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Research on Development of Circular Design of Sustainable Products for Resource Reuse under Circular Economy

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Abstract: Nowadays, many design models and strategies are mentioned in the development of a circular economy, and enterprises also are adopting their applicable implementation methods. There are different levels of consideration of the circular economy from the selection of raw materials to the production process of products and the final recycling. Therefore, it is required to further explore and analyze how and when companies better create and how they value sustainable products. Therefore, this research was carried out to understand the company's design thinking model for product sustainability and find out the relevant vital elements. After completing the expert interview, grounded theory was used to analyze the collected data by grouping them into the categories of "open coding", "axis coding" and "selective coding". The results allowed the understanding of all aspects of sustainable product design development such as the current environment, design methods, operations management, loop feedback, and future-looking projects. At the same time, a feasible business model with a sustainable product cycle design was discussed. Based on the result and discussion, suggestions and opinions were made for the practical circular design of enterprises, the direction of the design and necessary considerations, and the implementation of the design as references for sustainable product development of the industry.

Keywords: circular design, circular economy, sustainability, design thinking

1. Introduction

In a linear economic model, the product cycles without priority. Currently, the consumption rate is 50% higher than the replacement rate, and the demand for resources and commodities is increasing (Siegel and Bautista, 2014). The linear economic model of "mining, manufacturing, consuming, and discarding" has been inadequate for the needs of today's society and the goal of sustainable economic development. Hence, the emergence and development of the "circular economy" (Ghisellini et al., 2016) was proposed. The circular economy aims to provide society with well-being, economic growth, and jobs while reducing pressure on the environment (EEA, 2016). The European Union has been actively promoting the circular economy with the main goal of building a closed circular operation in the economy. Materials normally end their life cycles as wastes but most of them can be recycled through repair, refurbishment, and recycling (Su et al., 2021). Many Taiwanese companies pursue and promote the circular economy in the new era and are active in the research and development of circular economy-related technology, innovative business models, and future economic and trade rules (Huang, 2017).

The total amount of waste in Taiwan was 10,062,344 tons in 2021. Among them, general waste accounted for 38.8%, resource waste accounted for 56.3%, and kitchen waste accounted for 4.8% (Figure 1). The Recycling Foundation explained that during the pandemic, the number of people traveling abroad has decreased sharply, and most economic activities were not resumed until 2021. "Consumption is the output of waste containers", and the subsequent demand for reuse increased the overall recycling volume (Environmental Information Center, 2022). Unusable materials are discarded as "garbage". However, most of them can be recycled or upcycled with a sustainable design, which gives new value and life to the waste with reduced environmental harms and ecological impacts providing new business opportunities (Buchner et al., 2017).

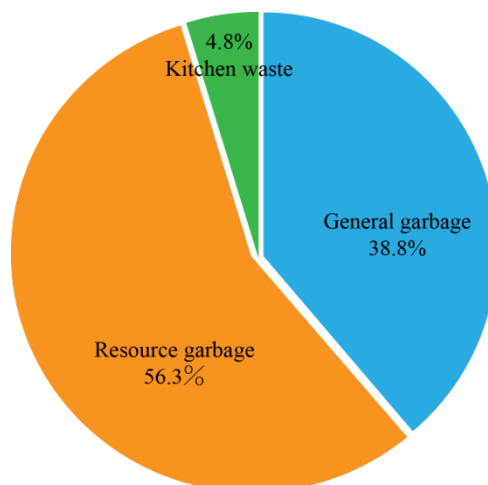


Figure 1. Percentage of total wastes in 2021.

Taiwan is a country that lacks natural resources. The waste and pollution problems in the past were the result of "resource misplacement". Due to unsophisticated economic models and poor product design, resources were not fully recycled, resulting in increased waste and pollution (Li, 2019). Given this, Taiwan has been committed to promoting the 6R policy of "resource recycling and zero waste" in recent years: Reduction, Reuse, Recycling, Energy Recovery, and Land Reclamation. There has been a change in the design and the concept of sustainable material management. Based on the previous waste management, it has been promoted that overall resource recycling improves domestic resource productivity and recycling rate and reduces direct material use (Environmental Protection Administration, Executive Yuan, 2020).

To convert waste into products, an effective cycle from resource acquisition to disposal is required for the reduction of waste. Appropriate design, production, and packaging as a system are necessary in reducing waste (McDonough and Braungar, 2018). Two circulatory systems of biological and technical cycles are an example of such a system, which is the so-called Cradle-to-Cradle (C2C) system (Figure 2). In the biological and industrial cycle, biological and industrial materials are used as raw materials for production. When the life of a product is over, biological and industrial materials are re-formed through biological decomposition or recycling and dismantling and enter another cycle smoothly.

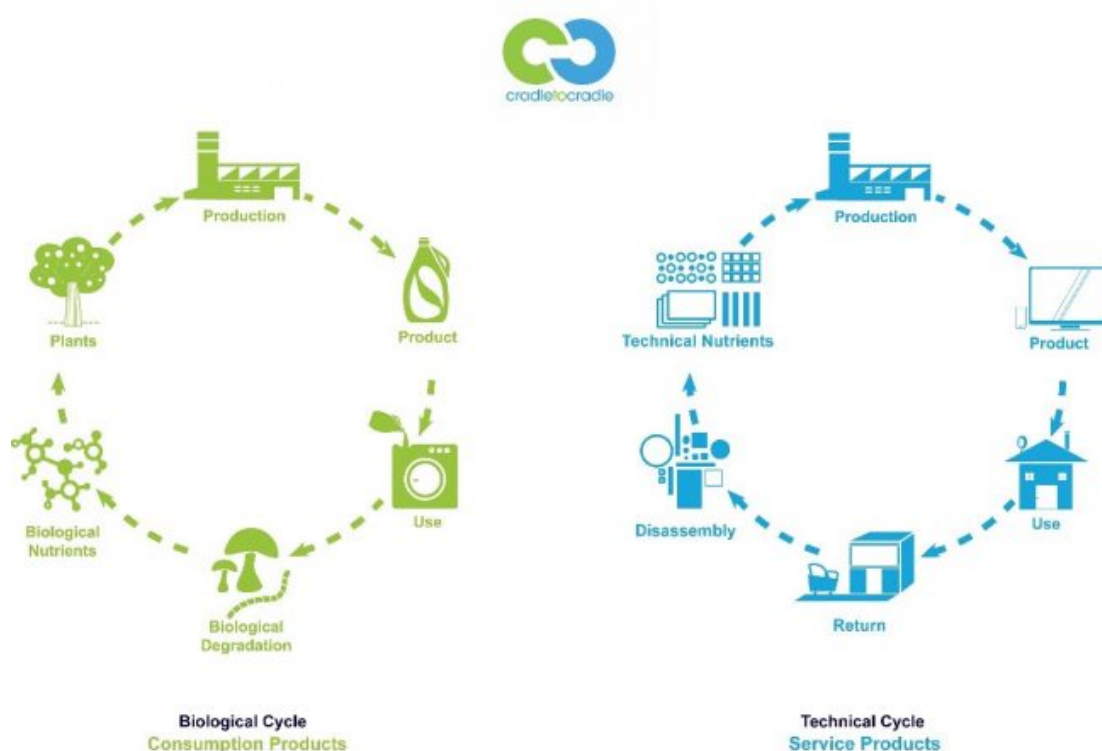


Figure 2. Cradle-to-cradle design.

(Source: Taiwan Cradle to Cradle Platform, 2016)

The Ellen MacArthur Foundation (EMF), the world's most influential circular economy organization, emphasizes that "design" is an integral part of the circular economy (Song and She Jiaui, 2018). Therefore, when designing products, enterprises must have a completed set of planning for the process from production to recycling. EMF and IDEO jointly released the Circular Design Guide, which defines four stages: (1) Understanding (Understand), (2) Definition (Define), (3) Action (Make), and (4) Release (Launch) as described in Table 1.

Table 1. EMF and IDEO circular design method guide

	Explanation
Understand	Learn about different circular design solutions and gain a deeper understanding of how to move from linear to circular thinking.
Define	Articulate a challenge, find opportunities for circularity, whether you are starting a project or revising an existing one, and set goals.
Make	Understand user needs, exchange ideas, develop concepts, make them tangible by building prototypes, and test them to learn.
Launch	Put the concept on the market to gather feedback that will allow the product or service to evolve and generate the necessary changes.

(Source : <https://www.iberdrola.com/social-commitment/circular-design>, 2017)

To plan an applicable sustainable circular economy, linear production needs to be transformed into circular production. User-centered various designs are used to make prototypes. Ultimately, the concept is introduced to the market, and feedback is continuously collected to allow continuous improvement of the product and service. Therefore, for enterprises to create sustainable products, they must take into account the composition of the product, the manufacturing process, and the needs of consumers to form an effective resource recycling system.

The above-mentioned C2C design concept needs to be applied with the circular design method of EMF and IDEO. As there is an effective integration of resources and changes in consumer cognition and behavior, a bond between manufacturers, designers, and consumers is required to make an effective regeneration system. Therefore, in addition to the establishment of a circular economy model mentioned by TDRI (2022), the specific circular design strategy proposed by EMF and IDEO is necessary. The circular design strategies have six key directions: a design for internal circulation (Close Loop/Take back), product life extension, product as service, smart material choices, embedding intelligence, and modularity, details (Table 2).

Table 2. EMF and IDEO cycle design strategy

Strategy	Explanation
Closed Loop/Take back	Adopt recycling, sharing, remanufacturing and repair, and refurbishment, prioritize internal recycled components, and design products to be easily repaired or remanufactured.
Product Life Extension	Let the product withstand wear and tear so that the life product was extended as much as possible, or the product was used multiple times, reused, or even provided to different users.
Product as Service	Instead of selling items forever, offer customers a variety of products through rental, subscription, or sharing.
Smart Material Choices	Choose safe and recyclable materials to create better products and services for users.
Embedding Intelligence	Digitization is a common example, through design optimization to use the minimum amount of physical material to manufacture products, or even

	convert products from physical to virtual.
Modularity	The modular design is to make the product easy to repair and re-manufacture. Make the product simple, only need to disassemble some parts, easy to disassemble, reduce the cost and workload of replacing parts when damaged.

(Source : <https://www.tdri.org.tw/37312/>, 2017)

The application of these strategies is similar to the four circular economy models proposed by Moreno et al. (2017) including (1) resource flow narrowed, (2) industrial symbiosis, (3) cycle time longer, and (4) resource cycle slowed down. Enterprises must realize that resource recycling enables materials to be continuously supplied and exported and effectively reduces the waste of resources. On the other hand, manufacturers design products that are easy to recycle, durable, and easy to repair. Enterprises even need to provide product services and develop sharing platforms, allowing consumers to think about the value of product sales, share resources, and achieve the effect of saving energy and resources.

In general, many different design patterns and strategies have been mentioned for the development of the circular economy. Major companies also have applicable implementation methods. There are different levels of consideration, from the selection of raw materials to the production process and the final recycling of products. Therefore, we explore and analyze how companies measure and create sustainable products. When enterprises develop various types of sustainable products, appropriate methods are adopted according to their characteristics. Therefore, this study is carried out with the following objectives.

- (1) Understanding the practical business model and philosophy of enterprises for circular design
- (2) Discussing the considerations of circular design for sustainable products
- (3) Implementing sustainable circular design based on research data in relevant businesses

2. Materials and Methods

2.1 Research Architecture

The circular economy pertains to every product. From design, manufacture, production, recycling, and to the unusable status, the circular economy is applied. Different recycling processes are found in a complete manufacturing process (Office of Small and Medium Enterprises, Ministry of Economic Affairs, 2018). Based on the expert interviews, we proposed a design thinking model for sustainable products and relevant elements. The research was conducted in the following four phases.

- (1) Research design: The model of the sustainable cycle and development status was understood through a literature review.
- (2) Expert interview: The expert interview was carried out to understand sustainable product design.
- (3) Data collection: The data was collected from expert interviews followed by data coding and analysis based on grounded theory.
- (4) Analysis and discussion: The analysis results were used to construct a sustainable circular design for products.

2.2 Research Objects and Methods

For the interview, three experts were invited who were the design directors of Red Army Jewelry, Dot Eye Design, and Green Box Round Design. The purpose of the expert interviews was to understand the details of the practices and considerations when developing sustainable circular designs for products. The interview was conducted using a semi-structured method, being consented to by the interviewees via email. In-depth interviews were conducted with the research questions which were adjusted or supplemented according to the needs of the on-site interviews. The whole process was audio recorded. After the interview, the audio files were converted into drafts using verbatim, and all the interview materials were summarized as the basis for the development and discussion of this research. The personal data of the three respondents were shown in Table 3.

Table 3. Objects of expert interviews

Number	Title	Affiliated unit	area for research
A	Design Director	Red Army Jewelry	Metalworking and Silver Design
B	Design Director	Dot Eye Design	Cultural and creative product design
C	Design Director	Green Box Round Design	Circular product design

3. Results

We recorded the opinions of the three experts on circular design for sustainable products. After completing the expert interview, grounded theory was applied to compile the data for this research. Through "open coding", "axis coding", and "selective decoding", the data was reorganized. A total of 30 codes were obtained as shown in Table 4.

Table 4. Number of codes from the three experts

Expert	Number of codes
Red Army Jewelry (CA1)	11
Dot Eye Design (CA2)	12
Green Box Round Design (CA3)	7

After completing the coding, categories were defined with 4 optional and 7 spindle codes were selected from the 30 codes as shown in Table 5. In the design method, the operation methods of the circular design mentioned by each company were provided as references. In terms of the corporate's design strategy, various methods were applied for circular design. The company's circular design and related business model bring advantages and benefits through resource recycling to the companies.

Table 5. Optional code, spindle code, and explanation for the codes in this study

Optional code	Spindle code	Explanation
Sustainable development	Situation	CA1.1 "Circular Economy" was a powerful tool for corporate organizations to implement "carbon emission reduction" and "climate change response". CA2.1 The international community was paying more and more attention to sustainability. The positive aspect of CA2.2 sustainability was to reduce the waste of resources. CA2.3 The more popular trends in recent years: were plastic reduction, recycling, reuse, and zero plastic. CA3.1 For most Taiwanese companies, the issue of sustainability was still environmental sustainability. They feel that it was an investment, not an activity with immediate economic benefits.
	Future outlook	CA2.5 hopes that in the past few years, we will try our best to promote the concept of sustainable design and actual products so that the world and society can accept more of such a theme. CA3.2 The sustainable trend should be discussed in a more comprehensive way, namely the environment, the economy, and the community.

		CA3.7 Pay attention to design and not start from the product, but start from the service.
Design development	Circular design operation	CA1.2 The circular design operation mode of Red Army jewelry: use of renewable energy→product modular design→3D printing technology→online shopping virtual platform→maintenance and repair services→recycling mechanism. CA3.3 The service process includes pre-service, design consultation in the middle, design time in the back, and after-sales service at the end.
	Corporate Design Approach	At the beginning of the modular design of CA1.3, whether its specifications are easy to disassemble, maintain and replace is considered. CA1.4 The service of the recycling mechanism needs to consider the circular economy and the profit of the enterprise, formulate an easy-to-understand service policy, and strike a balance between the two. The first part of CA2.4 is the brand of free design and the circular design, and the second part is the design service of sustainable design. CA2.6 considers many factors. 1. Attenuation and aging of materials. 2. It is the strength of the material. 3. Suitability of remanufactured materials. 4. The selling price of the product. CA2.11 Enterprises can introduce design thinking and models to understand consumers' perspectives from the user experience. CA3.4 focuses on the design phase and plans with the user as the center. The two links of the user center and product service are the factors that we need to focus on. CA3.5 When designing products, design the follow-up service process to the recycling

		process, even to the end. Assuming a product needs to be recycled, planning for the recycling process and its economic benefits are required.
Mode of operation	Circular design driver	CA1.5 In the process of promoting the sustainable cycle, employees need to agree with and understand the concept of the company's promotion of this service. CA1.8 Obtain the consensus of all stakeholders in the production and sales process. CA1.9 Whether the enterprise's business model can adapt to the resource recycling business model. CA1.10 Organizational culture and employee identity. CA1.11 Whether the main consumer groups of the enterprise have sustainable consumption awareness.
	Company strategy	CA1.6 Reasons why consumers are willing to buy products with sustainability awareness. In addition to sustainability awareness, sellers also provide consumers with after-sales service for the products they purchase. In addition, when consumers no longer wear them, they can recycle them at discounted prices, and then buy new styles, saving money, space, and time at the same time. About 70%~80% of consumers are willing to support CA2.7. There are two main reasons why CA2.8 is willing to buy sustainable products. The first is that he is a person who supports sustainable products, and the second is to buy them as gifts. CA2.12 All the information in the entire circle should be very transparent and clear. CA3.6 If a consumer has a demand for a sustainable product and meets his expectations, he will naturally have the willingness to buy it.
	Benefit	CA1.7 Reduce raw material input costs. Save process cost.

		Value-added brand image. Develop the second curve of the enterprise as the driving force for the growth and sustainable survival of the enterprise. CA2.9 If a large company promotes sustainable recycling, it will help its ESG annual report, which in turn will greatly help the company's listing, OTC listing, or sustainable and corporate responsibility. CA2.10 The benefits of sustainable development of small and medium-sized enterprises bring publicity effect to the company. Bring different competitiveness to the product.
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4. Discussion

We integrated and summarized the interview data with grounded theory. As a result, all aspects of sustainable product design were extracted and summarized into categories such as project status, design method, operation management, circular feedback, and future outlook (Figure 3). The concept of sustainable design has become a trend in recent years. To create sustainable products, an effective circular design needs to be constructed based on material selection, modular considerations, product recycling, and after-sales service. To implement sustainable design and development plans, effective cooperation between operational and management teams is required through employee training to raise awareness of sustainability and make sustainable management possible. The effective feedback obtained from the above process helps realize cost reduction, brand image enhancement, and ESG management. At the same time, in the future, it is needed to continue to promote the concept of sustainable design so that more companies adopt the sustainable design.

After understanding the design and development of sustainable products, operations with sustainable circular designs are required. Through expert interviews, it was found that different companies operate in different ways, however, similarities were found. After summarizing and integrating, a set of business models with feasible sustainable product circular design was developed as shown in Figure 4. To understand circular design, design thinking is demanded for product development. In terms of material selection, renewable energy was used, while the product itself adopted a modular design. In the promotion part, there was used the official website and social media to promote the concept of circular economy, provided maintenance and after-sales service, and extended the life cycle of products. Finally, offer take-back mechanisms and even discounts to encourage customers to participate in take-back programs.



Figure 3. Elements in sustainable product design development.

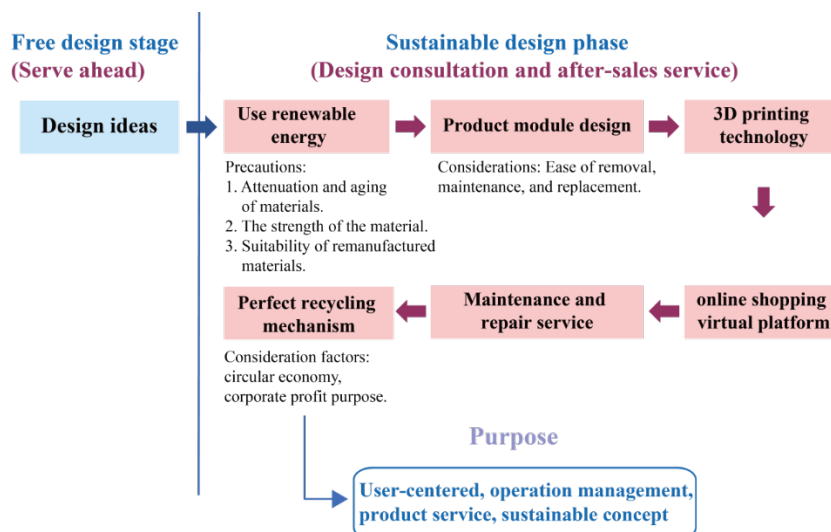


Figure 4. Business model with sustainable product cycle design.

5. Conclusions

From the literature review and expert interviews, the concept of sustainable circular economy and design was reviewed and the business model based on the concept was discussed in this study. The development of products needs to be based on circular design to conform to the concept of the circular economy. In this research, the following conclusions were drawn.

(1) The operation with the circular design needs to be implemented into the following.

- Manufacturing:** The modular design is needed to manufacture products that are easy to disassemble, maintain and replace. With 3D printing technology, the design can be changed in real-time. After the design is completed, manufacturing products can be performed immediately to shorten the process and reduce the use of raw materials.
- Recycling:** The operation needs to provide continuous maintenance services and means to recycle the product that is unusable at a preferential price.
- Management:** Employees must identify and understand the company's concept of promoting sustainable recycling, and a consensus among all stakeholders in the production and sales process must be obtained.

(2) The industry must accept the design of sustainable products. First, materials that can be reused must be chosen, and renewable energy needs to be used for manufacturing. The applicability of the material must comply with Taiwan's regulations, and it must be sure that the material does not contain harmful substances. Finally, the price must be considered to avoid spending a lot of cost on recycling the material. Otherwise, products with circular designs may result in higher prices than normal products. Therefore, the added value of products must be increased by combining circular design with sustainable recycling.

(3) In terms of promoting sustainable products with circular designs, ESG activities are important. Small and medium-sized enterprises compete fiercely in the market. Therefore, those who want to promote business models with the concept of circular economy and design must establish effective recycling systems based on the appropriate product design, material acquisition, product production, and recycling method. The recycling of products and materials must be conducted transparently. At the same time, employees must agree with the company's concept of sustainable recycling and explain the importance and significance of sustainable recycling to consumers. From this, consumers can be aware of sustainable development to agree with manufacturers, sellers, and consumers on the goal of sustainable development.

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