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Innovative Product Development from LDPE Waste using the Fusing Interlock Technique: A Material Driven Design Study Case

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ABSTRACT

In response to the escalating plastic waste issue in Indonesia, intensified by a lack of public knowledge on waste management, this research focuses on repurposing LDPE plastic waste collected from laundry service using the plastic fusing interlock technique. Employing a material-driven design method with research through design approach where design process is used as method of inquiry, exploring and investigating research questions through the creation of tangible prototypes from the LDPE plastic waste. The study identifies suitable recycling techniques for LDPE waste and assesses its feasibility in creating functional products. Through five experimental trials, the research establishes that layer-by-layer fusion is the most effective method, and cutting the fused plastic with a pond knife yields strong and versatile results. The interlocking modules produced through this technique provide flexibility for diverse configurations, offering myriad possibilities for product creation. The study concludes that the fusing interlock technique makes LDPE waste repurposing accessible and cost-effective, eliminating size limitations and enhancing product durability. The experiments utilized approximately 450 sheets of LDPE plastics, showcasing the potential for sustainable production and contributing to SDG 12: Responsible Consumption and Production.

INTRODUCTION

Plastic is often found in our daily lives. Due to its lightweight, waterproof, and inexpensive nature, plastic is used as a raw material in nearly all disposable items and packaging. However, despite its advantages and convenience, plastic waste has become an environmental issue due to its difficulty in decomposing. According to data from the National Waste Management Information System (SIPSN) of the Ministry of Environment and Forestry (KLHK), in 2022, the volume of waste generated in Indonesia reached 19.45 million tons. This represents a decrease of 37.52% compared to 2021, which reached 31.13 million tons. In terms of the types of waste, the majority of the national waste volume in 2022 was food waste, contributing as much as 41.55%. Plastic waste ranked second with a proportion of 18.55% [1]. Thus, creative ways are needed to manage plastic waste.

One way to address plastic waste is through upcycling, which involves repurposing waste into new products. However, upcycling alone is not enough to reduce plastic waste. As designers, the concept of circular design also needs to be considered. Circular design is an approach in design aimed at creating products and services that are durable, reusable, repairable, and recyclable, resulting in zero waste to support a sustainable economy [2]. This involves early thinking during the design phase about potential product improvements, how products can be enhanced, and the environmental impact of the products [3]. The goal is to create products designed with sustainability and circularity principles, ensuring efficient resource use, waste reduction, and extending product lifespan through repairs, updates, and recycling (Ratum et al., 2019). Referring to Circular Design and Economics by the Ellen MacArthur Foundation, some strategies that can be applied are dematerialization and modular design. Dematerialization focuses on reducing dependence on physical materials by offering digital alternatives or reducing the use of new materials. This approach minimizes resource consumption as much as possible and reduces waste by providing digital services rather than producing physical products.

Modular design involves creating products consisting of replaceable and upgradable modules. This allows users to easily replace or upgrade specific components of the product rather than replacing the entire product [4]. Modular design promotes longer lifespans, repairs, and reduces overall environmental impact by extending product lifespan and reducing the amount of waste generated [5].

In addition to circular design, there is the concept of Material Driven Design (MDD), an approach in design that emphasizes the role of material as the center of creativity in the design process [6]. This concept was introduced by Elvin Karana and encourages designers to not only see materials as tools to realize existing design ideas but also as the main source of inspiration in creating new design ideas. In this approach, designers open themselves up to experiments with material characteristics such as texture, color, and strength, allowing the material to shape the form and function of the product. MDD aims to create more sustainable, efficient, and innovative designs by thoroughly understanding the characteristics of the materials used. This approach also encourages the use of environmentally friendly materials and creativity in the design process.

By combining the principles of dematerialization and modular design implemented in the MDD stages, it is hoped that designers can contribute to more sustainable practices and reduce the environmental footprint of products throughout their lifecycle.

The primary objective of this study is to propose a standardized operating procedure for the utilization of LDPE waste collected from laundry services, incorporating circular design principles and the Material Driven Design (MDD) approach to achieve the SDG 12 goal responsible consumption and production. The specific research objectives are as follows:

1. To investigate the principles of circular design, exploring strategies of dematerialization and modularization.
2. To explore and understand the Material Driven Design (MDD) method, which focuses on utilizing material properties and characteristics to inform the design process.
3. To implement circular design principles, specifically dematerialization and modularization, in the utilization of LDPE waste with the plastic fusing interlock technique through the research process guided by MDD.
4. To recommend a standard operating procedure for the effective utilization of LDPE waste, employing the plastic fusing interlock technique.

By achieving these objectives, the study aims to contribute to the development of sustainable practices in utilizing LDPE waste and promoting circularity in design and material utilization.

LITERATURE REVIEW

To help the study achieve the responsible consumption and production, the SDG 12 goal

[7]. The study adopts circular design and material driven design approach. MDD, as developed by [6], prioritizes sustainable practices by placing the material at the forefront of the design process, considering not only its functional attributes but also its potential to evoke meaningful user experiences. This methodology aligns with SDG 12 by promoting a comprehensive understanding of the material's properties, fostering minimal waste, and ensuring efficient resource utilization. On the other hand, Circular Design, rooted in circular economy principles, emphasizes repairability, upgradability, and minimizing environmental impact during the design phase [8]. The combination of MDD and Circular Design promotes responsible production by encouraging tangible interaction with materials, fostering longevity, and considering end-of-life scenarios.

Circular Design

According to the Ellen MacArthur Foundation, design is a deliberate creation, encompassing the way we create products, services, and systems. It is the process through which a designer shapes materials into desired forms and mechanisms. Design involves considerations not only about the physical appearance, but also crucial decisions made throughout the design process, such as production processes and how the product will be used. Circular design, the inaugural phase in the circular economy, is embedded within this process. Circular design comprises four stages: 1) Understand - focusing on comprehending user characteristics and system understanding, 2) Define - articulating the design and the designer's intentions in words, 3) Make - generating ideas, designing, and creating multiple prototypes through iteration, renewal, and improvement, and 4) Release - launching the design and building user loyalty.

Figure 1. Circular Design
Source: [8]

It is essential to understand that circular design extends beyond considerations of repairing and reproducing products; it necessitates forward-thinking during the initial design phase about product repairability, potential upgrades, and environmental impact. Designers must grasp how their products are used and anticipate their longevity. Although achieving a product with zero waste may be challenging, designing products with extended lifespans, utilizing appropriate materials, and prioritizing product quality is achievable. By incorporating circular design principles, designers can reassess the manufacturing process and enhance production systems, thereby making meaningful contributions to society and the environment. Strategies to implement circular design include opting for safe and circular materials, avoiding substances harmful to humans and the environment. Other effective approaches involve dematerialization, addressing problems with minimal material use, such as offering digital services and utilizing reusable containers. Additionally, modular design allows users to easily upgrade and repair products, reducing repair costs by addressing only the damaged part. Circular design, therefore, emerges as a comprehensive strategy for sustainable and responsible product development.

Material Driven Design

Material Driven Design (MDD) is a sustainable design methodology developed by [6] that prioritizes the material as the central driver of the design process. It goes beyond functional considerations to encompass the material's unique properties, engineering limitations, and its potential to elicit meaningful user experiences. MDD is distinguished by its comprehensive approach, focusing on both the tangible and sensorial qualities of the material. The method encourages hands-on interaction with the material from the initial encounter, enabling designers to explore and comprehend its distinctive characteristics. Importantly, MDD extends beyond utilitarian assessments to envision and materialize design intentions, aiming to create new product concepts that deliver innovative and engaging material experiences.

The Material Driven Design (MDD) method comprises four key steps to guide its implementation. Firstly, the method emphasizes understanding the material by delving into its unique properties, sensorial qualities, and potential meanings. This involves technical characterization, where designers learn about the material's mechanical and technical properties, and experiential characterization, focusing on sensorial, interpretative, affective, and performative aspects. The second step involves creating a material experience vision, where designers formulate a comprehensive vision statement expressing the material's role in creating functional superiority and a unique user experience. Material benchmarking is conducted to gain insights from other materials, informing the vision. The third step, Manifesting Material Experience Patterns, entails visualizing and categorizing datasets to identify patterns and formulate material experience patterns. The final step is designing material/product concepts by integrating findings from the previous steps. Through these steps, MDD facilitates a holistic approach to material-driven design, guiding designers in creating meaningful and sustainable product experiences.

After conducting a literature review, the research aims to bridge the gap between material-driven design and circular design studies by integrating them into a single framework that guides designers in sustainable design. Hence, the research question is: How do we implement the material-driven design and circular design framework in the design process?

METHODS

The current study utilized a qualitative exploratory research design, employing the research-through-design (RtD) approach to examine the implementation of Material Driven Design (MDD) and Circular Design within a design project. RtD, as a research approach, integrates design practices and methodologies to tackle intricate problems and generate novel knowledge [9]. It entails employing the design process itself as a method of inquiry, delving into and addressing research questions through the development of tangible artifacts, prototypes, or interventions [10]. Unlike conventional research methods that predominantly rely on analysis and observation, RtD underscores the act of designing as a means to comprehend, explore, and contribute to knowledge across various domains, encompassing design, architecture, and human-computer interaction.

The research methodology involved a multi-step process. The research uses the material driven design method which consists of four stages: Understanding the material, creating material experience vision, manifesting materials experience patterns, designing material/product concepts. Through these four stages, the author begins the research by understanding the characteristics of the material being studied, which is LDPE waste. After understanding the characteristics of LDPE, the author creates a new experience that can be felt by users through this new material or by approaching the nearest material. The author then creates patterns from the material and designs new products using the new material that use the circular design principles of modularization and dematerialization.

RESULT AND DISCUSSION

The research results are elaborated based on the four steps of MDD.

Understanding the material

After conducting the experiments, it is discovered that gradually fused plastic yields neater results and reduces the risk of trapped air. The optimal fusing process is as follows:

- Switch on the heat press machine and set the temperature to 1500 C.
- Prepare four layers of LDPE plastic bags.
- During the fusing process, the plastic will always be sandwiched between two layers of Teflon paper. The bottom layer of paper prevents the plastic from sticking to the board, while the top layer of paper prevents the plastic from sticking to the heat press plate.
- Set the heat press to heat the upper part for 15 seconds, and then the bottom part for another 15 seconds.
- After 30 seconds of heating, remove the Teflon papers and test your fused piece to check for any trapped air inside.
- The process can be repeated several times to achieve the desired thickness of fused plastic.

Plastic waste collection > heat press preparation > heating process > fused plastic

Figure 2 Fusing Plastic Process

Source: [11]

The choice of media papers also influenced the results. Fusing results indicated that using Teflon paper as a medium resulted in a more even fusion of LDPE plastic. The thickness results after fusing tended to be more stable per layer. The suitable temperature for the production is 150°C in 15 seconds per step.

After identifying the optimal standard operating procedure (SOP) for fusing the plastic, the authors proceeded to implement the principles of circular design through modularization. Various module shapes were explored, and it was found that the arrow module (refer to figure 3) exhibited the most effective interlocking capability in terms of material utilization. The arrow module enabled the production of a greater number of modules, resulting in a larger final area compared to other modules. Consequently, it can be concluded that the geometric shape of the arrow module is the most efficient interlocking module, minimizing waste production and maximizing material usage.

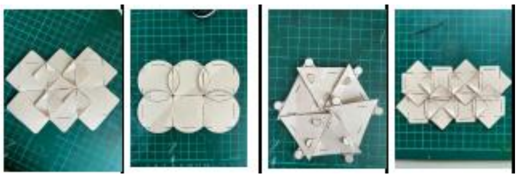
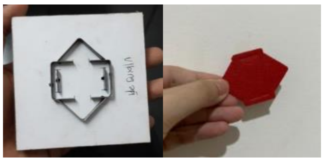


Figure 3 Interlock Modul Experiments
Source: [11]

In addition to shaping the modules, the authors explored the most efficient cutting method. Hand-cutting each module isn't practical for efficiency. Through experimentation with various cutting tools, it was determined that using a punch knife is the most effective method for cutting the modules. However, it's crucial to consider that the size of the pattern also influences the necessary pressure. If the module is too large, cutting the plastic accurately becomes challenging (refer to Figure 4).

Failed custom knife



Punch Blade

Figure 4 Cutting Tool Experiments
Source: [11]

Furthermore, in the pursuit of exploring different aspects of module creation, the authors experimented with the medium used to transfer heat. The findings revealed that the addition of texture to the fused plastic could be achieved by substituting teflon paper with aluminum foil as the heat transfer medium (see figure 5).

Figure 5 Medium Experiments
Source: [11]

Creating Material Experience

To know users' feedback about the material. The study conducts user testing on the fused plastic. This user testing process was conducted with two groups (see Figure 6). Group 1 consisted of three individuals. A (female) is 26 years old and works as an entrepreneur. She is not familiar with sustainable fashion products and lacks appreciation for recycled goods. B (female) is 28 years old and owns a laser-cutting business. She is interested in sustainable products and appreciates the production process. C (male) is 37 years old and runs a property business. He enjoys unique items.

Group 2 consisted of four individuals. A (female) is 27 years old and works as an entrepreneur. She is familiar with sustainable products, appreciates the process, and likes recycled products. B (male) is 30 years old and works in the property field. He is familiar with recycled goods but not very interested in them. C (male) is 26 years old and works in the technology and information field. He is not familiar with recycled products and lacks appreciation for the production process. D (female) is 29 years old and works in the food and beverage industry. She is familiar with local sustainable products.

The conclusion from the user testing results is that users are interested in the interlocking pattern and material. The interlock shape should be made more rounded at the edges so that it is not too sharp. Products made from this material are associated with fabric and can be used as wearable or decorative products. Most users are interested in using the material as a lampshade. The price range set by users varies depending on their awareness of the effort put into the product. When asked to guess what material this is made of, some users guessed that it was made of latex and plastic (but not LDPE). Some users were able to identify the material as plastic. Users also seemed interested and curious about the material. They held and examined the material, paying attention to the edges and the interlocking pattern. Users looked at both sides of the module.

The material sample tested

Figure 6 User Testing Process
Source: [11]

Manifesting Materials Experience Patterns

Based on the results of sample material testing, the positive characteristics of the selected material for development are the modular system, black and white color, texture, abstract composition, and asymmetry with the concept of anomaly. To shape this experience, benchmarking was conducted with other materials that can convey a similar impression (see Figure 7).

Figure 7 Material Benchmarking
Source: [11]

With the established characteristics, the next step is to initiate the brainstorming process by creating a moodboard (see figure 8). The moodboard serves as a tool in developing the material experience vision based on keywords such as modular, abstract, textured, asymmetric composition, and anomaly. This moodboard will assist in visually illustrating the concepts and feelings intended to be conveyed through the designed material. After researching and exploring the module connection method, several positive characteristics of the material were discovered, such as unlimited potential forms with the modular system and a level of transparency that allows light to pass through. These modules are highly flexible for connection in various configurations, providing numerous possibilities for creating different products.

Figure 8 Moodboard
Source: [11]

Designing Material/Product Concepts.

Based on the advantages of the characteristics of recycled LDPE material, which are modular, transparent, and abstractly textured, the researcher aims to integrate all exploration findings into the design of home decoration products, particularly lamps. The design process applies Circular Design methods to make the product cycle unlimited. It starts by collecting used plastic bags from the laundry, cleaning them, and pressing them into thicker plastic sheets. These sheets are then cut using a puncher knife, typically used for cutting paper or cardboard, which has been adjusted for exploration purposes into the shape of arrow module connections. Once the knife is ready, it is used to cut the melted plastic, and the modules are connected to assemble the final product, which is then processed into a finished product (see Figure 9). Subsequently, the product is distributed and tested on the target market to obtain initial feedback. When consumers want to replace the product with a new one, the waste can be easily recycled into raw materials as there is no mixture of other materials. If the product is damaged, the damaged part can be replaced with a new one, adhering to the modular principle.

Figure 9 Moodboard
Source: [11]

The finished product was evaluated by 5 users who represent the target market for the final product—individuals who appreciate artistic aspects, waste management processes, and have high environmental awareness (see table 1). Product evaluation was based on six predetermined design criteria. Evaluation scores were provided on a scale ranging from 1 to 5, with the following criteria:

Table 1. User Review

No	Factors	A	B	C	D	Average
1	Design idea	4	3	4	5	4
2	Material uniqueness	5	5	4	4,5	4,625
3	Pattern	5	4	5	5	4,75
4	Size	4	5	5	4	4,5
5	Color	5	5	4	5	4,75
6	Lighting	4	5	5	4	4,5
Overall average						4,52

Through a series of experiments and design processes based on the Material Driven Design (MDD) research method and the application of circular design principles, particularly dematerialization and modularization, this study has demonstrated the effective recycling of LDPE plastic waste using interlocking techniques. The recycled material can then be transformed into appealing table lamps for the market, especially with the use of captivating colors and patterns. Findings from this research underscore the potential to reuse LDPE plastic waste and provide insights into creating sustainable and visually appealing products.

The research findings, which showcase successful waste utilization through the Material Driven Design (MDD) method, are in line with previous research by [6]. Together, these findings emphasize the potential and effectiveness of MDD as a sustainable approach to waste utilization. Building on existing knowledge, this research contributes to the growing evidence supporting the feasibility of MDD in waste utilization and highlights the importance of promoting circular design practices.

CONCLUSION

The study reveals that integrating circular design principles, such as dematerialization, from the early stages of material process understanding, is beneficial for designers. By considering dematerialization, designers can consciously select products that can be effectively created using a single waste material. Additionally, the application of modular design principles allows designers to identify the most efficient modules that maximize the use of waste material while facilitating repair processes. By applying these principles, designers can contribute to a more sustainable and resource-efficient design approach.

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