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Modular Home Décor Design from Recycled Plastic Bottle Caps Inspired by Thai Gingerbread Fretwork Patterns

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Abstract

This research investigates the potential of repurposing plastic bottle caps into modular home décor items, inspired by traditional Thai gingerbread fretwork patterns that highlight the beauty of local craftsmanship. Utilizing a Creative Practice-Based Research approach, the study emphasizes design and experimentation. High-Density Polyethylene (HDPE) and Polypropylene (PP) plastic bottle caps are recycled through a melting process to create sheets, which are then used to craft modular fretwork patterns. These patterns are CNC-cut to produce prototypes suitable for shelves, light partitions, or other decorative elements. The prototypes are assessed for their cultural significance and sustainability through a modular design framework, alongside Siu's Outer–Intermediate–Inner Structure concept.

The evaluation conducted by four experts and six end-users demonstrated that the modular design utilizing recycled plastic bottle caps effectively met the research objectives, particularly regarding material quality, structural integrity, and usability. The design received a score of 4.00 (S.D. = 0.00) for structural strength and an impressive 4.50 (S.D. = 0.50) for assembly flexibility. Its versatility was similarly well-rated, achieving a score of 4.50 (S.D. = 0.50). User feedback highlighted the ease of assembly, which scored 3.83 (S.D. = 0.69), and noted good flexibility for reconfiguration, receiving a score of 4.17 (S.D. = 0.69). Aesthetic appeal earned the highest score of 4.50 (S.D. = 0.50). Suggestions for improvement included enhancing structural strength, adding safety features, and developing a supporting base system, indicating potential areas for future development.

Keywords: Modular Design, Plastic Bottle Caps, Gingerbread Fretwork, Home Décor

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Introduction

Plastic bottle caps play a crucial role in packaging by sealing, opening, and preserving beverages. However, despite their functional benefits, they present a significant environmental challenge, especially as small plastic waste in marine ecosystems. According to Geyer, Jambeck, and Law (2017), a mere 9% of all plastic ever produced has been recycled; 79% has ended up in landfills or the natural environment, while 12% has been incinerated. Moreover, plastic bottle caps are the third most frequently found litter item during global beach cleanups, with over 20 million pieces collected (Boonstra & van Hest, 2017). A report by Fletcher, March, Roberts, and Shiran (2023) highlights that the shape and size of bottle caps often lead marine animals to mistake them for food, resulting in ingestion and, ultimately, death. Additionally, plastic caps are made from rigid materials that can take hundreds of years to decompose, causing them to accumulate in the environment and break down into microplastics, which disrupt marine food chains.

Most bottle caps are composed of thermoplastic plastics, which can be recycled; however, the percentage that makes it into the recycling system remains low. Often, these caps are not processed in the same recycling stream as PET bottles (Gall et al., 2020). Recently, there has been a growing focus on recycling waste materials, such as plastic bottle caps, to create new products that possess both functional and aesthetic qualities. This concept is particularly enhanced when integrated with modular design, which emphasizes the creation of parts or modules that can be assembled, disassembled, and reconfigured in various ways. Modular design also facilitates ease of repair and part replacement while promoting better recycling prospects in the future, establishing it as a vital component of sustainable design processes (Li et al., 2022; Mazidah et al., 2024).

Melting plastics for reprocessing can pose risks to both health and the environment if not managed properly in terms of temperature and processes. Inappropriate temperatures during the melting or burning of certain plastics can release harmful volatile compounds, such as dioxins or furans (Hopewell et al., 2009). In this research, we implemented effective preventive measures, including controlling the melting temperature for specific types of plastics (HDPE and PP) within a safe range of 120–180 °C. Furthermore, we ensured an open space with adequate ventilation and selected equipment equipped with precise temperature control systems to safeguard the well-being of workers and the surrounding environment.

Despite the growing trend of utilizing waste materials in creative design, there are still constraints in creating products that meet the standards of aesthetics, safety, and usability. In some instances, these products may not match the quality of newly manufactured materials, particularly in the realm of home decoration (Kim, Do-Seung, & Jang, 2020). Furthermore, there is a scarcity of creative research that combines recycled materials with Thai cultural identity. To address this gap, the researcher suggests integrating traditional Thai gingerbread fretwork patterns, which are significant for their decorative, functional, and place-making attributes, into the design process.

Gingerbread fretwork is a distinctive style of woodcutting that draws inspiration from Western Victorian art and has been adapted to reflect the Thai context during the reigns of Kings Rama V and VI. These intricate patterns showcase the exceptional craftsmanship of Thai artisans and are commonly found in traditional Thai homes, historic commercial buildings, and the palaces of local nobility. They represent a unique blend of local architecture and foreign influence. Utilizing gingerbread fretwork as a design inspiration not only honors cultural heritage but also revitalizes cultural values through contemporary creation.

This research aims to investigate the potential of plastic bottle caps as a material for modular home décor, inspired by the unique patterns of Thai gingerbread fretwork. These designs are characterized by continuity, intricate detailing, and symmetry, aligning with modular design principles that emphasize assembly, adaptation, and reuse. The objective is to develop a design that balances functional, aesthetic, and cultural values in a systematic manner.

The research utilizes Siu's Outer–Intermediate–Inner Structure framework to analyze the various dimensions of perception and usage of the product. The Outer level addresses physical characteristics such as patterns and shapes; the Intermediate level pertains to practical applications, including assembly, modification, and utility in various contexts; while the Inner level reflects spiritual values, memories, and connections to local culture. This approach enhances the design's significance, meaningfully integrating modular structure with cultural identity.

Research Objectives

1.To study the potential of recycled plastic bottle caps as a material for modular home décor design.

2.To design modular home décor components using recycled plastic bottle caps, inspired by traditional Thai gingerbread fretwork patterns.

Hypothesis

1. The material derived from recycled plastic bottle caps has the potential to be effectively transformed into modular home décor materials, demonstrating suitability in terms of structure, strength, and aesthetics.

2. The design of modular components based on Thai gingerbread fretwork patterns can create home décor items that reflect cultural identity while responding to the concept of efficient resource use.

Conceptual Framework

The conceptual framework of this research intricately weaves together three essential components to develop a design that emphasizes material, functionality, and cultural significance. The process begins with the recycling of waste materials, such as plastic bottle caps, and applies modular design principles that promote circular economy practices by facilitating product reassembly and enhancing its lifespan. Inspiration is drawn from the elaborate patterns of Thai gingerbread fretwork, which serves as a vital aspect of cultural heritage and resonates seamlessly with the tenets of modular design. This approach is further enriched by the incorporation of the Outer–Intermediate–Inner Structure framework, enabling the assessment and articulation of deeper values related to social context, emotion, and cultural identity.

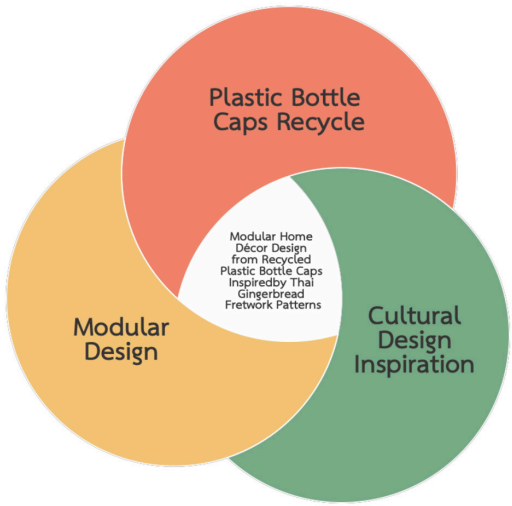

Figure 1. Conceptual framework

Source: Created by the author (Phueaknamphol, 2025)

1. Plastic Bottle Caps Recycling

Most plastic bottle caps are fabricated from materials such as Polypropylene (PP) or High-Density Polyethylene (HDPE), both of which are thermoplastics with melting points ranging from approximately 120 to 180°C. These materials can be melted and reformed without significantly altering their fundamental properties. They are lightweight, impact-resistant, and structurally robust when layered or stacked. Additionally, they are flexible in design, allowing for various shapes and sizes, and can be cut or carved into intricate patterns without becoming brittle (Aroonsrimorakot, 2020).

When bottle caps are melted and reformed into plastic sheets, they lend themselves well to modern technologies like CNC and laser cutting. These materials also facilitate modular assembly processes, such as drilling holes or joining corners, making them ideal for the design of home décor items that require disassembly, reassembly, or adaptation in diverse ways.

Recycling plastic bottle caps not only mitigates waste accumulation in the environment but also reduces the risk of these caps becoming hazardous marine debris. In the realm of interior design, using recycled bottle caps extends the material's lifespan, enhances its economic value, and promotes awareness of resource conservation. The surfaces of plastic sheets derived from melted bottle caps exhibit unique patterns and colors based on the

original cap hues, providing an opportunity to create distinctive artistic features for products. This characteristic aligns seamlessly with home décor design that emphasizes both aesthetic appeal and environmental sustainability.

2. Modular Design

The concept of modular design emphasizes the creation of components as smaller, interchangeable units or modules that can be disassembled, modified, repaired, or upgraded in specific parts, and reused in new configurations. This approach is vital in the context of the circular economy as it minimizes resource consumption by allowing for disassembly and improvements or part replacements without the need for complete re-manufacturing (Wongtongsanguan, 2022; Li et al., 2022; Mazidah et al., 2024).

3. Cultural Design Inspiration

Inspiration drawn from cultural heritage plays a crucial role in the design of creative products that embody both identity and social value (Keativipak, 2017; Wang, Z., 2022). This is especially pertinent in a time when product development trends emphasize sustainability, addressing both resource efficiency and cultural preservation. This aligns with the concept of a circular economy focused on responsible resource use alongside the enrichment of cultural values (Kim et al., 2020; Gall et al., 2020). Consequently, designers can leverage cultural heritage as a foundational element to create works infused with emotional depth, meaning, and social significance (Burke, Wallis, & Gorman, 2021).

The Outer–Intermediate–Inner Structure framework proposed by Siu (2003, as cited in Qin & Ng, 2020) serves as a useful tool for analyzing and adapting cultural symbols for contemporary products. The Outer level addresses physical attributes such as patterns, colors, or cultural motifs; the Intermediate level pertains to usage that reflects the consumer's lifestyle; and the Inner level connects to spiritual values or emotional ties. Furthermore, products inspired by cultural heritage can offer enhanced economic value and emotional resonance for users while simultaneously establishing market differentiation (Hsu, Lin, & Lin, 2011).

Research Methodology

The research design for this study is rooted in Creative Practice-Based Research, emphasizing the experimentation and development of home décor products crafted from recycled plastic bottle caps. This work draws inspiration from Thai gingerbread fretwork

patterns and employs modular design principles. The process unfolds in several stages, including the collection and preparation of recycled plastic bottle cap materials, analysis of gingerbread fretwork patterns, and the design of home décor products utilizing modular design principles. Each step is detailed as follows:

1. Collection and Preparation of Recycled Plastic Bottle Cap Materials

The researcher selected a method for transforming plastic bottle caps through melting and molding, utilizing heat to reshape the plastic into new products. The primary emphasis is on preserving the identity of Thai gingerbread fretwork patterns, which are intricate cut-out designs found on wood. A notable characteristic of these patterns is their function as light channels and their continuous, lace-like connections. By melting the plastic into thin sheets that mimic wood, the researcher enables precise cutting or perforation, facilitating the replication of this distinctive design.

Used plastic bottle caps, sourced from household waste, are collected and sorted by color before being thoroughly cleaned to eliminate dirt and stains. This cleaning process involves washing with environmentally friendly detergents, rinsing with clean water, and sun-drying to prepare the material for further use. Once cleaned, the plastic bottle caps are crushed to reduce their size, making the molding process more manageable. The color variations of the bottle caps depend on the packaging manufacturer, with white, blue, and green being the most common hues.

Figure 2. Crushed plastic bottles and bottle caps
Source: Photograph by the author (Phueaknamphol, 2025)

When bottle caps are melted and pressed using a heat press machine at a temperature of 180 °C, they produce a plastic sheet measuring 50 cm in width, 50 cm in length, and 1 cm in thickness. The width of the plastic molding mold determines the dimensions of the sheet. This plastic sheet serves as the foundation for creating patterns on the workpiece. The production of this sheet is supported by the community enterprise group “Transforming Waste into Value, Save the Sea, Charm of Ban Amphoe,” located in Chonburi Province.

Figure 3. The plastic press machine and the plastic produced from the pressing process
Source: Photograph by the author (Phueaknamphol, 2025)

2. Analysis of Gingerbread Fretwork

Gingerbread fretwork is a distinctive form of woodcutting that gained popularity during the Victorian era (1837–1901) and became prevalent in European architecture, as well as in countries influenced by Western culture. These patterns are marked by their interconnecting curved shapes, resembling lace, and often showcase the intricate beauty of Gothic art. Common motifs include tulips, spiral vines, geometric designs, and teardrops (Kuamsup, 2017).

In Thailand, the introduction of gingerbread fretwork patterns coincided with the transformation of traditional Thai houses during the reign of King Chulalongkorn (Rama V), following His Majesty’s visit to Europe. This artistic style merged with local architectural elements and gained popularity for decorating royal palaces, noble residences, and government buildings. These intricate patterns not only enhanced the aesthetic appeal of structures but also symbolized the cultural exchange occurring between nations at the time. Additionally, they served as ventilation openings, contributing to the regulation of internal temperatures within the homes.

The gingerbread fretwork patterns examined in this research were collected by the researcher from House No. 129 in the Chanthaboon Riverside Community. This house is noteworthy as an example of mixed architectural styles, reflecting influences from Thai, Chinese, Vietnamese, and Western cultures, particularly evident in its exquisite gingerbread fretwork. This location, part of a community with a history spanning over 300 years, was once a bustling trade area along the Chanthaburi River, recognized for its commerce in gems and other goods. The architectural design of House No. 129, with its orientation facing the street at the front and the river at the back, exemplifies the semi-commercial house style that was prevalent during the reigns of Kings Rama V and VI (Phueaknamphol, Joneurairatana, & Sirivesmas, 2024).

A striking feature of the house is the decorative wooden fretwork placed above the ventilation openings on the second floor as well as above the doors and windows, which adds both artistic and cultural significance. This fretwork showcases the craftsmanship of Vietnamese artisans of Chinese descent residing in the area, making House No. 129 a tangible representation of the cultural and aesthetic diversity within the community. The researcher identified gingerbread fretwork patterns located at the ventilation openings on both the first and second floors, on the doors of the second floor, and as decorative trusses within the house itself.

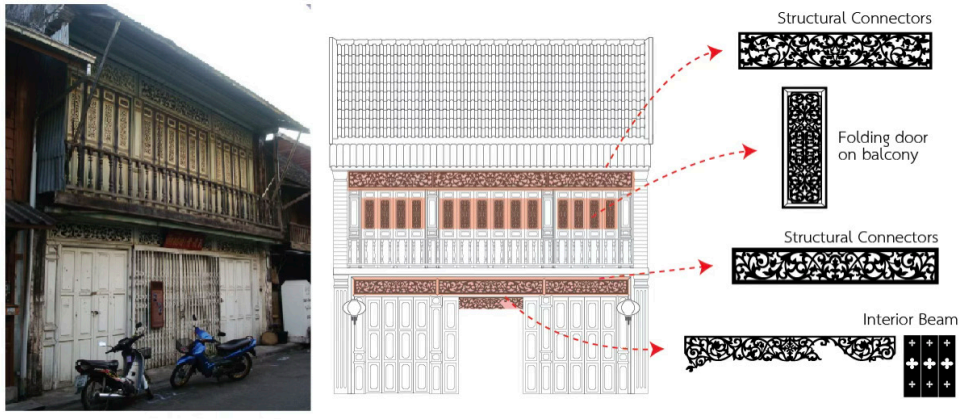

Figure 4. The gingerbread fretwork patterns found in House No. 129
Source: Photograph and illustration by the author (Phueaknamphol, 2025)

The researcher incorporated the pattern from the gingerbread fretwork on the second-floor ventilation openings with the decorative trusses inside the house. The main

motifs found, such as coil stems, flower blooms, flower buds, and leaves, were utilized in the design. The symmetry, characterized by equal balance on both the left and right sides—a key feature of gingerbread fretwork patterns—was applied and controlled to ensure that the cut-out design could support the weight.

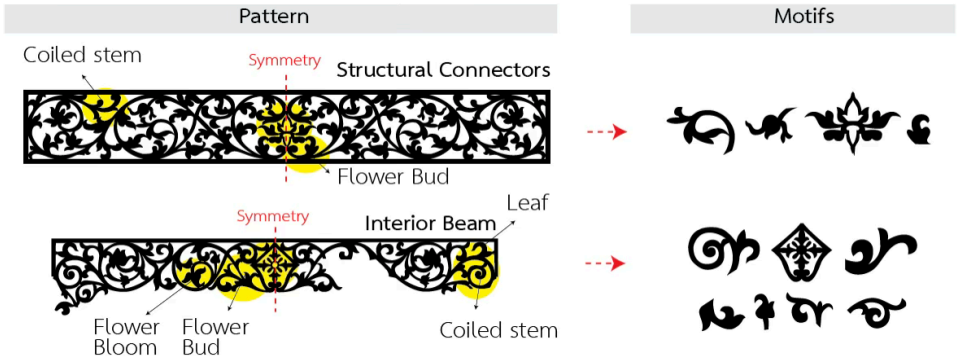

Figure 5. Analysis of the gingerbread fretwork patterns found in House No. 129
Source: Illustration by the author (Phueaknamphol, 2025)

3. The Design of the Shelf Using Modular Design Principles

3.1 Design: The unique characteristics of gingerbread fretwork patterns—such as their symmetry, graceful curves, and the seamless flow of lines—were utilized in organizing the elements of the modular design draft. The designer opted to use the structure of these patterns to shape the cut-outs, which can function as channels for light or as storage spaces. The forms created by the fretwork also affect the weight-bearing capacity of the piece and the arrangement of the modules. Experiments were carried out to strategically position the main design elements, including flowers, stems, and vines, in locations that would enhance both the strength and balance of the shelf. This approach not only improved stability but also created dynamic shadows when placed in actual spaces, all while maintaining the delicate essence of the gingerbread fretwork patterns and their intricate, lace-like connections.

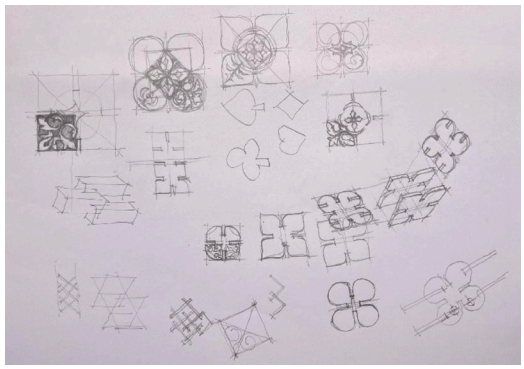

Figure 6. Pattern draft

Source: Drawing by the author (Phueaknamphol, 2025)

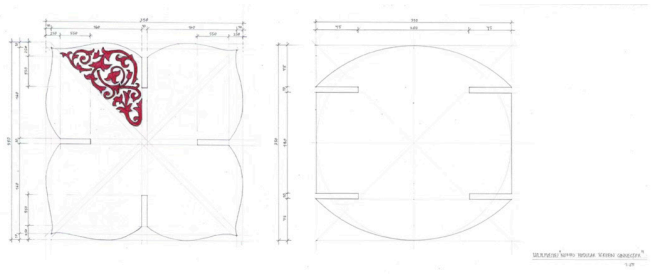

Figure 7. Production design

Source: Drawing by the author (Phueaknamphol, 2025)

3.2 Prototype Testing: After finalizing the draft design, we developed a production design that established the ideal size and spacing for the patterns. The design was then imported into Rhino3D to evaluate the arrangement of the patterns, specify dimensions, and assess overall functionality.

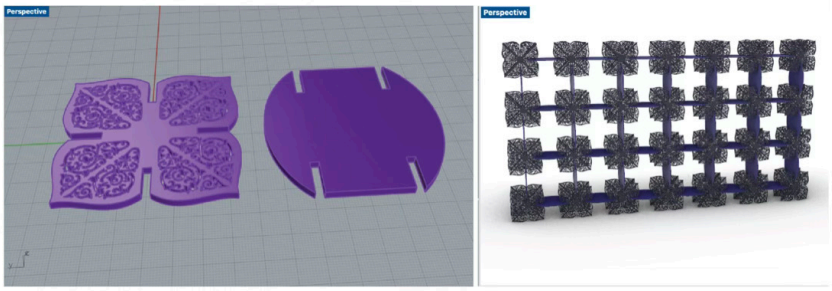

Figure 8. 3D modeling using Rhino3D software

Source: Created by the author (Phueaknamphol, 2025)

Following that, a 3D printer was utilized to develop a prototype for evaluating the assembly and layout of the modular design, while also investigating viable configurations with visually appealing attributes.

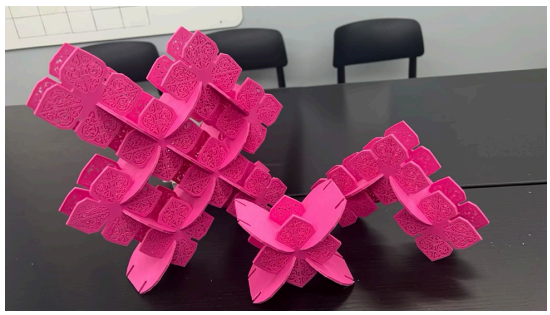

Figure 9. Testing the modular assembly

Source: Photograph by the author (Phueaknamphol, 2025)

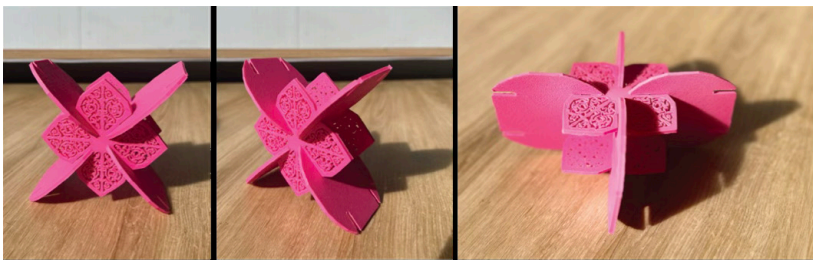

Figure 10. Testing the arrangement of the work

Source: Photograph by the author (Phueaknamphol, 2025)

3.3 Production: The process involves cutting the pattern onto a plastic sheet with a CNC machine. The resulting imperfect plastic pieces are then gathered and assembled.

Figure 11. CNC laser cutting of plastic sheets

Source: Photograph by the author (Phueaknamphol, 2025)

Research Results

1. Usage of the Design: This design serves a dual purpose as both a storage solution and a decorative element for interior spaces. Each modular unit comprises a total of six plastic sheets: two patterned sheets and four plain connecting sheets that form the main structure, enhancing durability. The versatility of each modular unit allows it to function as a wall decoration, an installation for interior lighting, or a small shelf. When multiple modular units are combined, they can be expanded into a room divider or a large decorative wall.

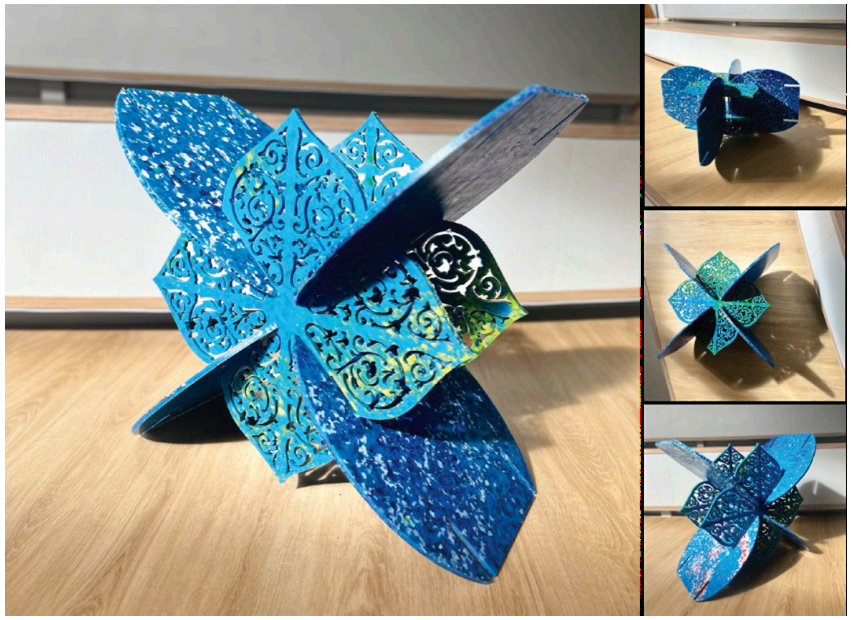

Figure 12. Design work

Source: Photograph by the author (Phueaknamphol, 2025)

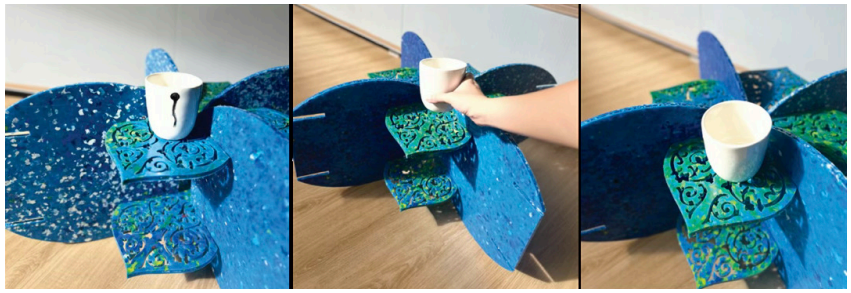

Figure 13. Design work and usage

Source: Photograph by the author (Phueaknamphol, 2025)

2. Materials and Production Process: This project utilizes two patterned plastic sheets, each measuring 35 cm in width, 35 cm in length, and 1 cm in thickness, with an approximate weight of 438 grams per sheet. Therefore, the total weight for both sheets amounts to 438 grams × 2 = 876 grams. Given that the average weight of a single plastic bottle cap is 1.2 grams, this means the project requires approximately 876 ÷ 1.2 = 730 bottle caps.

In addition, four connecting plastic sheets, also measuring 35 cm in width, 35 cm in length, and 1 cm in thickness, are used. Each of these sheets weighs about 706 grams, resulting in a total weight of 706 grams × 4 = 2,824 grams. Using the average weight of one plastic bottle cap, this portion of the project requires approximately 2,824 ÷ 1.2 = 2,353.33 bottle caps.

In summary, the final product consists of two patterned plastic sheets and four connecting plastic sheets, with a total weight of 3,700 grams and a cumulative use of approximately 3,083.33 plastic bottle caps.

Figure 14. Weighing the design to calculate plastic usage
Source: Photograph by the author (Phueaknamphol, 2025)

Table 1 Plastic Characteristics and Quantity Used in the Design

Topic	Quantity	Size (cm)	Weight (grams)
Full plastic sheet	1 sheet	50 wide × 50 long × 1 thick	2017 g
Patterned plastic sheet	1 sheet	35 wide × 35 long × 1 thick	438 g
Connecting plastic sheet	1 sheet	35 wide × 35 long × 1 thick	706 g
Bottle cap	1 cap	3 in diameter × 0.8 in height	1.2 g

This research utilized a range of technologies to create works from recycled plastic bottle caps. The process involved melting and molding the caps to reduce their size and transform them into a material suitable for various applications. CNC machining was employed to carve intricate, precise patterns into the plastic sheets, drawing inspiration from gingerbread fretwork. The Rhino3D software was essential for drafting patterns, testing

layouts, and adjusting dimensions to ensure they were appropriate for practical use. This approach enhanced the design process, allowing for refinement and customization to meet specific requirements. Additionally, a 3D printer was used to produce prototypes that tested the feasibility of the pattern arrangements and modular design, facilitating an evaluation of assembly and functionality before actual production.

Conclusion and Discussion

1. Results of the Modular Design Utilizing Recycled Plastic Bottle Caps

The prototype, crafted by melting and molding recycled plastic bottle caps, features a modular design. Each modular unit includes two patterned sheets and four structural connecting sheets. These units can function independently (e.g., as a storage shelf or lighting installation) or be combined for various applications (e.g., as a room divider or decorative wall). The total weight of each modular unit is approximately 3,700 grams, incorporating approximately 3,083 plastic bottle caps.

2. Results of Expert and User Evaluations

To evaluate the material properties, structure, and design concept of the prototype, four experts with over five years of experience in product design were engaged. They assessed the modular piece using a questionnaire that included seven key criteria, rated on a five-point satisfaction scale. The results of the evaluation are summarized in Table 2.

Table 2. Expert Evaluation Results (n = 4)

Evaluation Criteria	Mean	Standard Deviation (S.D.)	Evaluation Result Level
Material strength	4.00	0.00	Excellent
Structural strength when assembled	4.25	0.83	Good
Disassembly system	4.50	0.50	Excellent
Safety in use	3.75	0.43	Good
Flexibility in use	4.50	0.50	Excellent
Flexibility in assembly/expansion	4.75	0.43	Excellent
Clarity of the assembly system	4.00	0.50	Excellent

The design received ratings ranging from good to excellent across all criteria, with strengths in assembly flexibility and expandability. This highlights the practical potential of modular design for user applications. Although there were some suggestions to reinforce the attachment points for larger applications and to further improve the pattern elements, the overall assessment suggests that the design is well-suited for practical use and holds significant promise for product development.

To evaluate the suitability of the prototype for practical use, the research involved testing the design with a group of six users. Participants were tasked with assembling, disassembling, and using the product in various ways, and then completed an evaluation regarding usability, convenience, aesthetics, and overall satisfaction. The evaluation results are summarized in Table 3.

Table 3 Results of Real-World Testing by Users (n = 6)

Evaluation Criteria	Mean Score	Standard Deviation (S.D.)	Evaluation Result Level
Understanding of usage	2.67	1.89	Average
Ease of assembly and disassembly	3.83	0.69	Good
Flexibility in changing usage configurations	4.17	0.69	Excellent
Weight suitability for indoor use	4.17	0.69	Excellent
Aesthetic appeal and distinctiveness of the pattern	4.50	0.50	Excellent
Connection to Thai culture through the pattern	4.50	0.50	Excellent

The design received a high level of satisfaction, particularly in terms of usability, assembly flexibility, and the aesthetic appeal of the pattern, which clearly reflects Thai identity. While user understanding of how to use the product varied, additional suggestions—including reinforcing the connection points, refining the edges and corners, and improving the recycled plastic surface—underscore the design's potential to evolve into a home décor product that effectively meets the needs of users.

3. Exhibition and Field Testing

This research project was presented in collaboration with the community enterprise group "Transforming Waste into Value, Save the Sea, Charm of Ban Amphoe" in Chonburi Province. The objective was to assess the feasibility of using recycled plastic

bottle caps in the design of modular home décor. The exhibition took place at the Ban Suan Municipal Public Hall in Chonburi City on June 10, 2025, as part of the Marine Waste Management exhibition. This practical demonstration aimed to evaluate the potential of recycled plastic bottle caps as a material for modular home décor components while also raising awareness among community members about its applications.

Figure 14. The work was displayed at the Marine Waste Management exhibition at Ban Suan Municipal Public Hall in Chonburi City.
Source: Photograph by the author (Phueaknamphol, 2025)

The research findings indicate that recycled HDPE and PP plastic bottle caps can be converted into sheets suitable for home décor items through a melting and molding process. This technique allows for precise control over the material's properties. The resulting product is strong, lightweight, and designed for easy disassembly and reassembly. Furthermore, it is compatible with CNC pattern-cutting technology. Feedback from industry experts and end users has been overwhelmingly positive, underscoring the material's appropriateness for contemporary product design, particularly in terms of functionality and environmental impact.

For the prototype design, drawing inspiration from Thai gingerbread fretwork patterns in a modular format, the product can be adapted for various applications, including shelves and light partitions. The patterns have been thoroughly analyzed and refined to align with the modular concept, ensuring both structural integrity and aesthetic appeal, while also effectively conveying cultural values. This research meets its objectives in both material and cultural design aspects, showcasing the potential for future development into tangible products.

4. Discussion

The findings of this research correspond with the established objectives and hypotheses, demonstrating that recycled plastic bottle caps possess adequate structural and aesthetic qualities for development into modular home décor components. By melting and molding the plastic bottle caps into smooth sheets, followed by CNC machine carving, the material achieves a uniform texture, enhanced strength, and practical suitability, thus validating the first hypothesis of this study. From a cultural perspective, the design embodies Thai identity through gingerbread fretwork patterns inspired by traditional Thai woodcarving architecture, characterized by symmetry and continuous lines. These design elements resonate with the principles of modular design, which prioritize connectivity, expansion, and rhythmic reconfiguration. When applied to recycled materials, this approach yields products that offer both functional and aesthetic value while also encapsulating social and emotional dimensions, particularly in evoking memories and connections at the Inner level of Siu's Outer–Intermediate–Inner Structure. At the Outer level, the product showcases cultural identity through the visible gingerbread fretwork pattern. At the Intermediate level, the modular design accommodates various user interactions, such as arranging, installing, or disassembling. At the Inner level, the connection to historic homes in the community fosters emotional attachment and shared memories, especially among individuals with ties to the area or cultural heritage.

The analysis conducted by both experts and users supports the concept of modular flexibility, highlighting the design's adaptability for various applications. This aspect also embodies the principles of circular design, which emphasizes the reuse of resources to maximize value. Additionally, the prototype successfully meets material, structural, and cultural requirements, resonating with the work of Jamroenpuek (2024), who explored the potential of using recycled plastic materials in modular design for decorative applications. Moreover, the ability to disassemble and create patterns that reflect individual identity closely aligns with Srikhongchan's (2022) proposal for modular design aimed at enhancing product flexibility in confined spaces.

This research has certain limitations, including the energy required for melting plastic sheets, dependence on specialized production technologies, and the necessity for tools that are appropriate for community-level use. Additionally, enhancing the connection points to better support weight may be required, and conducting long-term environmental testing represents a crucial area for future inquiry. Nonetheless, the findings indicate that

recycled plastic bottle caps hold promise as a versatile material that can reflect local culture while yielding products that excel in functionality, aesthetics, and social value.

Recommendations

1. The development of small-scale production systems capable of efficiently and sustainably processing plastic bottle caps is essential. This could involve designing mobile plastic melting machines or DIY kits for everyday users, which would promote the sustainable reuse of waste materials and create local employment opportunities.

2. Furthermore, it is important to study the long-term durability of materials made from recycled plastic bottle caps, assessing their resistance to sunlight, heat, humidity, and impact to determine their suitability for real-world applications. Conducting Life Cycle Assessments (LCAs) would also provide valuable insights into the environmental impact of these materials.

3. In addition, strategies to communicate the value of these products through storytelling should be developed. For instance, incorporating QR codes that detail the design process, source of materials, or inspiration drawn from gingerbread fretwork patterns would enhance emotional engagement and elevate the cultural value of the products, making them more meaningful.

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