

Sustainable Materials in Malaysia: A Systematic Review on Academic Research and Application in Product Design Industry

Zati Hazira Ismail¹, Liew Yong Kian², Fadzli Irwan Bahrudin³, Nuraini Daud⁴
{zhismail@iau.edu.sa¹, zhazira2@utm.graduate.my¹, liewyongkian@mia.edu.my²,
fadzliirwan@iium.edu.my², n.daud15@imperial.ac.uk⁴}

Imam Abdulrahman bin Faisal, Dammam Saudi Arabia¹, Universiti Teknologi Malaysia, Kuala Lumpur, Malaysia¹, Malaysian Institute of Art Kuala Lumpur, Malaysia² Universiti Islam Antarabangsa, Kuala Lumpur Malaysia³, Imperial College London United Kingdom⁴

Abstract. A more circular economy is necessary to mitigate the current production and consumption system's environmental impacts. One prominent global strategy is to utilize alternative natural and recycled materials to close the loop of biological and technical resources. Such materials are often referred to as environmentally benign materials or sustainable materials. More than a quarter of the research and development expenditures since 2018 are spent implementing sustainable economic development in Malaysia. However, despite government supports for industries to focus on sustainability aspects in their business operations, the case for sustainable materials in product design development is less clear. An overview of the breadth of development and current status of sustainable materials development and commercialization remains unavailable. This paper presents a systematic review of academic articles and industrial applications of sustainable materials in Malaysia, using the Reporting Standards for Systematic Evidence Syntheses (ROSES) method. The review shows promising sustainable material exploration, and the overall development reflects an early transition to a circular economy. However, greater coordination and concerted efforts are needed as there is a significant gap between academic research and commercial product applications in terms of sustainable material types and product commercialization.

Keywords: Industrial Design, Sustainable Materials, Malaysian Industry, Systematic Review.

1 Introduction

The idea to optimize materials cycles has been around since the dawn of industrialization. It is an open secret that the linear manufacturing model dominates the overall industrial development, and it has caused irreversible environmental harm. As a solution, many policymakers and industry stakeholders currently adopt the Circular Economy concept to address the linear economy issues [1]. Principally, the regenerative approach of the Circular Economy is contrasting to the traditional “take, make, dispose of” production model [2]. A circular economy aims to eliminate waste and optimize the flow of resources [3]. The system promotes reuse, share, repair, refurbish, remanufacture and recycle to create a closed-loop of

resources. Notably, waste materials and energy are considered inputs for other processes: either a component or recovered resource for another production cycle or biological resources for nature. Besides, the circular economy keeps products, equipment, and materials in use for longer, extending their period of life. Hence, making the usage of the materials or resources more sustainable. The Oxford Dictionary defines “sustainable” as “conserving an ecological balance by avoiding depletion of natural resources”. Meanwhile, sustainable development is organizing principles that secure the needs of the present without jeopardizing the future [3], including protecting the environment. Currently, stakeholders in the product design field show a progressive effort to pursue sustainable development. Product developers and designers’ sustainability measures, including country enforcement, industry commitments, and green initiatives, are promising [4,5].

In optimizing resource flows, product developers and designers have developed and utilized sustainable materials in products. Sustainable material refers to “a practical substance that fulfils specific sustainability attributes” [6]. They can also be defined as materials that reduce hazards in an industrial process, safeguard public health and minimize environmental impact throughout their life cycles [7]. In engineering and design, sustainable material is often referred to as natural or recycled materials [8]. Commonly, material’s reusability and recycling potentials can indicate the sustainability dimension within this field [9].

Globally, the linear economy is no longer a sound approach in making products. Hence, the search for a new economic system has become necessary, and the circular economy is seen as the ideal alternative to secure a sustainable future. In Malaysia, proactive steps have been taken to pave the way to sustainable development. The country has adopted green technology in its industrial activities such as palm oil, mining and manufacturing [10]. Such initiative aims to establish sustainable growth, progressive innovation, prosperous citizens, and a full-fledged circular economy by 2050. The national survey for the country research and development report in 2019 stated that 25.5% of research and development expenditures in 2018 are spent towards sustainable economic development, and 13.1% spend on environmental research needs. Regarding sustainable materials, one of the visions highlighted by the Malaysian Ministry of Science Technology and Innovation (MOSTI) is leading the country towards free from non- biodegradable materials use.

However, despite the government’s great initiatives and supports for sustainability agenda in industrial operations, the case for sustainable materials in product design development is less clear. An overview of sustainable materials application and commercialization remains unavailable. It is vital to investigate these knowledge gaps to reflect the country’s progression to a circular economy. Through a systematic review of academic articles, this paper will answer the following question:

“What is the breadth and status of sustainable materials development in research activities and application in the product design industry in Malaysia?”

2 Materials and Sustainability

Sustainability is dependent on many factors in the context of materiality. Among the factors are the control of material reserve and consumption rate. Strategies for material sustainability include efficient design and engineering's such as 'lean manufacturing' and 'dematerialization'. Notably, the circular economy system shares a generic concept with 'cradle to cradle' [11]. The principal notion is that materials are considered flowing technical or biological nutrients. These nutrients are to be constantly utilized in the supply chain [12]. Technically, such strategies seek to move away from the linear consumption model to form a closed-loop production system. The following sections elaborate on sustainable materials, their significances in the circular economy, and sustainable materials exploration in Malaysia.

2.1 Sustainable Materials in Circular Economy

The circular economy concept is built on system thinking and aims to retain resources within an industrial system. When a product reaches the end of its useful life, the waste materials are extracted, processed and returned to the system for further use. The system relies on effective new business models, like take-back schemes, records of materials, and mass recycling to ensure optimum material flows.

Within the ambit of circular practice, various natural and waste materials have emerged in consumer product applications. For example, materials from natural substances are converted into everyday products. E.g. plant fibres are used as toothbrushes. Natural materials are well recognized for their technical properties. Their potential to substitute fossil-based plastics is well-known in product design. For instance, a study on pine-fibre composites indicated that their wear performance is better than glass-fibre reinforced composites [13].

In the science and engineering domain, 'sustainable materials' are prevalently used to describe alternative natural materials [14]. Commonly, the word 'sustainable' is used as the prefix to material types, such as 'sustainable polymers' or 'sustainable bio-composites' describing the resource origin and the end-of-life stage of the materials [15]. In addition, various other terminologies are used within the design domain, such as 'environment-conscious materials', 'materials with high sustainable potential' and 'eco-sensitive materials' [16,17]. All of these terms refer to either natural or recycled materials.

However, the application of sustainable materials in product design is also dependent on their perceived value, though their functional qualities are proven. Moreover, these materials are often visibly distinguishable from traditional materials and complemented with sustainable claims. Hence, the uptake of such new materials would depend on how users experience and accept them.

2.2 Sustainable Materials in Malaysia

Research on sustainable materials in Malaysia has predominantly focused on the study of natural fibres. Malaysia trade lignocellulosic fibres to be used in products and various applications [18]. The country produces natural fibre from abundant agricultural biomass materials of different plants and fruits such as oil palm, date palm, bamboo, rattan, coconut, kenaf, and pineapple [19–21]. Numerous research regarding sustainable materials

development in products and applications is focused on their performances—for instance, studies on structural properties, composite mixture, material strength, application durability, life-cycle assessment and potential use [22,23].

Another dominant theme in literature is the development of alternative materials to minimize reliance on high-priced natural resources. For example, woods have been the primary material for furniture in South East Asia. Thus, researchers in Malaysia explore bio composite materials made from natural fibres to be applied in the furniture industry [24]. The natural fibres investigated are plant fibres such as pineapple, banana and Lemba leaf [25,26].

Natural materials, however, has long been a typical material applied to traditional and craft products in Malaysia. Traditional products are mainly dependent on rich and diverse local natural resources [27–29]. The localization of resources is the essential sustainability factor for the material used. Local craftsmen and artisans take full advantage of using readily available natural raw materials from their surroundings. A vast selection of plant materials includes rattan, bamboo, bemban, palm leaves, pandan, coconut, screw-pines, seashells, fish skin, and animal bones used as household and everyday products.

3 Review Method

This study employs the Reporting Standards for Systematic Evidence Syntheses (ROSES) review protocol. ROSES was initially used as a systematic review method for the environmental management field [30]. ROSES aims to guide researchers to report information with an appropriate level of detail, and, recently, the method has also been applied in the industrial design field [31]. Following this review protocol, three searching strategies are employed. The first search strategy consists of the following three sub-processes: identifying, screening, and determining the eligibility criteria for exclusion and the inclusion of the articles to be reviewed. The second strategy is about the articles quality assessment. Finally, the third search strategy consists of abstraction, analysis and validation of the data. The summary of the ROSES review method is shown in figure 1.

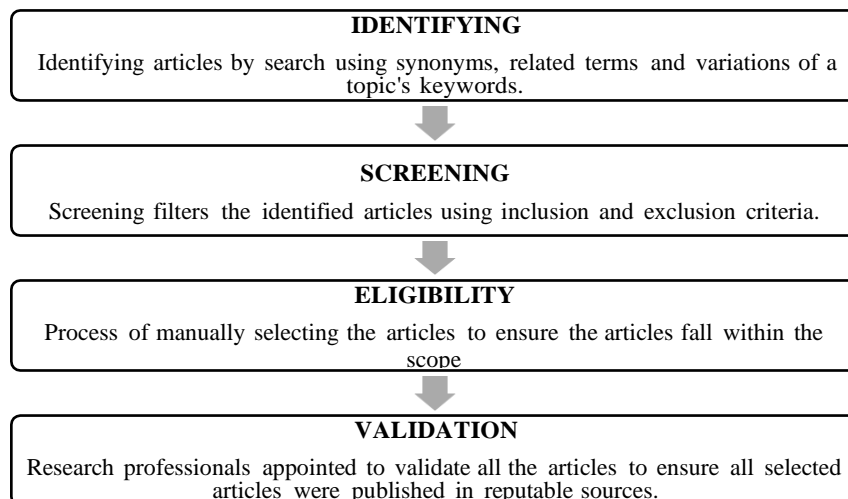


Fig. 1. Reporting Standards for Systematic Evidence Syntheses (ROSES) review protocol

Notably, this study's reviewed data consists of two major sources; (i) academic articles and (ii) news articles. The underlying reason is to reflect the breadth of sustainable materials developed and applied in products in Malaysia. It is well known that in the country's context, data from the first source would portray research-based activities by the scientific and academic institutions. In contrast, the second source would depict business-oriented activities by the industry, particularly the small and medium enterprises (SMEs). Additionally, it is expected that the former is often limited to research and development, whereas the latter is commonly centred on marketing and commercialization.

3.1 The Selection Strategy for Academic Articles

The first search strategy consists of identifying, screening and assessing articles' eligibility for exclusion and inclusion. Identifying is essential to search for synonyms, related terms and variations of a topic's keywords. Screening filters the identified articles in multiple stages using the inclusion and exclusion criteria. Assessing the eligibility of articles refers to the process of manually selecting articles from the previously screened articles to ensure that the articles reviewed in this study fall within the scope of the study. All articles utilized in this systematic review were published between 2010 to 2020.

In this study, Google Scholar is used for searching academic articles. Google Scholar produces tremendous results compared to other databases [32]. Also, the Google Scholar search is effective, considering that this study is conducted to find data for a specific country. The data, consisting of academic articles, were manually pre-validated. The provided links for each search string result were thoroughly reviewed. Table 1 shows the search strings used to find the articles and the results for the first collected articles. 1151 data is found from all search strings, and 165 articles were collected from first-stage exclusion processes. The first stage article exclusions are done through the title and abstract scanning. The exclusion criteria for the first screening are; 1) Provided link is not from academic resources 2) The title indicates that the publication belongs to other study fields such as construction, architecture or infrastructure. 3) The title clearly states that the study describes sustainable materials development in another country. 4) The link is broken, i.e. the article is not reachable.

Table 1. The search strings and the number of results for the first stage collected articles.

Search Strings	Results	Exclusion Stage 1
"sustainable material" "Malaysia" "industrial design"	47	16
"sustainable material" "Malaysia" "product design"	163	28
"sustainable material" "Malaysia" "packaging design"	34	10
"eco material" "Malaysia" "industrial design"	6	0
"eco material" "Malaysia" "product design"	28	11
"eco material" "Malaysia" "packaging design"	0	0
"green material" "Malaysia" "industrial design"	16	2
"green material" "Malaysia" "product design"	131	15
"green material" "Malaysia" "packaging design"	18	9
"waste material" "Malaysia" "industrial design"	22	3

"waste material" "Malaysia" "product design"	474	20
"waste material" "Malaysia" "packaging design"	37	10
"natural material" "Malaysia" "industrial design"	45	9
"natural material" "Malaysia" "product design"	118	28
"natural material" "Malaysia" "packaging design"	12	4

The 165 articles then go through the whole article screening. Within this second screening, the exclusion criteria are; 1) Repetition of articles, i.e. articles found in other search strings, 2) Not focus on the material discussion, 3) The study only refers to the article from Malaysia but not studied in the context. In total, 18 repeated articles and 56 articles not focusing on specific material development or merely referring to materials research in Malaysia are omitted from the dataset. An example of an excluded article is a publication that presents a generic discussion on sustainable development in Malaysia. After the articles screening, 120 articles were left for quality assessment and use for final review.

The relevance of the articles in the dataset was ensured through a quality assessment. Several appointed research professionals examined the 120 articles. The articles were analyzed in terms of their publishers' reputations, publication index, and types, e.g. journal, conferences and thesis. The appraisers excluded 29 articles in this screening stage, leaving 91 final articles reviewed in this study. Figure 2 illustrates the process flow of the data screening and selecting the final academic articles for the review.

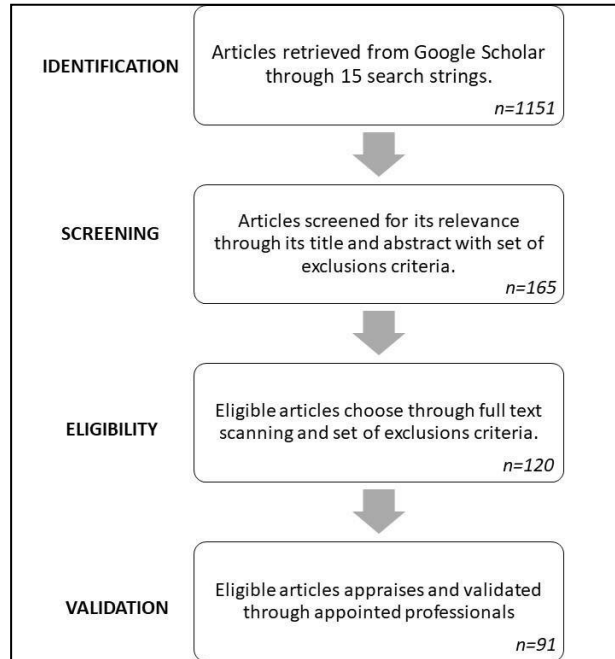


Fig. 2. The process flow of articles selection.

3.2 The Selection Strategy for News Articles

The data for news articles are obtained through advanced search keywords in the Google News search engine. The search strings used to identify the products are consistent with the academic articles search. The search string used in this study is: ("*sustainable material*" OR "*eco-material*" OR "*green material*" OR "*waste material*" OR "*natural material*" AND *Malaysia*.). A total of 1040 data is found from the search results, and the full-text article of each data is reviewed. The products' producers or companies are then recorded and checked further on their industrial background, products, and service. Multiple companies and products are sometimes mentioned in a single news article.

Then, the data went through the exclusion screening. The exclusion criteria are; 1) Repeated companies found from other news write-ups, 2) Not focus on the material discussion, 3) The news is written in Malaysia, but not describing locally developed or manufactured products. For example, news that reports a generic discussion on waste management and environmental issues is omitted from the dataset. After the screening, a dataset of 30 companies with multiple product categories was left for quality assessment and used as data to be further analyzed.

The found companies and their sustainable materials product application are discussed within the research group members. In particular, the members validated the shortlisted companies by reviewing the information on the products and materials used, provided at the companies websites or social media accounts, e.g. Facebook and Instagram pages. Details such as products commercialization state, sustainable materials types, recognition or award and any environmental sustainability labels certification from international and local sustainability organizations determine the validity of companies in this study. This step was conducted to ensure that all products were developed and manufactured by reputable and legit companies in Malaysia. As a result, a total of 30 companies was finalized to be used as comparative data in this study. Figure 3 illustrates the flow search process and screening for sustainable materials product applications in Malaysia.

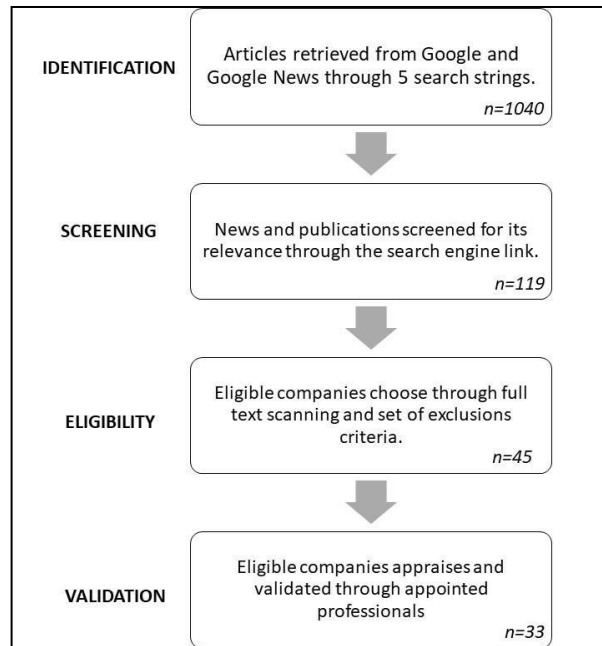


Fig. 3. The process flow of companies selection.

3.3 Content Analysis

The finalized dataset from the academic and news articles was analyzed through an abstraction approach and thematic analysis. In the stage of article abstraction, all validated articles and selected products in the companies were analyzed. The data abstraction process was conducted according to the research questions of this study. Any data from the reviewed documents that could answer the research questions was noted. The notes were then abstracted and placed on a table.

Next, the themes that emerged from the contents were identified through a thematic analysis. Notes that were collected from the abstraction process guided the themes. This process involved noting patterns, clustering words, counting repeated terms and noting the similarities and relationships within the abstracted data [33]. After the themes were developed, the similarities and differences of each developed theme were compared. The themes and analyzed data were then visualized. These findings from all contents analyses are discussed in the next section.

4 Results

The results from the contents analysis are extracted into two categories; (i) The types of sustainable materials and (ii) The types of product applications. Sustainable materials are categorized according to the established material types [34]. On the other hand, product application categories emerged from the distinct patterns of the analyzed data.

The articles and news contents analyses show three types of sustainable materials applied and researched in Malaysia; 1) Natural Fiber, 2) Natural Material, and 3) Recycle Material. Natural fibre refers to fibre that is made from natural resources and processes into bio-composite or bio-textile. Natural material refers to materials from nature that are applied directly to products or minorly processed. Lastly, recycled materials refer to synthetic materials that are repurposed into new product applications.

The data has shown that the main stakeholders involved in sustainable materials development and utilization in academic and news articles are the academics and the product design and manufacturing industry, respectively. The products types studied in academic research and applied in the product design and manufacturing industry are; 1) Wearables & Accessories, 2) Packaging, 3) Office and Household Items, and 4) Gift & Souvenirs. However, two types of products are only found in the industry are; 1) Personal Care Products and 2) Food- Related Products.

The following section further discusses the results for the materials and products found in this research.

4.1 Types of Materials

The types of materials found through this study are segregated into three categories. The categories are; 1) Natural fibre, 2) Natural material, and 3) Recycled material. In terms of material origins, there are ten types of natural fibres, ten natural materials and ten types of recycled materials used in product application by the product industry. Meanwhile, there are fifteen types of natural fibre, eleven types of natural materials, and six types of recycled materials studied for product applications in academic research. Figure 4 shows a list of materials found in academic research and materials applied in the product design and manufacturing industry.

Category	Types of Materials in Product Design and Manufacturing Industry	Types of Materials in Academic Research
Natural Fibre	jute lotus bamboo fibre sugarcane wood pulp/fibre wheat straw/stalk palm pineapple	bio composite / bio textile kenaf bamboo sugar palm agriculture waste screw-pine areca palm sago bark

	husk / rice husk bagasse	husk / rice husk abaca banana bagasse palm fibre/palm waste/palm leaf pineapple durian skin fibre
Natural Material	pandan leaves beeswax bamboo rubberwood wool loofah rattan local wood cork cotton	pandan leaves mycelium bamboo rubber lemba leaf bacterial cellulose algae wood coconut leaf Marine Life Fish Scale/Skin
Recycle Material	seat belt kimono in-flight material Fabric paper wood plastic Banner from event Felt from event Canvas from event	aluminium electronic parts plastic fabric paper wood

Fig. 4. Type of Materials

Predominantly, academic research has shown a diverse exploration of natural fibre materials. Though limited to early research, the abundant availability of natural materials such as sago bark and kenaf has justified their usage. Research for natural fibre in Malaysia also explores fibre resources from plants common to the country, such as fibre waste from durian and pandan screw pine [35,36]. On the contrary, the product design and manufacturing industry mainly utilize natural fibres sourced from readily available by-production materials, such as wood pulp, rice husk and sugarcane husk.

Natural material refers to substances or matters applied or transformed directly into products with minimal processing. This material category in the product design and manufacturing industry is commonly used to produce furniture, craft and home furnishing

[37,38]. Natural material in commercial products is also commonly applied in the self-care product category, such as wood, loofah, and beeswax. This natural material category is studied in academic research, mainly for furniture, crafts and packaging [29,39]. The dataset has shown that many atypical natural materials found in academic research are not yet applied in the industry. Examples of such materials are algae, mycelium and bacterial cellulose. Though yet to be commercialized, research indicates that the potential use of food-industry waste such as fish skin and fish scale is promising.

Within the recycled material category, the product design and manufacturing industry has shown more variance of material origin. The academic research, however, most state the generic material types. For example, there are products marketed with the origin of the recycled materials used, such as kimonos, seat belts, and banners; meanwhile, the academic research study recycles plastic and textiles [40,41].

To summarize, sustainable materials applied in the product design industries are predominantly limited to readily available and easily accessible materials. Such factors can be attributed to the fact that many product developers in Malaysia are SMEs. Natural materials used in the product design and manufacturing industry are the common natural materials for products such as wood and bamboo. However, the product design industry has expanded the usage of such common natural materials into more product variance, such as self-care products.

In contrast, academic institutions have produced much exciting research on the potential of local plant-based fibres as superior composites. Further, there are advanced research for natural materials focusing on furniture, crafts, and industrial packaging. In addition, academics have started to venture into new emerging living natural resources such as algae, mycelium, and bacterial cellulose.

The following section elaborates the results for the type of products applied with sustainable materials in Malaysia.

4.2 Type of Products

The products made of sustainable materials found in the dataset are divided into seven categories. They are; 1) Wearables & Accessories, 2) Packaging, 3) Office and Household Items, 4) Gift & Souvenirs, 5) Food-Related Products, 6) Personal Care Products and 7) Industrial Products.

The first wearables and accessories category refers to a variety of styling and fashion products from various developers. The academic research does not state the specificity of the products. However, the industry indicates potential applications, such as fashion wear and jewellery [25,42,43]. Also, the category includes product accessories such as caps, face masks, and scrunchies made from recycled materials.

The packaging category mainly exists in academic research, as disposable and plastic packaging has caused severe environmental problems. The research has also highlighted that various industries should explore sustainable materials for their packaging, such as food and medical packaging [44,45]. Meanwhile, there are jute bags and recycled paper commercialized

by the product design and manufacturing industry.

Items for offices and households are the category explored most by the product design and manufacturing industry. The selling features stated in the news are usability and the high-performance of the products and materials. Like the first product category (wearables and accessories), academic research suggests the generic use of materials such as home furnishing and furniture instead of stating the specific product applications. In contrast, the industry markets various interesting products within this category. For example, a company called Palmy and Green Planet offers Home DIY Kit from sustainable materials and encourages users to be creative.

The gift items category is equally explored by academics and industry. It is a fact that the gift and souvenir product sector is a big industry locally, and sustainable materials application is progressive [46]. The variety of companies that produce this product category is wide despite the non-variance of the product type. Examples of gift items and souvenirs made with sustainable materials in Malaysia are; Air Asia Foundation using their in-flight waste, Beyond Bins by Biji Biji Initiative using recycled plastic, and Eco quote using natural materials.

The food-ware and utensils category consists of various products: cup, cutlery set, tumbler, cutting board, and lunchbox. These products are commonly made with natural fibres or natural materials as the materials evoke naturalness. Also, it is easier to associate the materials with the edibility factor. The similar applied to the personal care products category, where the naturalness perception of the sustainable materials conforms with the function of the products. For example, personal care items such as a hairbrush, toothbrush, cleaning and bath gel have been marketed with multiple sustainable claims by companies, e.g. Minus zero waste and The Hive. These companies use natural materials such as rice husk, bamboo, beeswax and loofah. However, the food-ware and utensils, and personal care products are non-existent in academic research.

The final category is industrial products. The category is sub-categorized according to products made with specific materials such as leather-based and paper-based. This category emerged from the type of products found in academic research. Hence, the application is commonly referred to as not specific and subject to the materials performative aspects. Other products in this category are automotive products and electrical appliances [41,47]. Figure five shows the product category from the content analysis.

Category	Types of Product Design and Manufacturing Industry	Types of Products in Academic Research
Wearables and Accessories	Scarves Scrunchies Clothing Lingerie and Nightwear Sportswear Towel Cap Face Mask Landyard Bangle/ Necklace/ Earrings Bags/ Handbag/ Tote Bag	Fashion Accessories Fashion Wear Footwear Jewellery

	Purse/ Clutch Pouch/ Bag Pack	
Packaging	Food Packaging Shopping Bag Gift Packaging General Product Packaging	Food Packaging Medical Packaging Take-Out Container General Product Packaging
Office and Household Items	Furniture Electronic Devices Sleeves Clock Phone Holder/ Phone Case Name card and Memo Holder Calendar/ Bookmark Notebook Table Organiser Pen/ Pencil Pen Holder DIY Kit and Raw Material Supplies Pot/ Planter/ Vase Document Folders Knob/ Handle Hanger Clothes Pin	Furniture Public and Outdoor Furniture Home Furnishing Interior Elements Household Products
Gift & Souvenirs	Ornament Trophy/ plaque/ Award Keychain	Ornament Trophy/ Plaque Stonewear
Food-ware and Utensils	Cutlery Set/ Cutlery Case Coaster Chopping Board Lunchbox Tumbler Pill Box Food Organiser/ Container Plate/ Bowl Straw Cup/ Mug	
Per	Comb/ Hair Brush Razor Ear Cleaner Body Brush/ Body Sponge Wipes Toothbrush Soap Holder/ Case	
Industrial Products		Automotive Products Electrical Products Industrial Raw Materials Material Based Products (Paper, Leather, Textile, Rubber)

Fig. 5. Type of Product

5 Findings

Sustainable materials development and commercialization in Malaysia has shown a plausible progression. The materials explorations and utilization by the academic research and product design and manufacturing industry are diverse in material and product types. This finding demonstrates that there is a growing sustainability awareness within both sectors. However, the study found that much academic research focuses on developing natural fibre composite for big industries such as automotive and furniture. In contrast, product design and manufacturing industry stakeholders show interest in utilizing natural and recycled materials for much more daily product variance.

Concerning product application, academic research focuses on the performance of the materials. In particular, the discourse of sustainable materials in the research domain is about scientific studies of the structural at molecular level of natural fibre materials projected to be used by large industries. For example, kenaf composite is studied for automotive and electrical applications. Emphasis is often made on the properties of matter, including the materials' physics, chemistry, manufacturing capabilities and mechanical properties. This finding is unsurprising as many of the academic articles are written within the material science domain. Hence such research always proposes or speculates the application of the studied materials, and evidence for the commercialization is lacking.

In contrast, the products made of sustainable materials by the product design and manufacturing industry demonstrates various practical usability. It is noteworthy to highlight that Malaysian SMEs explore and apply various natural fibres and natural materials in everyday products. For example, such materials are used to make food-ware and utensils such as plates, tableware, travel cutleries, cookware, and personal care products such as toiletries. Data from the news articles also exhibit more product applications for recycled materials. Within the recycling strategy, quite many companies opt to reuse the materials as it is. For example, old kimonos from the fashion industry and expired in-flight seatbelts are transformed into new products. Moreover, recycled and natural materials are commonly used as they involve minimal and less complex processes. For example, it is more feasible for the industry, especially the SMEs, to use bamboo directly than turn it into fibre composite.

Notably, the material origins used in the product design and manufacturing industry are more diverse than academic research. It seems that the companies use the rarity of the material origin as the marketing pull. Whereas within the academic research, potentially the details of the source of the material composite is a trade secret in the material development.

Overall, the study's finding shows promising sustainable material exploration and the overall development reflects an early transition to a circular economy. However, concerted efforts from all stakeholders are needed to close the gap between academic research and commercial product applications. The scenario can be attributed to various factors such as funding and trends in academic research and the nature and capabilities of SMEs. Furthermore, there is a lack of evidence of an impactful industry-academia partnership in developing sustainable materials. Notably, material research under the product design domain is also minimally founding the dataset. Such research is essential to facilitate the commercialization and uptake of materials in the market.

6 Suggestion and Future Works

Academic research on sustainable materials needs to be expanded to encompass product design and marketing domains. It is essential to understand how users would experience such materials in the local context, and better facilitate the circulation of the materials before, during and post-consumption. For example, would any natural materials evoke a similar level of naturalness? Moreover, would the material usage inculcate responsible disposal when the product is obsolete? i.e. recycle, compose. In addition, research is also needed to understand how the local market accepted the material application and the overall perception towards products embodied with sustainable materials.

Sustainable materials research in Malaysia is mainly focused on huge industries. Further study is needed to understand how SMEs will be benefited from sustainable materials research. For instance, a strategy is needed to push SMEs beyond the standard natural fibres and recycled materials. Importantly, SMEs' design and manufacturing capability need further investigation to expand their sustainable product lines.

7 Conclusion

This paper reviews the breadth and status of sustainable materials development in Malaysia's research activities and application in the product design and manufacturing industry. The study shows that sustainable materials development in Malaysia is generally progressive. Within both sectors, the efforts to circulate materials in pursuing sustainability is promising. Three main categories of materials and eight types of products made of sustainable materials have been identified. However, the differences in material types and applications indicate a dichotomy between academic research and product application. Academic research focuses on scientific discovery and the advancement of sustainable materials. However, there is inadequate evidence showing that these materials have been successfully commercialised.

In contrast, the product design and manufacturing industry utilise common material types, employing basic manufacturing processes to convert them into everyday products. By and large, such scenarios project the classic issues that cut across a developing country. The SMEs capacity, such as lack of capital and limited access to technology, hamper industrial progress. On the other hand, reform is needed within the academic institution to increase research commercialisation. Without immediate solutions, Malaysia will need a longer time to shift to a circular economy entirely. Hence, greater coordination from all stakeholders, including product developers, designers and academia, is needed to mobilise the circular system.

References

- [1] Brennan G, Tennant M, Blomsma F. Business and production solutions: Closing loops and the circular economy. *Sustain Key Issues*. 2015.
- [2] Invernizzi DC, Locatelli G, Velenturf A, Love PE, Purnell P, Brookes NJ. Developing policies for the end-of-life of energy infrastructure: Coming to terms with the challenges of decommissioning. *Energy Policy*. 2020;

- [3] Geissdoerfer M, Savaget P, Bocken NMP, Hultink EJ. The Circular Economy – A new sustainability paradigm? *J. Clean. Prod.* 2017.
- [4] Ashby MF. Bamboo for Sustainable Flooring. *Mater Sustain Dev.* 2016.
- [5] Wagner M, Curteza A, Hong Y, Chen Y, Thomassey S, Zeng X. A design analysis for eco-fashion style using sensory evaluation tools: Consumer perceptions of product appearance. *J Retail Consum Serv.* 2019;
- [6] Bauer S. Sustainable materials: With both eyes open. *Mater Today.* 2012;
- [7] Geiser K. Making materials matter. *New Solut.* 2002;
- [8] Bahrudin FI. *The Experiential Dimension Of Sustainable Materials.* Imperial College London; 2019.
- [9] Zarandi MHF, Mansour S, Hosseiniyou SA, Avazbeigi M. A material selection methodology and expert system for sustainable product design. *Int J Adv Manuf Technol.* 2011;
- [10] Isa NM, Sivapathy A, Adjrina Kamarruddin NN. Malaysia on the Way to Sustainable Development: Circular Economy and Green Technologies. *Model Econ Growth Contemp Malaysia.* 2021.
- [11] Muktadir MA, Rahman T, Rahman MH, Ali SM, Paul SK. Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh. *J Clean Prod.* 2018;
- [12] Muktadir MA, Rahman T, Rahman MH, Ali SM, Paul SK. Drivers to sustainable manufacturing practices and circular economy: A perspective of leather industries in Bangladesh. *J Clean Prod.* 2018;
- [13] Delgado-Aguilar M, Julián F, Tarrés Q, Méndez JA, Mutjé P, Espinach FX. Bio composite from bleached pine fibers reinforced polylactic acid as a replacement of glass fiber reinforced polypropylene, macro and micro-mechanics of the Young's modulus. *Compos Part B Eng.* 2017;
- [14] Poletto M, Luiz H, Júnior O, Visakh PM, Arao Y. Composites and nanocomposites based on renewable and sustainable materials. *Int J Polym Sci.* 2016;
- [15] Zhu Y, Romain C, Williams CK. Sustainable polymers from renewable resources. *Nat Clim Chang.* 2016;540.
- [16] Karana E, Pedgley O, Rognoli V. *Materials Experience: Fundamentals of Materials and Design.* Mater. Exp. Fundam. Mater. Des. 2013.
- [17] Rognoli V, Karana E, Pedgley O. Natural fibre composites in product design: An investigation into material perception and acceptance. *DPPI'11 - Des Pleasurable Prod Interfaces, Proc.* 2011.
- [18] Siti Suhaily S, Abdul Khalil HPS, Asniza M, Nurul Fazita MR, Mohamed AR, Dungani R, et al. Design of green laminated composites from agricultural biomass. *Lignocellul Fibre Biomass-Based Compos Mater Process Prop Appl.* 2017.
- [19] Da Costa CR, Ratti A, Del Curto B. Product development using vegetable fibers. *Int. J. Des. Nat. Ecodynamics.* 2014.
- [20] Selamat MZ, Zhafri Tahir MS, Kasim AN, Dharmalingam S, Putra A, Yaakob MY, et al. Effect of starch sizes particle as binder on short pineapple leaf fiber composite mechanical properties. *MATEC Web Conf.* 2018.
- [21] Mazani N, Sapuan SM, Sanyang ML, Atiqah A, Ilyas RA. Design and fabrication of a shoe shelf from kenaf fiber reinforced unsaturated polyester composites. *Lignocellul Futur Bioeconomy.* 2019.
- [22] Saferi SKA, Yusof Y. A review: Natural fiber as reinforcement in waste paper recycling and its processing methods. *Appl Mech Mater.* 2013.
- [23] Mansor MR, Sapuan SM, Zainudin ES, Nuraini AA, Hambali A. Conceptual design of kenaf fiber polymer composite automotive parking brake lever using integrated TRIZ-Morphological Chart-Analytic Hierarchy Process method. *Mater Des.* 2014;
- [24] Suhaily SS, Jawaid M, Abdul Khalil HPS, Ibrahim F. A review of oil palm biocomposites for furniture design and applications: Potential and challenges. *BioResources.* 2012;7:4400–23.
- [25] Shaari N. Lemba (*Curculigo latifolia*) leaf as a new materials for textiles. *Proc - Fourth Int Symp Environ Conscious Des Inverse Manuf Eco Des 2005.* 2005.
- [26] Vigneswaran C, Pavithra V, Gayathri V, Mythili K. Banana Fiber: Scope and value added product development. *J Text Apparel, Technol Manag.* 2015;

- [27] Kamarudin Z, Latip NSA, Mansor M, Salleh NH, Hakim L, Syala Abdul Latip N, et al. Sustainability of Malay traditional craft and craftsmanship as cultural heritage in Kuala Kangsar, Perak, Malaysia. *J Archit Plan Constr Manag*. 2013;
- [28] Azahana A, Wickneswari R, Noraini T, Nordahlia AS, Solihani NS, Nurnida MK. Notes on *Pandanus atrocarpus* Griff and *P. tectorius* Parkinson in Peninsular Malaysia. *AIP Conf Proc*. 2015.
- [29] Sahari F, Hasan R. Innovation in orang ulu indigenous craft. *J Borneo Kalimantan*. 2016;
- [30] Haddaway NR, Macura B, Whaley P, Pullin AS. ROSES Reporting standards for Systematic Evidence Syntheses: pro forma, flow-diagram and descriptive summary of the plan and conduct of environmental systematic reviews and systematic maps. *Env Evid*. 2018;7.
- [31] Ismail Z, Hamat B, Amrin A, Allahham A. Smell in Industrial Design: A Systematic Review. *Basic Appl Sci - Sci J King Faisal Univ*. 2021;1–7.
- [32] Guseinbauer M. Google Scholar to overshadow them all? Comparing the sizes of 12 academic search engines and bibliographic databases. *Scientometrics*. Springer International Publishing; 2019.
- [33] Yin RK. *Case Study Research and Applications: Design & Methods*. Applied So. Sage Publication; 2017.
- [34] United Nation. *Agenda 21. United Nations Conf Environ Dev. Rio de Janeiro, Brazil: United Nations Division for Sustainable Development*; 1992.
- [35] Manshor MR, Anuar H, Nur Aimi MN, Ahmad Fitrie MI, Wan Nazri WB, Sapuan SM, et al. Mechanical, thermal and morphological properties of durian skin fibre reinforced PLA biocomposites. *Mater Des*. 2014;
- [36] Nazri W, Ezdiani Z, Romainor M. Effect of fibre loading on mechanical properties of durian skin fibre composite. *J Trop Agric Food Sci*. 2014;
- [37] Hamid AGA, Rahman KAAA, Ismail S. The Factor of Industrial Development Problems on Bamboo Furniture Designs in Malaysia: A Concept Paper. *Glob Bus Manag Res*. 2018;
- [38] Latib HA, Liat LC, Ratnasingam J, Law EL, Aziin AAA, Mariapan M, et al. Suitability of paulownia wood from Malaysia for furniture application. *BioResources*. 2020;
- [39] Mustafa M, Nagalingam S, Tye J, Shafii ASH, Dolah J. Looking Back To the Past : Revival of Traditional Food Packaging. 2nd Reg Conf Local Knowl (KEARIFAN TEMPATAN). 2012;
- [40] Sakundarini N, Taha Z, Abdul-Rashid SH, Ghazila RAR. Optimal multi-material selection for lightweight design of automotive body assembly incorporating recyclability. *Mater Des*. 2013;
- [41] Ho FH, Abdul-Rashid SH, Ghazilla RAR, Woo YL. Resources sustainability through material efficiency strategies: An insight study of electrical and electronic companies. *Resources*. 2019;
- [42] Ahmad A, Fatima MA, Ali A, Apandi N, Kamarudin M. Sustaining baba-nyonya cultural heritage products: Malacca as a case study. *Int J Innov Creat Chang*. 2019;
- [43] Khandual A, Sahu S. Sabai grass: Possibility of becoming a potential textile. *Environ Footprints Eco-Design Prod Process*. 2016.
- [44] Wan Nadirah WO, Jawaid M, Al Masri AA, Abdul Khalil HPS, Suhaily SS, Mohamed AR. Cell Wall Morphology, Chemical and Thermal Analysis of Cultivated Pineapple Leaf Fibres for Industrial Applications. *J Polym Environ*. 2012;
- [45] Salwa HN, Sapuan SM, Mastura MT, Zuhri MYM. Conceptual design and selection of natural fibre reinforced biopolymer composite (NFBC) takeout food container. *J Renew Mater*. 2021;
- [46] Sapuan SM, Hemapriya G, Ilyas RA, Atikah MSN, Asyraf MRM, Mansor MR. Implementation of design for sustainability in developing trophy plaque using green kenaf polymer composites. *Des Sustain*. 2021.
- [47] Ahmed Ali BA, Sapuan SM, Zainudin ES, Othman M. Implementation of the expert decision system for environmental assessment in composite materials selection for automotive components. *J Clean Prod*. 2015;