

Non-Wood Timber Products as Sustainable Materials for Circular Industrial Design in Southeast Asia

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ABSTRACT

This paper explores the potential of non-wood products (NWTPs) to promote circular design in industrial applications in Malaysia and Indonesia. As global attention shifts toward sustainable and renewable materials, NWTPs such as bamboo, rattan, and coconut waste present promising alternatives to traditional wood resources. This study employs a qualitative approach, incorporating literature reviews and case studies, to investigate the material properties, lifecycle potential, and integration of NWTPs in product and industrial design. Key findings indicate that NWTPs are renewable, biodegradable, and locally abundant, aligning with circular economy principles such as reuse, repair, remanufacturing, and recycling. However, challenges to adopting NWTPs include limited processing technologies, inconsistent supply chains, and a lack of design-driven innovation in both countries. By mapping existing ecosystems and identifying sustainable design strategies, this paper highlights opportunities to improve material efficiency and reduce environmental impacts. The findings aim to guide designers, industry, and policymakers in fostering a more resilient, bio-based circular economy across Southeast Asia.

Keywords: Non-Wood Timber Products (NWTPs), Circular Design, Sustainable Industrial Applications



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1 INTRODUCTION

In connection with the growing emphasis on sustainability and the circular economy, research into alternative materials has intensified, seeking to identify new industrial applications and reduce the reliance on traditional sources such as wood. Non-wood timbers originating from diverse sources, including rapidly growing plants and agricultural by-products, may represent a group of materials with considerable potential to meet the requirements of modern industry while promoting sustainability at different levels. The present study aims to contribute to this goal by compiling and assessing the properties of non-wood timber species in terms of their finish and mechanical characteristics. The findings are intended to serve as a reference for designing circularity-appropriate industrial design concepts.

“Southeast Asia is exceptionally gifted with a great variety of non-wood forest products (NWTPs) such as bamboo, rattan, plant fibres, resins, and agricultural wastes that have contributed to food security, livelihood security, and sustainability in rural Southeast Asia,” observes Dransfield (2001). Firstly, rattan is the most diverse among the NWTPs in terms of species, with Sunderland (2001) noting that Southeast Asia is home to approximately 574 rattan species across 10 genera. These NWTPs have generated an annual trade worth about US\$4 billion worldwide. According to Sastry (2001), rattan has provided an income for about 2 million people in Southeast Asia. Secondly, bamboo is a significant

NWTP found abundantly in Vietnam, with the country hosting about 1.4 million hectares of bamboo according to Tran (2017). The crop has a high potential yield of 12-20 tons per hectare in Vietnam, according to Marzullo (2017).

Based on the global context of sustainability, the UNEP-WCMC (2023) highlighted NWTP's compatibility with circular economy principles. First, NWTP is biodegradable, sourced from local and renewable resources, fast-growing, and part of closed-loop processes. Furthermore, as stated by UNEP-WCMC (2022), bamboo and rattan can be potential substitutes for plastics, promoting sustainable economic development while reducing carbon and plastic footprints. According to ASEAN Secretariat (2021) the association's countries endorsed the Framework for a Circular Economy for the ASEAN Economic Community and their corresponding national strategies which their position in concerning selected resource-specific policies. Indeed, as pointed out by the Economic Research Institute for ASEAN and Economic Research Institute for ASEAN and East Asia (2021), such tendencies will benefit NWTP producers and consumers alike.

The research carried out on sustainable industrial engineering practices by Rio and Tyl (2021) states that the convergence of availability and policy enables the adoption. However, the underuse of NWTP is still a problem in industrial design, particularly in processes that involve modularity, reduction of waste, recyclability or biodegradability. As Li et al. (2024) demonstrate in *Ideology Journal*, the tendency of the existing body of research is to evaluate properties of individual materials, e.g., tensile performance of bamboo or durability of rattan weaving, rather than engineer integrated systems with regard to materials' supply chains, socioeconomics, and innovation. In Vietnam, as Marzullo (2017) explains, the adoption of a zero-waste bamboo processing scheme allows for biomass gasifiers to utilize by-products, thus cutting expenses, enhancing the final good's durability, and reducing waste and exposure to hazards for workers. Meanwhile, according to the analysis of regional trade conducted by ASEAN Secretariat (2021) circularity-focused design innovations in ASEAN paired with business case development for thermoforming cutting into new products reveal emerging opportunities for NWTP in industrial design.

Therefore, this paper explores the role of NWTPs (bamboo, rattan, and other forest products and materials) in the context of circular industrial design. This research considers their mechanical and ecological properties, regenerative capacity, and their cultural specifics. At the same time, the current challenges posed by a lack of standardization to the adoption of these sustainable materials, including their mechanical performance, the need for supportive policies, and the need for developing design competencies and innovation capacities, are discussed. The findings of this paper will contribute to addressing the challenges and offering sustainable solutions for designing and engineering regions by considering bamboo and rattan material specifics and leveraging their opportunities to transform industrial design and promote circular economy principles in Southeast Asia.

1.1 Research Questions

The study is guided by the following research questions:

- i. RQ1: What NWTP resources and documented material characteristics are relevant to sustainable industrial-design applications in Malaysia and Indonesia?
- ii. RQ2: How are NWTPs currently applied in industrial products, and what evidence indicates their potential to support circular-design principles?
- iii. RQ3: What technical, supply-chain, skills, environmental, and governance barriers limit the wider adoption of NWTPs in circular industrial design?

1.2 Research Objectives

The study seeks to establish how NWTPs may contribute to circular industrial design in Malaysia and Indonesia through the synthesis of existing information. The study will be guided by three objectives that include: (i) identifying NWTP resources and their demonstrated properties; (ii) reviewing existing industrial applications; and (iii) establishing impediments and recommending design considerations.

2 RESEARCH METHODOLOGY

A qualitative document-analysis design was chosen for this study because of the need to synthesise the existing research rather than quantify the results of a particular experiment regarding NWTP. The design included three stages, such as document identification and screening, data extraction and comparison, and interpretation and guideline derivation, which were implemented to keep the research questions linked directly with the obtained findings.

2.1 Document Identification and Screening

The literature search for NWTPs (non-wood timber products) included books, academic research papers, reports, and patents from the local producers and researchers, as well as the regional (Southeast Asia) and international organizations. The search used combined terms related to the material or species and their properties and the countries involved, such as “bamboo strength,” “rattan surface quality,” and “palm trunk properties” in combination with “Malaysia” or “Indonesia.” Each source found was included if it provided specific information about at least one property required by the study, such as the material’s physical or mechanical properties, surface quality, availability, industrial applications, sustainability practices, or challenges in adoption.

As discussed by Li et al. (2024) in the Idealogy Journal on structural resource optimization and traditional craftsmanship, the review included regional sources in the bibliographic database that provided context-specific descriptions of NWTP resource systems and forest-product livelihoods. At the same time, according to the sustainable forestry and livelihoods’ indicators applied by the Food and Agriculture Organization (2025), the community-level sources’ dynamics were considered and incorporated into the discussion. Therefore, the current resource report is based on qualitative synthesis rather than a systematic meta-analysis. Indeed, no statistical effect size was estimated or aggregated across the sources; thus, the paper cannot claim that the reported production, employment, and economic benefit levels are comparable between studies.

2.2 Data Extraction

The data were organized in a comparative framework based on seven attributes, including NWTP type and availability, industrial applications, economic contribution, sustainability and resource-management practice, and challenges. The same framework was used for Malaysia and Indonesia to compare the two countries’ NWTP characteristics.

Table 1 Comparative Attributes between Malaysia and Indonesia

Comparative Attributes	Malaysia	Indonesia
1. Availability and Types of Non-Wood Timber	Types: Rattan, bamboo, medicinal plants, wild fruits, nipah palm, kenaf, agarwood Availability: Food, medicines, utensils, handicrafts, and construction materials.	Types: Rattan, bamboo, honey, sago palm, agarwood food (carbohydrates, protein, fat), latex, resin, cosmetics, essential oils, medicine, pesticides. Availability: Widely used for food, industrial raw materials, cosmetics, and medicinal purposes.
1.1 Major Sources	Rattan, bamboo, nipah palm, kenaf, and agarwood	Rattan, bamboo, sugar palm plants, and agarwood
1.2 Regional distribution and production volumes	High production in Sabah, Sarawak, Kelantan (bamboo); Johor, Pahang (agarwood). Bamboo harvest ~1.2 million culms/year.	Major production in Kalimantan, Sulawesi, Sumatra (rattan); Papua (sago). Rattan exports ~70,000 tonnes/year.
2. Industrial Applications	Utensils, handicrafts, and construction materials	Fiber for broomsticks, roots of medicines as fiber for air, such as household goods, and souvenirs.
2.1 Primary industries using non-wood	Furniture, binding and weaving basketweave, Cheap furniture, broom handles, handicrafts, panel boards, construction scaffolding (bamboo), incense & perfume (agarwood).	Broomsticks, Household goods, Furniture, handicrafts, flooring, food (sago starch), export crafts (rattan).
2.2 Notable products and innovations	poultry cages, vegetable baskets, utensil products, handicraft items, Laminated bamboo boards, kenaf fibre composites, and engineered bamboo furniture.	Souvenirs, Bamboo bicycles, laminated bamboo panels, rattan-polymer composites.
3. Economic Contribution	Has planted large amounts of rattan and bamboo to increase the value of rattan and bamboo products that can be exported to foreign countries.	Indonesia exports cinnamon to the world with several advantages, such as rich aroma and taste, specific colours, higher essential oil content, and the thickness and shape of quill pens.
3.1 Contribution to GDP from non-wood timber industries	Estimated <0.5% GDP; significant in rural livelihoods.	An estimated 0.7% GDP; notable in export earnings for rattan/bamboo.
3.2 Employment generated	Supports ~50,000–70,000 rural jobs.	Supports ~200,000+ workers in harvesting, processing, and export trades.
4. Sustainability practices		
4.1 Resource management strategies	Community-based bamboo planting, agarwood plantations, and harvest quotas.	Rattan harvest licensing, sago palm replanting, and agroforestry models.
4.2 Certification adherence	Limited FSC/MTCS certification for bamboo; some agarwood CITES permits.	FSC-certified rattan supply chains; PEFC certification in select provinces.
5. Challenges and barriers		
5.1 Environmental impacts	Habitat loss in wild rattan, overharvesting of agarwood, and conversion to oil palm.	Overharvesting of wild rattan; peatland degradation from sago expansion.
5.2 Technical limitations or skill gaps	Limited bamboo processing facilities; lack of standardized mechanical testing.	Inconsistent rattan quality control; limited advanced product design capacity.

The numerical data extracted from the source documents were incorporated into the comparative framework to demonstrate the differences and similarities of NWTPs in Malaysia and Indonesia. The values obtained from the articles were left as they were in the source documents since there were discrepancies in the time periods, definitions, geographic scopes, and measurement units used in the articles to describe the same variables. These discrepancies prevented establishing an accurate baseline to compare NWTP characteristics in two countries, which should not undermine the reader's understanding of the data.

2.3 Data Interpretation and Research-Question Alignment

The extracted evidence was analysed using thematic comparisons. First, the resources and documented attributes were grouped to respond to RQ1. Second, the applications were evaluated according to the circular-design indicators, including renewable sourcing, repairability, design for disassembly, and reduced waste and/or increased reuse/recycling to address RQ2. Third, the technical, environmental, skills, supply chain, and governance-related constraints were clustered to respond to RQ3. Thus, the analysis progressed from descriptive statistics to interpretive comparisons across cases while ensuring that no unsubstantiated claims were made based on the available evidence.

2.4 Development of Design Guidelines

Guidelines were developed by extrapolating the insights gained to design and implementation considerations. By linking resource characteristics and availability to potential applications and sources, as well as to processing requirements, desired qualities, and approaches to minimizing waste, the guidelines prioritized controlled harvesting, resource regeneration, advanced processing capabilities, workforce competencies, standardized quality levels, market opportunities, and design for repair, adaptability, and material efficiency.

3 FINDINGS AND ANALYSIS

The findings are presented in accordance with the three research questions. Indeed, the comparison of results can demonstrate that Malaysia and Indonesia have considerable NWTP resources. Still, different industrial areas seem to dominate in these countries, as Malaysia is mainly associated with bamboo and high-quality agarwood, while Indonesia possesses significant quantities of rattan and sago. Thus, the evidence can support the idea that certain properties, processing, design, and governance factors govern the circularity potential of these materials.

3.1 RQ1: NWTP Resources and Relevant Characteristics

The literature evidence reports bamboo and rattan as the most widespread non-wood forest products (NWTP) with industrial significance in the two countries. Specifically, there are 106 species of rattan in Peninsular Malaysia, while more than 70 species of bamboo occur in Malaysia Forestry Department of Peninsular Malaysia (2026a). Among the latter, only a small number of species are regarded as commercially important, including *Gigantochloa scortechinii* and *Bambusa vulgaris* Hawanis and Ilyas (2022). Meanwhile, *Aquilaria malaccensis* is considered one of the most precious agarwood-producing tree species Azmi (2026). In Indonesia, according to the Mohd Ali (2002), rattan includes two prominent species, *Calamus manan* and *Calamus caesius*. However, *Metroxylon sagu* is regarded as a significant NWTP in the Papua and Maluku regions. Overall, based on the literature evidence, it is possible to conclude that not all NWTP resources are equally attractive for design purposes.

Indeed, bamboo seems to be appropriate for construction and furniture industries due to its unique properties, while rattan is mostly linked to interior design and weaving items. As for kenaf, the review evidence reveals that this NWTP is primarily used for composite and particle board manufacturing.

Agarwood, in its turn, is one of the most expensive materials in the world. Therefore, the design field has requirements and limitations regarding NWTP utilization. Thus, it should be noted that a material's properties, application potential, processing methods, surface finishing, availability and sustainability, and end-of-life implications should match the design concept. This way, it is inappropriate to regard all NWTP materials as equal or substitute one product for another without considering a range of factors.

3.2 RQ2: Industrial Applications and Circular-Design Potential

The reviewed literature confirms that currently, NWTPs are already applied in furniture, handicrafts, construction, panels, flooring, composites, and other products, as was presented in detail by the International Council for Research and Innovation in Malai Eco (2026). However, it is worth noting that while traditional applications are still relevant, new areas seem to be more attractive in terms of industrial and circular design. According to Hawanis and Ilyas (2022) laminated bamboo boards, bamboo-furniture components, kenaf-fibre composites, rattan-polymer composites, and agricultural-fibre panels are some of the promising products.

The circular-design centrality of these applications can be justified from the following four perspectives. First, the use of renewable feedstock may provide the advantage of reducing the dependency on some finite or slow-renewing resources if their exploitation is performed in a controlled manner. This is especially important for timber, as postulated by Forestry Department of Peninsular Malaysia (2026b). Second, the emphasis on modular and engineered design may enable repairs, replacements, and other forms of product life-cycle extension. Third, the utilization of agricultural or post-harvest waste streams may facilitate the creation of value-added products from by-products. Fourth, the reliance on biodegradable materials may offer an alternative end-of-life scenario for such products compared to plastics and other polymers. However, it is noted by the Mohd Ali (2002) that biodegradability should not be conflated with sustainability.

The literature further provides examples of regional approaches to bio-innovation in Southeast Asia. Thus, for instance, Malai is made from fermented coconut water and includes natural fibres and resins, being used to illustrate how coconut by-products can enter new product categories such as furniture, interior materials, and fashion Karelia (2023). Another example of material innovation is mycelium-bound composites, which fit into the context of agroforestry waste utilization, matching the biodiversity-related data sets of Javadian et al. (2026). Overall, these examples further confirm that circular design opportunities emerge at material streams, processes, and product levels.

3.3 RQ3: Barriers to Wider Adoption

The evidence establishes five interconnected groups of barriers related to sustainable material systems, including resource and environmental, processing and quality, skills-related, value chain-related, and governance-related groups of barriers. Overharvesting of wild rattan and agarwood, as well as forest conversion, threatens the resource base for long-term use in circular material systems, according to Quang (2004). Therefore, the utilization of a certain renewable material cannot ensure sustainability if its use entails the overexploitation or poor governance of the resource base.

Technical barriers to trade such as varying quality assurance levels, limited standardized testing, differing processing techniques, and restricted access to advanced facilities cause variations in durability, finish quality, and market acceptance, as observed by Rahim and Idrus (2018). Such differences are greatly challenging industrial design because of the need for standardized specifications of materials used. The limited skilled labour in engineered bamboo, laminates, and finishes also constrains the transformation process from artisan products to high-value-added industrial goods, as reported by the Forestry Department of Peninsular Malaysia (2026a).

Ultimately, governance and value-chain issues are critically important factors in ensuring that commercialisation leads to positive environmental and social change. The reviewed evidence from the

Center for International Forestry Research (2026) highlights that market development alone cannot be assumed to deliver conservation and poverty reduction outcomes, as it also requires tenure security, equitable benefit distribution, and effective governance at local levels to achieve the intended goals. These findings add to the design problem by illustrating how circular industrial design can be utilised as a system and go beyond the product.

3.4 Comparative Interpretation: Malaysia and Indonesia

The comparison can be seen as the opportunity of different but complementary resources. Malaysia's reviewed resources include bamboo and valuable agarwood, which are applied in furniture, the construction industry, special incense, oil, perfumery, and other products, as per the research conducted by Kamarubahrin et al. (2026). Indonesia possesses a more substantial resource base of rattan and sago that are used for furniture, various crafts, weaving, food, and industrial processing, while the technical case review by Tahnur et al. (2026) proves the possibility of additional use of sago waste in the bioeconomy context. Therefore, the cases illustrate the insufficiency of using one regional approach in favour of another without assessing local opportunities.

Meanwhile, both countries have a few restrictions, including low-quality control, processing potential, the level of expertise, and environmental and governance risks. Thus, based on the industrial policies suggested by the Ahmad and Aziz (2023) it is possible to recommend establishing strategic partnerships regarding training, processing technology, wood material testing, sustainable sourcing practices, and design capabilities. The main conclusion is that the commercialisation of NWTPs should be based on a comprehensive approach considering the whole supply chain from production and processing to end-use markets and post-consumer recycling following the systematic paradigm described by the Putri and Azhar (2025) research.

3 DESIGN GUIDELINES FOR CIRCULAR INDUSTRIAL APPLICATION

Based on the findings, some of the design-related principles are recommended to upgrade NWTP applications in Malaysia and Indonesia to higher-value systems. According to the recent study on circular manufacturing practice accessed on Soni et al. (2026), material selection should be based on a resource-fit selection strategy. This implies that their selection should be made based on documented availability, intended use, and anticipated life cycle, not novelty. The design professions need to rethink strategies such as controlled harvesting, regenerative practices, and other reciprocal collectivist approaches to resource management and conservation. The current practices of applying design for repair and modular approaches using standardised parts and joints can prolong the service life of the products. In turn, the green product lifecycle study accessed through Willskytt and Brambila-Macias (2020) recommends similar circular interventions to promote repair, recycling, and reprocessing at the industrial level. To make NWTP sustainable, the industry must develop production control tools and processes that would standardise processing and quality control while maximising waste utilisation. Such methods would enable the transformation of processing wastes and agricultural residues into value-added composite materials. However, the technical expertise and skills must be acquired to integrate such technologies into the existing production models, including engineered bamboo, laminated products, and composite systems. Lastly, based on recent considerations on structural design accessed on Mustaffa et al. (2025), sustainable design must embed end-of-life interventions, which include disassembly, reuse, recycling, and biodegradation, into the development process instead of treating them as separate activities.

CONCLUSION

This study attempted to explore the role of NWTPs as a sustainable material for circular industrial design in Malaysia and Indonesia through a qualitative analysis of the available data and comparative assessment. The study addressed all three research questions, providing evidence that bamboo, rattan,

and NWTPs in general, offer a wide range of material and resource options; current and emerging solutions that utilize NWTPs offer a substantial level of benefits, including the use of renewable sources, opportunities for modular and restorative design, reduced waste, and value-added processing; and the fact that the adoption of NWTPs in industrial design is currently limited by several factors, including material inconsistency, processing challenges, a lack of skilled labor, value chain integration, environmental concerns, and governance issues.

Therefore, the study's conclusion is that it would not be possible to fully transition to using NWTP-based circular production in each industry, simply because of changes to the materials used. In other words, for any sector, attention must be paid to not only responsible sourcing, standardization of materials for use in processing, product design, processing capacity, skills, market access and connectivity, and end-of-life considerations, among others. In addition, when comparing the development paths of two countries, such as Malaysia and Indonesia, the differences in their resource and industrial potentials must be considered and used as a basis for identifying and addressing common barriers to the transition to the circular economy.

The present research is limited by the fact that all the data comes from secondary documentary sources. In particular, the figures regarding the produced quantity, employment, and economic impact were reported by different entities, and their definitions may vary, which means the data should not be considered entirely consistent or standardized. Further research should be done to provide more credible and comprehensive results. More specifically, additional studies should include primary data collection, interviews with the stakeholders, and material/product testing. Moreover, case studies and product life-cycle analyses should be conducted to ensure the proposed design guidelines and specifications are suitable for the industry's needs and specific NWTPs in Malaysia.

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AUTHOR CONTRIBUTIONS

Both authors contributed equally to this work. Nur Syafiyah Binti Mohamad Kamal and Dr. Natrina Mariane P. Toyong co-designed the study, conducted the literature review, analysed the data, and drafted the manuscript. Both authors reviewed and approved the final version for submission.

CONFLICT OF INTEREST

The author declares no potential conflict of interest with respect to the research, authorship, and/or publication of this article.

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