 2022.
7. A. O. Šišková, P. Peer, A. E. Andicsová, I. Jordanov, and P. Rychter, "Circulatory Management of Polymer Waste: Recycling into Fine Fibers and Their Applications," Materials, vol. 14, no. 16, p. 4694, 2021.
8. A. Naimušin and T. Januševičius, "Development and Research of Recyclable Composite Metamaterial Structures Made of Plastic and Rubber Waste to Reduce Indoor Noise and Reverberation," Sustainability, vol. 15, no. 2, p. 1731, 2023.
9. J. Y. Vawa and P. M. Manga, "Assessment of Expanded Styrofoam and Polyurethane as Sustainable Building Materials; Mubi General Hospital Adamawa State, Nigeria," Journal of Art and Architecture Studies, vol. 10, no. 1, pp. 14–23, 2021.
10. C. Kohphaisansombat, Y. Jongpipitaporn, P. Laoratanakul, S. Tantipaibulvut, J. Euanorasetr, N. Rungjindamai, C. Chuaseeharonnachai, P. Kwantong, S. Somrithipol, and N. Boonyuen, "Fabrication of Mycelium (Oyster Mushroom)-Based Composites Derived from Spent Coffee Grounds with Pineapple Fibre Reinforcement," Mycology, vol. 15, no. 4, pp. 665–682, 2024.
11. J. Bojković, M. Marašević, N. Stojić, V. Bulatović, and B. Radičević, "Thermal and Sound Characterization of a New Biocomposite Material," Materials, vol. 16, no. 12, p. 4209, 2023.
12. M. Łach, K. Pławecka, A. Bąk, K. Lichocka, K. Korniejenko, A. Cheng, and W.-T. Lin, "Determination of the Influence of Hydraulic Additives on the Foaming Process and Stability of the Produced Geopolymer Foams," Materials, vol. 14, no. 17, p. 5090, 2021.
13. N. Thongcharoen, S. Khongtong, S. Srivaro, S. Wisadsatorn, T. Chub-Uppakarn, and P. Chaowana, "Development of Structural Insulated Panels Made from Wood-Composite Boards and Natural Rubber Foam," Polymers, vol. 13, no. 15, p. 2497, 2021.
14. J. Marczyk, A. Przybek, K. Setlak, P. Bazan, and M. Łach, "Energy-Efficient Insulating Geopolymer Foams with the Addition of Phase Change Materials," ACS Omega, vol. 10, pp. 2488–2500, 2025.
15. N. T. Alwan, A. L. Tarish, S. J. Yaqoob, M. Bajaj, and I. Zaitsev, "Enhancing Energy Efficiency in Buildings Using Sawdust-Based Insulation in Hot Arid Climates," Scientific Reports, vol. 15, 2025.
16. E. Lakot Alemdağ, O. İlhan, A. Akkan Çavdar, A. U. Birinci, H. Öztürk, A. Demir, C. Demirkır, A. C. Altunışık, E. D. Gezer, A. K. Karahasan, and E. Küçükbekir, "Evaluation of Structural and Thermal Performance of Polystyrene Integrated Cross Laminated Timber Panels," Scientific Reports, vol. 15, 2025.
17. Yeou-Fong Li, Walter Chen, and Ta-Wui Cheng (Eds.), The Sustainable Composite Materials in Civil and Architectural Engineering. Basel, Switzerland: MDPI, 2022.