Thai Environmental Engineering Journal Vol. 39 No. 3 (2025) : 31-41
www.eeat.or.th

An Innovative Method for Upcycling Leaf Waste from Green Areas in Bangkok's Government Agencies

**Aroon Akaravarothai[1], Napattchan Dansawad[2], Pattama Jitrabiab[1]
Jessadanan Wiangnon[3] and Ananya Popradit[1*]**

[1*]Valaya Alongkorn Rajabhat University under the Royal Patronage,
Prathum Thani Province 13180, Thailand
[2]Department of Mathematics, Faculty of Science, King Mongkut's University of Technology Thonburi, Bangkok 10140, Thailand
[3]Institute of Metropolitan Development, Navamindradhiraj University,
Bangkok 10300, Thailand
[*]E-mail : ananya.po@vru.ac.th

Article History; *Received: 7 October 2025, Accepted: 2 December 2025, Published: 24 December 2025*

Abstract

The rapid growth of urban green spaces in Bangkok's government agencies generates substantial amounts of organic leaf waste, which imposes significant financial burdens and environmental challenges when managed through conventional disposal methods. This study quantifies leaf waste generation in three government agencies and evaluates its potential valorization into composite panels as a sustainable alternative to plywood. Over a 30-day period, daily leaf waste generation ranged from 86.50 to 172.33 kg, highlighting a consistent biomass stream with high potential for reuse. Composite panels were fabricated by combining leaf waste with a urea-formaldehyde adhesive and a paraffin emulsion and then hot-pressed into 30 × 30 × 3 cm sheets. Mechanical testing revealed an average tensile strength of 0.063 MPa and a compressive strength of 5.45 MPa, values that are below the Thai Industrial Standard (TIS 966-2547) for Medium-Density Fiberboard (MDF) requirements for structural applications but are acceptable for lightweight, non-load bearing uses, such as interior decoration and furniture components. The findings underscore the dual benefits of this approach: reducing greenhouse gas emissions and landfill dependency while lowering waste management costs. By integrating circular economy principles, this research demonstrates the feasibility of upcycling leaf waste into innovative products, providing both environmental and socio-economic value.

Keywords : leaf waste; composite panel; organic waste management; material innovation

Introduction

Globally, the management of organic waste has become a pressing sustainability challenge. This issue is escalating due to rapid urbanization, population growth, and unsustainable consumption patterns. According to the United Nations Environment Programme (UNEP, 2021) [1], organic waste—including food scraps, yard trimmings, and agricultural residues—accounts for more than 40% of total municipal solid waste worldwide. When improperly managed, this waste contributes significantly to greenhouse gas emissions, leachate contamination, and land use burdens. These impacts undermine several United Nations Sustainable Development Goals (SDGs), especially SDG 11 (Sustainable Cities and Communities), SDG 12 (Responsible Consumption and Production), and SDG 13 (Climate Action) [2]. Recent scholarship emphasizes that organic waste should no longer be viewed merely as a disposal problem. Instead, it is a valuable resource that can be transformed into energy, compost, or innovative biomaterials [3, 4]. This paradigm shift aligns with the principles of the circular economy, which seeks to extend material lifecycles, minimize environmental impact, and foster socio-economic benefits through waste valorization [5].

The global environmental situation is deteriorating with increasing severity, particularly the problem of solid waste, the volume of which is escalating due to consumption, especially in large urban areas. According to the Pollution Control Department (2023) [6], Thailand generated 28.71 million tons of municipal solid waste nationwide. Of this amount, 9.81 million tons (34.20%) were properly disposed of, 12.52 million tons (46.60%) were recycled or utilized, and a significant 6.38 million tons (22.20%) were improperly managed. In Bangkok alone, 4.95 million tons of waste were generated, with 1.10 million tons utilized and 3.85 million tons properly disposed of. Although no data on improper disposal in Bangkok was specified, a portion of the properly disposed waste could potentially be upcycled [7].

The operation to achieve the nation's solid waste management goals effectively according to international standards is mentioned in item 18 of the master plan under the National Strategy, 2018–2037 [8] emphasizes the need to achieve efficient waste management goals aligned with international standards. This requires focusing on waste reduction at the source. It calls for campaigns and awareness-building among the public and all relevant sectors, including households, educational institutions, businesses, and government offices. The plan also supports the use of environmentally friendly goods and services. It promotes the separation and recycling of waste and encourages the design of long-lasting, reusable products. This aligns with the principles of a circular economy, which seeks to resolve waste issues by adding value to discarded materials [9].

Government agencies are numerous and widespread throughout Bangkok. These agencies provide various public services and facilitate visitors, and nearly all maintain landscaped gardens and green spaces to create a pleasant and aesthetically pleasing environment [7]. However, managing these extensive green areas incurs significant annual expenses. These costs include landscape maintenance, monthly decorations, and the disposal of specific waste types, such as leaves, branches, and grass clippings. The daily accumulation of this waste presents a major disposal challenge, as municipal services often do not collect this type of waste, necessitating special private hauling services at a considerable budgetary expense.

This study specifically explores the management of leaf waste generated in the green areas of government agencies in Bangkok, addressing the practical challenges of collection, processing, and utilization. Three agencies with landscaped areas of at least 1 rai (1,600 m²) were selected as study sites. The research focuses on developing an innovative panel material by using leaf waste as a substitute for plywood and evaluating its properties in accordance with the Thai Industrial Standard for medium-density fiberboard (TIS 966-2547 for MDF) [10] for panels thicker than 15 mm. The study is guided by two primary objectives: (1) to quantify the amount of organic leaf waste generated in the green areas of these government agencies, and (2) to produce and assess the quality of composite panels derived from the collected leaf waste. By integrating waste quantification with material development and performance testing, this research aims to provide a sustainable approach for valorizing leaf waste while addressing practical challenges in urban waste management.

Methodology

Phase 1: Quantifying Leaf Waste

Population and Sample: For this phase, the population consisted of green areas at government agencies in Bangkok, each measuring at least 1 rai and maintained by staff or external contractors. Among 30 such agencies identified, a sample of three agencies volunteered to participate: (1) The Faculty of Science, Chulalongkorn University, (2) The Office of the Permanent Secretary, Ministry of Finance, and (3) The National Learning Museum.

Data Collection: At each of the three sites, leaves were collected and weighed daily for 30 consecutive days in May 2022 to measure the quantity of leaf waste. We collected leaf samples in May 2022 because this month represents the period with the lowest leaf-fall in the study area. By selecting a month with minimal leaf drop, we aimed to establish a baseline measurement of leaf waste, which allows for consistent comparison across sites. Collecting during months with higher leaf fall, such as in the autumn, could introduce variability that might obscure underlying patterns in leaf waste generation.

Phase 2: Production and Quality Testing of Composite Panels

Previous research has explored methods for producing plywood substitutes from natural waste materials, such as leaves, to add value and reduce waste volume. The general process involves collecting and cleaning the leaves, shredding them into small particles, and mixing them with a binder such as urea-formaldehyde adhesive before pressing. To avoid redundant experimentation, this study adopted a formula from a similar study.

This approach is further supported by the fact that, although leaf waste and cattail fiber originate from different plant sources, both materials are fundamentally lignocellulosic fibers, composed primarily of cellulose, hemicellulose, and lignin [11-13]. The presence of these polymers provides structural rigidity and binding potential, which are essential properties for fiberboard production. Despite differences in chemical composition ratios and particle morphology, the shared lignocellulosic nature of the two materials indicates that production methods and adhesive systems optimized for cattail fiber can be transferred, with minor adjustments, to leaf waste. Therefore, adopting the existing formula from the cattail fiber study is justified, providing a practical and scientifically supported starting point while maintaining material performance.

1. **Materials and Equipment**

Materials: Leaf waste from the sample sites, urea-formaldehyde adhesive, and paraffin emulsion.

Equipment: A material shredder, a Master Model 24N hot press, forming molds, a digital precision scale, a Universal Testing Machine (UTM) for tensile and compressive strength, and a moisture tester.

2. **Production Formula** The production ratio was based on the optimal formula identified by Phonieum (2016) [14] for producing composite panels from cattail plants. The optimal cattail particle board formulation was determined to be a ratio of 50 (Cattail): 75 (Urea formaldehyde): 10 (Paraffin emulsion) (10:15:2). This formulation yielded excellent physical properties, including a Modulus of Rupture (MOR) of 15 MPa, a Tensile Strength of 5.75 MPa, and a Moisture Content of 4.97%. Crucially, these measured properties were found to be in accordance with the requirements stipulated by the Thai Industrial Standard for Flat-Pressed Particle Boards. Consequently, the produced particle board is deemed highly suitable for various craft-making applications.

The ratio of materials is shown in **Table 1**.

3. **Production Process**

3.1 Selected leaf waste was sun-dried, ground in a semi-fine shredder, and then dried again before being formed (**Figure 1**). In a mixing container, 100 g of dried, ground leaf waste was combined with 150 g urea-formaldehyde adhesive and 20 g paraffin emulsion.

3.2 The mixture was poured into a 30 x 30 cm square mold at a thickness of 3 cm. The material was spread evenly, covered, and placed in a hot press at 120°C for 3 minutes. After pressing, the sheet was moved to a cooling rack for 3 minutes.

3.3 The finished composite panel was demolded and conditioned at room temperature for one week before testing.

Table 1 Material Ratio for Composite Panel Production

Component	Ratio	Experimental Quantity (g)
Leaf Waste	10	100
Urea-Formaldehyde Adhesive	15	150
Paraffin Emulsion	2	20

Figure 1 Preparation of leaf waste: leaves were sun-dried, ground using a semi-fine shredder, and dried again prior to forming

4. Physical Property Testing The physical properties of the composite panels were tested and compared against the TIS 966-2547 standard. Two key properties were evaluated:

a. Tensile Strength: This test measures the panel's ability to resist being pulled apart. Samples were cut to a standard size of 10 x 10 x 3 cm. Each sample was secured in the grips of a Universal Testing Machine (UTM). The samples were subjected to a standardized pulling force until failure. The maximum force before the sample broke was recorded. The tensile strength (σ) of a material represents its ability to resist deformation and failure under a pulling force. It is calculated using the following formula [15]:

$$\sigma = \frac{F_{\max}}{A}$$

Where:

σ = Tensile strength (MPa)
$F_{\max}$ = Maximum load applied to the specimen before failure (N)
A = Cross-sectional area of the specimen (mm²)

b. Compressive Strength: This test measures the panel's ability to withstand a crushing force. Samples were cut to a standard size of 5 cm × 5 cm × 5 cm. Each sample was placed in the UTM and subjected to an increasing compressive force until it deformed permanently or fractured. The maximum force the sample could withstand was recorded. The compressive strength (σ_c) of a material indicates its ability to withstand axial compressive forces without failure. It is calculated using the following formula [16]:

$$\sigma_c = \frac{F_{\max}}{A}$$

Where:

σ_c = Compressive strength (MPa)
$F_{\max}$ = Maximum load applied to the specimen before failure (N)
A = Cross-sectional area of the specimen (mm²)

Results and Discussion

Quantity of Organic Leaf Waste study

The study quantified leaf waste generation in the green areas of three selected government agencies in Bangkok. The results are summarized in **Table 2**.

Table 2 The amount of leaf waste in the sample areas

Agency	Area (rai)	Total Volume (kg/30 days)	Average (kg/day)	Transportation Cost (THB/month)
Faculty of Science, Chula.	9.18	2,750	88.71	3,000.00
The Office of the Permanent Secretary, Ministry of Finance	44.00	5,170	172.33	4,500.00
National Learning Museum	7.00	2,595	86.50	3,000.00

The results indicate that the three agencies—Faculty of Science, Chulalongkorn University; the Office of the Permanent Secretary, Ministry of Finance; and the National Learning Museum—generated differing amounts of leaf waste from their landscaped areas, averaging between 86.5 kg and 172.33 kg per day. This highlights a substantial and consistent source of organic waste with significant potential for valorization.

Transforming leaf waste into value-added products, such as composite panels, can address multiple challenges. First, it contributes to greenhouse gas mitigation by reducing methane emissions from landfill disposal, a major source of anthropogenic emissions [17]. Second, it offers cost-saving opportunities by lowering expenditures associated with waste collection and transportation, particularly in locations generating large volumes of leaf waste [3].

Moreover, the development of leaf-waste-based products aligns with circular economy principles, providing a sustainable pathway for resource recovery while adding economic value to organic residues. Advanced processing technologies, including biochemical or thermochemical conversion, can further enhance the quality and durability of these products, increasing their industrial applicability [18].

In conclusion, the significant volume of leaf waste from urban green areas presents a promising feedstock for sustainable product development. Utilizing this resource can simultaneously mitigate environmental impacts, reduce operational costs, and support circular economy strategies in urban waste management.

Composite panels from the leaf waste production

The production process successfully yielded 30 x 30 x 3 cm composite panels from the collected leaf waste (**Figure 2**).

Figure 2 Composite panels from the leaf waste

The Physical property tests of Composite panels from the leaf waste

Tensile Strength

Three samples of the composite panels (CP1, CP2, CP3) were tested. The results were 0.068 MPa, 0.080 MPa, and 0.038 MPa, respectively, yielding an average tensile strength of 0.063 MPa. When compared to the Thai Industrial Standard (TIS 966-2547) for Medium-Density Fiberboard (MDF) (thickness > 15 mm), which requires a minimum tensile strength of 0.5 MPa, the leaf-waste panels were significantly below the standard (**Figure 3** and **Table 3**).

The tensile strength of three composite panels (CP1, CP2, CP3) from leaf-waste was evaluated, and the results are summarized in Table 3. The measured tensile strengths were 0.070, 0.080, and 0.040 MPa, respectively, yielding an average tensile strength of 0.063 MPa. Compared to the Thai Industrial Standard (TIS 966-2547) for Medium-Density Fiberboard (MDF) with a thickness greater than 15 mm, which requires a minimum tensile strength of 0.5 MPa, the leaf-waste panels exhibited considerably lower mechanical performance. At the same ratio, when compared with the study of Phonieum (2016), which used *Typha angustifolia* (Cattail) as raw material, it was found that the fiberboard made from cattail had a tensile strength of 5.75 MPa. In contrast, the leaf-waste fiberboard showed an average tensile strength of only 0.063 MPa, which is considerably lower than that of the cattail board.

This significant deviation from the standard highlights the inherent limitation of using untreated leaf waste as a primary material for structural panels, likely due to the low fiber cohesion and insufficient binding strength. Previous studies have shown similar trends when using agricultural residues or natural fibers in composite panels, highlighting the need for chemical or physical modifications to enhance tensile performance [19, 20]. These modifications may include the use of stronger adhesives, fiber pre-treatment, or hybridization with higher-strength fibers to improve the load-bearing capacity of the panels.

Figure 3 Tensile strength measurements of composite panels from the leaf waste.

Table 3 Mean Tensile Strength Values of Leaf-Waste Composite Panels from Triplicate Tests

Three samples of leaf-waste panels	Tensile strength (MPa)
CP1	0.070
CP2	0.080
CP3	0.040
Average	0.063
Standard	0.500

Note: Units are in megapascals (MPa). FS refers to the standard value for medium-density fiberboard panels with a thickness greater than 15 mm, according to TIS 966-2547.

Implications: While leaf-waste panels may not meet structural standards for MDF, they still hold potential for non-structural applications, value-added products, or as eco-friendly alternatives in furniture and decorative panels, aligning with the principles of the circular economy and sustainable waste management [3, 17].

Compressive Strength:

Three samples (CP1, CP2, CP3) were tested (**Figure 4**).

The compressive strength of the composite panels fabricated from leaf waste was assessed through standard testing procedures. The results are as **Table 4**.

The compressive strength values obtained for the leaf waste composite panels, ranging from 4.96 MPa to 6.36 MPa with an average of 5.45 MPa, are lower than those of conventional construction materials; however, they still demonstrate potential for specific applications. For instance, the compressive strength of concrete typically ranges from 17 MPa to 70 Mpa [21], while fiber-reinforced composites often exhibit compressive strengths around 20 Mpa [22]. Although the values of leaf waste composites are comparatively lower, their performance suggests promising potential for lightweight, non-structural applications in sustainable construction. At the same ratio, when compared with the study of Phonieum (2016), which used *Typha angustifolia* (Cattail) as raw material, it was found that the fiberboard made from Cattail had a compressive strength of 15 MPa, while the leaf-waste fiberboard showed an average compressive strength of only 5.45 MPa, which is much lower than that of the cattail board.

Figure 4 Compressive Strength test of composite panels from the leaf waste

Table 4 Mean Compressive Strength Values of Leaf-Waste Composite Panels from Triplicate Tests

Sample	Compressive Strength (N)	Compressive Strength (MPa)
CP1	12,600.00	5.04
CP2	15,600.00	6.36
CP3	12,400.00	4.96
Average	**13,533.33**	**5.45**

Note: The compressive strength values are calculated by dividing the maximum load (in Newtons) by the cross-sectional area (in square millimeters) of each sample.

Besides mechanical performance, using leaf waste in composites offers environmental benefits by reducing waste and diverting organic matter from landfills, thereby reducing greenhouse gas emissions, such as methane [23]. Valorizing this biomass also supports the circular economy and sustainable waste management.

From an economic perspective, producing such composite panels can lower waste management costs and reduce dependence on virgin raw materials. By incorporating locally available leaf waste, transportation and procurement expenses are minimized, resulting in more cost-effective and environmentally sustainable production of building materials [24]. Although the leaf-waste panels did not satisfy industrial requirements for structural (load-bearing) applications, their current composition, manufacturing form, and measured mechanical behaviour indicate clear suitability for non-load-bearing uses, such as interior decoration, wall cladding (coverings fixed to walls), partitioning (dividing interior spaces), and certain furniture components. Evidence from recent literature shows that biomass-derived panels and natural-fiber composites (materials made from plant fibers and resins) have been successfully applied in lightweight interior panels and decorative elements when mechanical demands are moderate and surface treatment or lamination (applying a protective or decorative layer) is applied [25, 26]. Such applications capitalize on the low density (light weight), thermal, and acoustic (Sound-insulating) benefits, as well as the lower embodied carbon (total greenhouse gases emitted during production), of biomass panels compared with many conventional materials [27].

To improve applicability and marketability for interior, non-structural roles, several development pathways are recommended. First, mechanical reinforcement and hybridization, blending leaf fiber with higher-strength fibers or wood particles, or incorporating particulate reinforcements, have been shown to increase stiffness and compressive/tensile performance without excessively increasing density [28, 29]. Hybrid panel formulations and optimized particle size distributions can substantially reduce thickness swelling and improve modulus of rupture. Second, adhesive chemistry and pre-treatments (e.g., fiber surface modification, alkaline treatments, or coupling agents) can significantly enhance fiber matrix bonding and long-term durability, thereby raising tensile and bending strengths and improving moisture resistance [28]. Third, process and finishing improvements, including hot-press parameter optimization, the addition of suitable binders or thermoset/thermoplastic matrices, and the application of surface laminates or coatings, enhance surface aesthetics, abrasion resistance, and dimensional stability, rendering panels suitable for visible interior applications [25, 27].

Beyond technical performance, valorizing leaf waste into panels delivers notable environmental and economic co-benefits. Life-cycle and environmental assessments of upcycled panel products indicate reductions in landfill demand and associated methane emissions, lower embodied carbon relative to many conventional materials, and potential operational cost savings from reduced waste hauling and lower raw-material procurement needs, outcomes that strengthen the circular-economy case for on-site or municipal valorization programs [27]. For example, one life-cycle assessment (LCA) study of wood waste panels showed cradle-to-grave GHG emissions of approximately 321 kg CO_2 - eq per tonne of panel, compared to ~1,610 321 kg CO_2 - eq for conventional disposal routes (Al-Saadi et al., 2022). Another bio-based multilayer panel study reported a ~12% reduction in climate-change impacts compared to a fossil-based benchmark [29].

In summary, while further R&D is needed to enhance mechanical properties for structural use, current evidence supports a practical approach: utilizing leaf-waste panels initially in non-structural interior applications (such as decorative panels, partitions, and furniture), while pursuing improvements in reinforcement, finishing, and processes to broaden their use and acceptance. This staged strategy balances short-term environmental and economic benefits with ongoing performance advances [25, 28].

Conclusions and Recommendations

This study demonstrates that the substantial amount of leaf waste from government green areas in Bangkok represents an underutilized resource of great value. The tests showed that panels made from leaf waste are not yet strong enough for building structures, but they are firm and suitable for indoor uses, such as room dividers, wall coverings, and decorative furniture. Besides being useful, making these panels helps lower greenhouse gas emissions, reduces city waste costs, and aligns with Thailand's goals for improved waste management and the United Nations' Sustainable Development Goals. Future research should aim to enhance the material's strength and appearance by combining fibers, treating the leaves with chemicals, and refining the surface, as recent studies suggest these steps are highly beneficial. Turning leaf waste into panels presents a practical and creative approach to supporting the circular economy in cities, yielding positive outcomes for the environment, economy, and society.

References

[1] United Nations Environment Programme (UNEP). 2021. Annual Report 2021. Nairobi: UNEP. Available at: https://www.unep.org/resources/annual-report-2021

[2] Ram, M., & Bracci, E. 2024. Waste Management, Waste Indicators and the Relationship with Sustainable Development Goals (SDGs): A Systematic Literature Review. Sustainability, 16(19), 8486. https://doi.org/10.3390/su16198486

[3] Kaza, S., Yao, L. C., Bhada-Tata, P., & Van Woerden, F. 2018. What a Waste 2.0: A Global Snapshot of Solid Waste Management to 2050. https://doi.org/10.1596/978-1-4648-1329-0

[4] Zhang, Y., Hwarari, D., Yang, Y., Huo, A., Wang, J., & Yang, L. 2022. Biochar-Induced Mitigation Potential of Greenhouse Gas Emissions Was Enhanced under High Soil Nitrogen Availability in Intensively-Irrigated Vegetable Cropping Systems. Agronomy, 12(10), 2249. https://doi.org/10.3390/agronomy12102249

[5] Abubakar, I. R., Maniruzzaman, K. M., Dano, U. L., AlShihri, F. S., AlShammari, M. S., Ahmed, S. M. S., Al-Gehlani, W. A. G., & Alrawaf, T. I. 2022. Environmental Sustainability Impacts of Solid Waste Management Practices in the Global South. International Journal of Environmental Research and Public Health, 19(19), 12717. https://doi.org/10.3390/ijerph191912717

[6] Pollution Control Department. 2023. Thailand's POPs Inventory Assessment Report. Available online: https://www.pcd.go.th/wp-content/uploads/2023/05/pcdnew-2023-05-26_03-27-36_620650.pdf (accessed on 19 September 2025).

[7] Akaravarothai, A., Dansawad, N., Jitrabiab, P., Boruah, I., Chetia, R., & Popradit, A. 2025. Economic Value-Added Innovative Management of Leaf Waste in Green Areas of Government Agencies, Bangkok, Thailand. Sustainability, 17(18), 8511. https://doi.org/10.3390/su17188511

[8] Office of the National Economic and Social Development Council (NESDC). 2018. National Strategy 2018–2037. Available online: https://www.nesdc.go.th/en/ (accessed on 19 September 2025).

[9] Kirchherr, J.; Reike, D.; Hekkert, M. 2017. Conceptualizing the Circular Economy: An Analysis of 114 Definitions. Resources, Conservation & Recycling, 127, 221-232. https://doi.org/10.1016/j.resconrec.2017.09.005

[10] Thai Industrial Standards Institute. 2004. Thai Industrial Standard: Medium density fibreboards (MDF) (TIS 966-2547). Bangkok: Thai Industrial Standards Institute.

[11] Hafez RM, Abdel-Rahman TM, Yahia MM, El-Gabry KI, et al. 2024. Biochemical and cytological studies of Typha domingensis used for bioethanol production. SN Applied Sciences, 6:423. doi:10.1007/s13399-024-06229-2.

[12] Kishor K, Singh MK, Chakraborty S. 2024. Extraction and characterization of cattail fibre and lignin recovery from retting bath. Journal of Natural Fibres, 21(2): 451-465. doi:10.1016/j.jnf.2023.12.005.

[13] Scurlock JMO, et al. 2002. Leaf fibres: An overview. Industrial Crops and Products, 15(1): 3-22.

[14] Phonieum T. 2025. Production of Particle Board from Cattail and Application for Craft [Thesis]. Rajamangala University of Technology Thanyaburi; [cited 2025 May 10]. Available from: http://www.repository.rmutt.ac.th/dspace/handle/123456789/2956

[15] Alshgari, H. et al. 2022. Experimental Investigations on the Mechanical Characteristics of Natural Fiber Particle-Reinforced Polymer Composites under Cryogenic Environment. Journal of Nanomaterials, 2022, Article ID 1864169. https://doi.org/10.1155/2022/1864169

[16] Syapawi, A., Nasution, M., & Situmeang, S. Y. (2024). The Study of Compressive Strength of Wall Panels with a Mixture of Used Tire Rubber Waste and GRC. Proceedings of the 7th FIRST 2023 International Conference on Global Innovations (FIRST-ESCSI 2023), 186-195. https://doi.org/10.2991/978-94-6463-386-3_21

[17] Zhang, Y., & Zhang, T. 2022. Biowaste Valorization to Produce Advanced Carbon Material–Hydrochar for Potential Application of Cr(VI) and Cd(II) Adsorption in Wastewater: A Review. Water, 14(22), 3675. https://doi.org/10.3390/w14223675

[18] Zhang, Y., Li, H., & Wang, J. 2024. Advanced bioprocessing of urban organic waste for circular economy applications. Sustainability, 16(9), 3617. https://doi.org/10.3390/su16093617

[19] Ashori, A. 2008. Wood–plastic composites as promising green-composites for automotive industries. Bioresource Technology, 99(11), 4661-4667. https://doi.org/10.1016/j.biortech.2007.09.043

[20] Rowell, R. M. 2012. Handbook of Wood Chemistry and Wood Composites (2nd ed.). CRC Press. https://doi.org/10.1016/J.CARBPOL.2005.08.048

[21] Neville, A. M. (2011). Properties of Concrete (5th ed.). Pearson Education.

[22] Mohammed, L., Ansari, M. N. M., Pua, G., Jawaid, M., & Islam, M. S. 2015. A review on natural fiber reinforced polymer composite and its applications. International Journal of Polymer Science, 243947. https://doi.org/10.1155/2015/243947

[23] Pace, S. A., Yazdani, R., Kendall, A., Simmons, C. W., & VanderGheynst, J. S. 2018. Impact of organic waste composition on life cycle energy production, global warming and Water use for treatment by anaerobic digestion followed by composting. Resources, Conservation and Recycling, 137, 126-135. https://doi.org/10.1016/j.resconrec.2018.05.030

[24] Akpabio, U., Ede, A. N., Ivie, J., & Oyebisi, S. 2019. Catalysing a Construction Project Using Novel Software Technology. In IOP Conference Series: Materials Science and Engineering, Vol. 640, No. 1, p. 012039. IOP Publishing. https://doi.org/10.1088/1757-899X/640/1/012039

[25] Amarasinghe, I. T., Qian, Y., Gunawardena, T., Mendis, P., & Belleville, B. 2024. Composite Panels from Wood Waste: A Detailed Review of Processes, Standards, and Applications. Journal of Composites Science, 8(10), 417. https://doi.org/10.3390/jcs8100417

[26] Lisowski, P., & Glinicki, M. A. 2025. Promising biomass waste–derived insulation materials for application in construction and buildings. Biomass Conversion and Biorefinery, 15(1): 57-74. https://doi.org/10.1007/s13399-023-05192-8

[27] Meireles, I., Martín-Gamboa, M., Sousa, V., Kalthoum, A., & Dufour, J. 2024. Comparative environmental life cycle assessment of partition walls: Innovative prefabricated systems vs conventional

construction. Cleaner Environmental Systems, 12, 100179. https://doi.org/10.1016/j.cesys.2024.100179

[28] Khoaele, K. K., Gbadeyan, O. J., Chunilall, V., & Sithole, B. 2023. A review on waste wood reinforced polymer composites and their processing for construction materials. International Journal of Sustainable Engineering, 16(1): 104-116. https://doi.org/10.1080/19397038.2023.2214162

[29] Manickaraj, K., Thirumalaisamy, R., Palanisamy, S., Ayrilmis, N., Massoud, E. E. S., Palaniappan, M., & Sankar, S. L. 2025. Value-added utilization of agricultural wastes in biocomposite production: Characteristics and applications. Annals of the New York Academy of Sciences. https://doi.org/10.1111/nyas.15368

[29] Barrio, A., et al. (2021). Life Cycle Sustainability Assessment of a Novel Bio-Based Multi-layer Panel for Construction Applications. Resources, 10(10), 98. https://doi.org/10.3390/resources10100098