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Developing a Decision Model of Sustainable Product Design and Development from Product Servicizing in Taiwan

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In response to the global trend of low carbon and the concept of sustainable development, enterprises need to develop R&D for the manufacturing of energy-saving and sustainable products and low carbon products. Therefore, the purpose of this study was to construct a decision model for sustainable product design and development from product servicizing in Taiwan. The study used the grounded theory to extract the results of the expert interviews to analyze factors of sustainable product design and development under principles of product servicizing. Then, this study established a sustainable development checklist of product servicizing based on life cycle as the criterion of evaluation for sustainable product design and development. Finally, the study constructed a decision model for sustainable development of product design and servicizing.

Keywords: product servicizing; life cycle; sustainable development; low carbon society; office furniture

INTRODUCTION

In recent years, due to the rapid development of industry, carbon dioxide and other greenhouse gases accelerate global warming and climatic change, spread new environmental and ecological diseases, etc., thus, posing a threat to human life. Therefore, in response to worsening "global warming" and "climatic change" issues, and to achieve 21st century stable atmospheric greenhouse gas concentrations below 450ppm, strengthening the reduction of the greenhouse gas emissions and capping total emissions has become a national policy priority(Saikku et al., 2008).

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According to the Copenhagen Accord, by the end of the January 2010 deadline, countries submitted their commitments to reduction targets and National Appropriate Mitigation Actions, (NAMAs) to the United Nation Framework Convention on Climate Change, (UNFCC), which indicate significant progress in two international agreements: (1) a more active commitment to reduction targets, with an average reduction of about 20%, and (2) developing the reduction targets (emissions and baseline emissions). To achieve the above objectives of the Accord, promoting a Low Carbon Society and Green Economy has become the most important national policy strategy (Ye et al., 2015). Thus, how to slow down the speed of generation and emission of greenhouse gases through the Low Carbon Society concept is an important issue and challenge currently facing humanity for sustainable development and environment maintenance.

The concept of servicizing to achieve dematerialization objectives is in line with the trend of a low carbon society. White et al. suggested providing functions or services to replace previously sold products, which reduces the output and sales of physical products in order to improve resource and energy use efficiency and reduce waste generation, thus, achieving the goal of dematerialization and ultimately improving the impact of product life cycle on the environment (White et al., 1999). Servicizing is mainly to provide product features to meet consumer demand and reduce the total product production capacity to promote an environmentally oriented product design environment (Sun & Meristo, 1999; Herman, 1990; Beuren, 2013; Ijomah, 2009). Therefore, the establishment and application of more servicizing can help the development needs of the impending low carbon society. Regarding this purpose, sustainable product design and development concepts can be further extended to the level of service. A complete set of products and services to meet consumer demand and reduce the total production volume of products, as well as repeated use and remanufacturing of products, materials, and components, can lead to more efficient use and reduced consumption of resources and waste generation to achieve dematerialization through the best use of materials, thereby, lessening the impact of product life cycle on the environment (Ricardo et al., 2012; Lifset & Graedel, 2015; Guidat, 2014).

Therefore, with the construction of a decision model for sustainable development of product servicizing under a low carbon society as the goal, and through literature review and expert interviews, this study proposes indicative development guidelines for a decision model of sustainable development of product servicizing under a low carbon society as the basis of sustainable development of product research and development, before constructing a decision model for sustainable development of product servicizing under a low carbon society, with the empirical case study of "executive desk" furniture. As a result of study, the research findings

State of the literature

- The majority of researches only conduct life cycle assessment over existing products, which offer limited assistance to the development of new products.
- It is difficult to apply the overall product design process by assessed improvement for a single period, as it cannot understand the impact of the product's life cycle during product development.
- Based on the suggestions of expert interviews, this study learns the situation faced by the office furniture industry in Taiwan. In order to comply with the regulations of environment, relevant small and medium-sized enterprises intend to overcome such issues.

Contribution of this paper to the literature

- The main contribution of study is to help the office furniture industry in Taiwan to find suitable models for sustainable development of products through decision-making model.
- The decision-making model of product servitization in this study enables enterprises to conduct preamble assessment and testing during product R&D. The advantages of model lie that the assessment methods are apt to be employed by enterprises to conduct overall environment an assessment.
- This study is based on the green life cycle, tests the sustainable design and development and inspection product servitization, selects different improvement resolutions through the life cycle design strategies of LiDS, and assesses and compares the overall improvement of different resolutions.

can help companies implement the management of new ideas of both economic development and environmental protection, and create a more sustainable business model. The findings provide Taiwanese companies with different thoughts and visions for business operations, bring new development opportunities, and create a new era of peaceful coexistence between humans and nature, thus, achieving a new vision for a "low carbon society".

Product servicizing

Servicizing is based on products, and combines the boundary between traditional products and services departments, and closely links the manufacturers with product life cycle (Figure 1), meaning enterprises provide services to replace product sales, and the ownership of products still belongs to the enterprises (Ijomah, 2009). As most consumers only require the function available from the product, rather than the product itself, consumers could use the product by payment, while requiring the enterprises to directly provide the function and service of such products.

Mont (2001) divided the patterns of product servicizing into 2 categories, including primary pure services and secondary product-based services. The former services that do not need products are rather few, for instance, extension of fixed services, while the latter could be sub-divided into services that are beyond products, and replace products. Services that are beyond products generally refer to services that accompany aftersales of products; while services that replace products have the greatest potential field for product servicizing, which are categorized into use-oriented and result-oriented services. Figure 2 shows the classification of product servicizing. The use-oriented services mainly focus on product use, such as sharing and taking buses; while the result-oriented services are not focused on products sold in the market (e.g., pesticide), but expect the results of products for the right price (Integrated pest management). For example, it boasts integrated pest management, which could save 50% of the pesticide cost for farmers and increase output.

The emergence of product servicizing provides the win-win strategies of creating economic benefits and eco-friendly environments. There are many cases of product

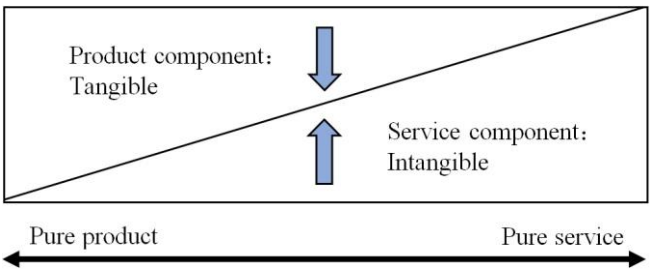

Figure 1. The combination of products and services

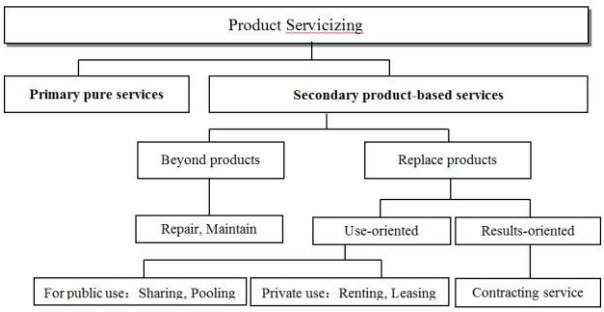

Figure 2. The classification of Product servicizing type

servicizing in society, such as leasing automobiles, office equipment, etc.

Mont suggested that product servicizing is conducive to the overall ecology, and stimulates enterprises to think how to meet customer demand, while using relatively less materials and energy, and promoting resources regeneration and reproduction, which is capable of achieving the objectives of Dematerialization (Mont, 2002). Only when enterprises are liable for the likely environmental impact during product consumption and discarding periods would they seriously consider how to design products that achieve maximum user rate and effective recovery rate. Product servicizing extends the manufacturers‘ liabilities, and enterprises must consider how to internalize follow-up service costs in order to reduce production quantity and increase use quantity (Vezzoli et al., 2015). The environment benefits likely to be generated for product servicizing can be categorized into 3 types: (a) reduction of resources and energy use quantity; (b) reaching the scale economy of recovery and disposal; (c) effective management of hazardous substances.

Product service systems

The concept of product service systems was put forward by economist Stanley Jevone in 1871, namely, the durable products we own are not what we expect to own in an absolute manner, and if they are rearranged, the effect of products might be enhanced. For example, leasing, subletting, or seeking common owners to possess. Proposed in in the 1990s, the concept of product service systems has relatively intensive research and promotion, which shows that the product service systems have been receiving attention in recent years.

Mont further defined it as “a system which combines products, service, personnel and support framework. The system has competitiveness, can satisfy customers’ needs and have lower environmental impact than traditional system”. In the statements of Mont, three concepts are important. First, PSS is a combination of products and services and it should be comprehended from the perspective of the system. Secondly, it should have market competitiveness and satisfy customers’ needs. In other words, it is valuable innovation that can deal with market competition (Mont, 2002). Finally, its impact on the environment is low. It is a new development model for a sustainable society and it can enhance the benefits of sustainable products (Hung, 2012; Silveira, 2001).

In the classification of product service types proposed by Tukker in 2003, the three orientations were further subdivided into the eight subcategories, as shown in

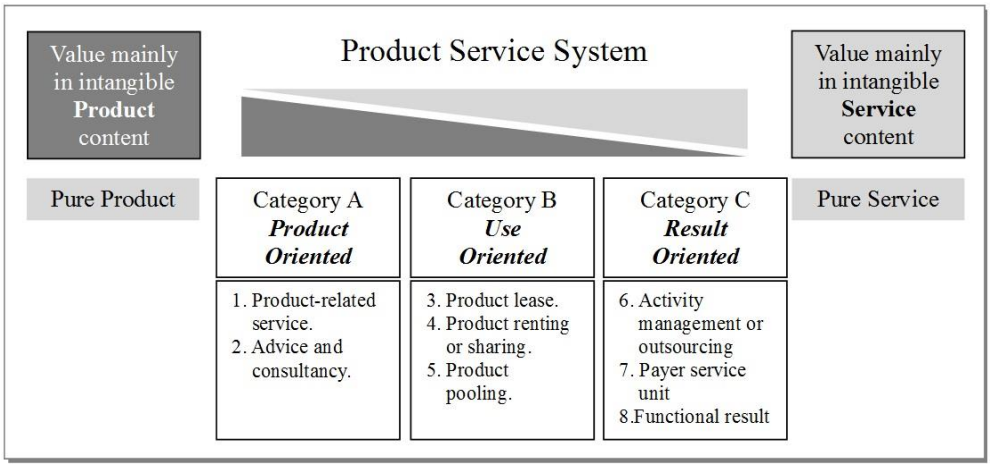

Figure 3. Eight categories of product service system proposed by Tukker

Figure 3 (Marcel et al., 2009). It is known that, among the 8 service types of product service systems, many different industries have introduced new business models, thus, it is no longer only one type of service model, but a compound and diversified product service system. It can be seen that the applications of product service systems have become one of the inevitable important strategies for enterprises to develop commercial models (Vezzoli et al., 2015; Herman et al., 1990; Marcel et al., 2009).

Sustainable product design and development

In 1992, in "Changing Course", Stephan Schmidheiny, the founder of BCSD, pointed out that the previous views of industries being the main cause of destroying the environment should be transformed into "industries critical to sustainable development worldwide". Enterprises could still gain profits by mastering business opportunities through combining environmental improvements and society. As a result, the concept of "Eco-efficiency" was gradually developed; where products produced by traditional industries are profit-oriented; while green enterprises that introduce ecology benefits have green economic marketing from "birth to death" and "from cradle to cradle", and are no longer profit-oriented, but mutual reliance and long-term cooperation oriented. Moreover, based on the "sustainable production and consumption" of ecological benefits (Figure 4), it emphasizes the appropriateness of resource use and reduction of the quantity of waste, and achieves the goal of environmental quality and sustainable development through efficiency in production and change of the consumption model.

The concept of sustainable design aims to enable tangible and intangible factors, such as products, parts, systems, and services to better conform to environmental protection requirements. Elkington (1986) pointed out that green design is "recyclable, low-pollution, and energy saving". The designers endeavor to employ the methods of product recovery and regeneration to make waste materials into new products via reuse or total recovery, meaning a cycled product life cycle rather than the product design itself.

According to Burall, the author of *From Cradle to Cradle*, "the generation of waste means the failure of the design". "Designers should know the end of products from the product design period, and how to begin another cycle. The key point in design is that, prior to the formation of a concept, the impact of products on the environment is considered, then the damage of environmental impact is mitigated" (Cohan, 1996). A good design strategy has great significance, as it is decided during the design

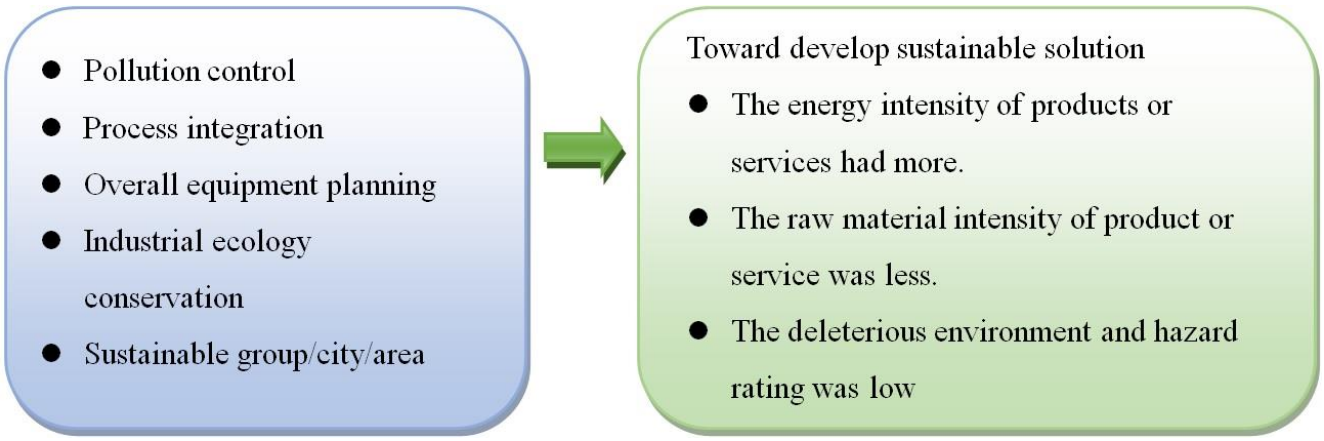

Figure 4. The ecological benefits of sustainable production and consumption

period whether a product is green or not. Tu conducted this "strategy of sustainable design" planning with the aim of a green design strategy (Table1) (Tu, 2002).

The analysis concept of the green product life cycle deems that, by employing the method of product recovery and regeneration to make waste materials into new products, via reuse or total recovery; designers no longer make designs purely for the product itself or consumer demand, but consider the relationship of the product life cycle and the environmental cycle chain (Tu, 2002). Cohan proposed the key points required to be considered during the various periods of Life Cycle Design (LCD), as shown in Table 2 (Cohan, 1996).

METHOD

This study established a checklist of sustainable product design and development based on the related literature reviews, analysis of expert interviews and Tu's (2002) checklist of green product design. The main difference between this study and the others is the principles of education and research. According to the suggestions from expert interviews, the other's principles need to be considered in the evaluation criteria. As a result of the study, we have improved the checklist of sustainable product design and development in green product design practice. We

Table 1. The strategy of sustainable design

Stage	State	Content
Short-term strategy (Green life cycle design)	● According to the existing products and services to redesign ● Redesigning the product that was mainly focus on the improvement of the manufacturing process.	Specific principles are: ● Emphasize durable. ● Using the "clean technology". ● Reducing energy use. ● Using the less toxic material. ● Using the green life cycle assessment.
Mid-term strategy (Green function design)	To provide environmental benefit of the new products and service. Advantage: ● Innovation product not only emphasize environmental quality, also increase the market competition Disadvantages: ● The high degree of innovative products and service could produce risk in mature markets.	Specific principles are: ● Redefine the way of meet the demands. ● Explore the Various technology feasible ● Importing the system operation. ● Emphasis the multi-functional features.
Long-term strategy (Green system design)	● According to system services to achieve environmental benefit. ● Establishing a comprehensive "system framework" to develop the new demand and more accord with environmental benefit.	Specific principles are: ● Designing a product that can conform to the mental and change the behavior. ● Encourage decrease use the products, but emphasize service. ● Devoting to the system development.

Table 2. The evaluation point of life cycle design

Stage	Content
Production	Designers can through improved product function, using better technology and select the appropriate materials and surface treatment methods to reduce environmental impact to achieve the lowest level.
Transportation	Designers can reduce product weight, product size, choose to use the low hazardous material and packaging materials etc. to further effectively reduce the products weight.
Use	Using stage energy consumption more than manufacturing stage, and disposable products could cause the garbage in increase. Designers need to solve or alleviate the situation of product design. For example: the design of modularization, multi-function, provincial electrical appliances product design.
Recycle	Some products are difficult to maintenance or hard to dismantle, and therefore cannot be recycled. Designers can try to save material, extend the product life, easy to dismantle and recycling use of component design to avoid unnecessary environmental damage etc.

present the basis of sustainable product design development, strategies, and methods for sustainable product design and development from product servicizing standpoint. By applying the grounded theory, this study analyzed the guidelines for the development of a decision model for sustainable development of product servicizing under a low carbon society. By using semi-structured interviews, this study conducted in-depth interviews with four experts with backgrounds and practical experiences of sustainable product design and development, including: design director, R & D manager, project manager, and industrial designer (showed as Table 3). With the overall design and development strategies as the main axis, understand the development basis of sustainable product design and provide strategic methods to implement the sustainable product design of enterprises.

RESULTS AND DISCUSSION

Analysis of sustainable design and development of product servicizing

From the checklist analysis of four experts regarding sustainable design and development, this study summarized six major dimensions, including: "material", "processing", "assembling", "using", "dismantle", and "recycle". It was found that sustainable product design mainly focuses on education, material, processing, and recycle stages.

Material

The issue of "material" emphasizes the in-depth understanding of materials and their properties before the design stage. Different materials will give users different senses; e.g., metal is relatively hard and cool; wood gives the user a warm, natural feel. In addition, from the perspective of the operations of companies and firms, material costs and the limits of environmental directives will be considered; while the designer's point of view will be focused on user experience. However, as most users have large differences in attitudes regarding leased products of servicizing, as well as personal products, such as durability and comfort of use, the selection of material properties is the main key.

Process

During the product manufacturing stage, the main issues to be considered include "material and process relationships" and "processing steps". It can be learned from the four experts' opinions that reducing poorly made products is another focus, in addition to the discussion of the impact of the steps and materials used in manufacturing to the application of sustainable design in the manufacturing process. Regarding the relationship between materials and manufacturing processes, processing methods will affect the manufacturing process, as well as the consumption of energy. Well-known process knowledge is basic for designers, and strengthening awareness of the manufacturing process in product design can avoid mistakes in the manufacturing process in advance. In addition, the devices and

Table 3. Research subjects' backgrounds

No.	Name of Corporation	Subjects	Years	Specialty
A	AURORA Group/ Department of furniture	Design Director	18	Design and development process, sustainable product design
B	AURORA Group/ Department of furniture	R&D Manager	12	Environmental Evaluation, Sustainable product design development plan
C	AURORA Group/ Department of furniture	Project Manager	10	Sustainable product design development
D	AURORA Group/ Department of furniture	Industrial design	15	Modular Design

process equipment used in the manufacturing process, as well as changes in the corporate system, will affect the steps and sequence of the manufacturing process. Thus, appropriate reform and amendments for businesses can not only reduce human resources, but can also reduce energy consumption and carbon emissions.

Assemble

When a product is assembled, high assembly efficiency can reduce labor costs. For example, designing with foolproof devices or simplified assembly allows operators to reduce the failure rate in the assembly of products; moreover, parts simplification allows consumers to self-assemble. "Assembly efficiency" contains two main themes: "parts life cycles" and "assembly convenience", where the underlying factors include unified standardized parts, interior structured product designs, and appropriate operating manuals that direct the user to assemble products more conveniently.

Usage

Early in a design, designers should analyze the user experience and learn their usage demands, in order to minimize errors or injuries occurring at the usage stage of the product life cycle, thus, the usage stage can be prolonged to reduce the number of repeated purchases.

Disassemble

The extent of damage in the product should be considered in product disassembly to prevent sharp edges of products. Operating instructions and safety precautions for disassemble should be available.

Recycle

Recycling is a basic demand. The sustainable design philosophy emphasizes that raw materials can be recovered after repeated use, meaning 30% -40% of product casing materials can be recycled for the next generation of products, as based on the premise that early product enclosures have not undergone other processing, and the integrity of plastics remains without reprinting. The main issue in the dimension of recycling is the "sustainable recovery trend", with "material recycling" and "recycling form" as the main factors.

This test sheet is used for environmental analysis of sustainable design development of product servicizing, and has overall understanding and design verification of environmental problems encountered during each period of the product life cycle, in order to propose more effective design improvement plans. The content of the examination items acts as the product inspection standard, as based on the design principles and results of expert opinion for each period of the product life cycle, and lists the scored ranks for designers assessment, in order to determine the shortcomings and improvements required for products.

Decision model for sustainable design and development of product servicizing

Regarding the development of sustainable products to help companies conduct more detailed and accurate analysis of the degree of improvement in a variety of product designs and development solutions, and through relevant literature review and expert opinion, this study proposes ideal sustainable product designs, development guidelines, and strategies. The decision-making mode architecture, as shown in Figure 5, shows that the main components are divided into four stages, as follows:

(1) Stage I: product servicizing MET Matrix analysis and assessment: Graedel and Weinberg argued that product matrix analysis is a rapid qualitative product analysis

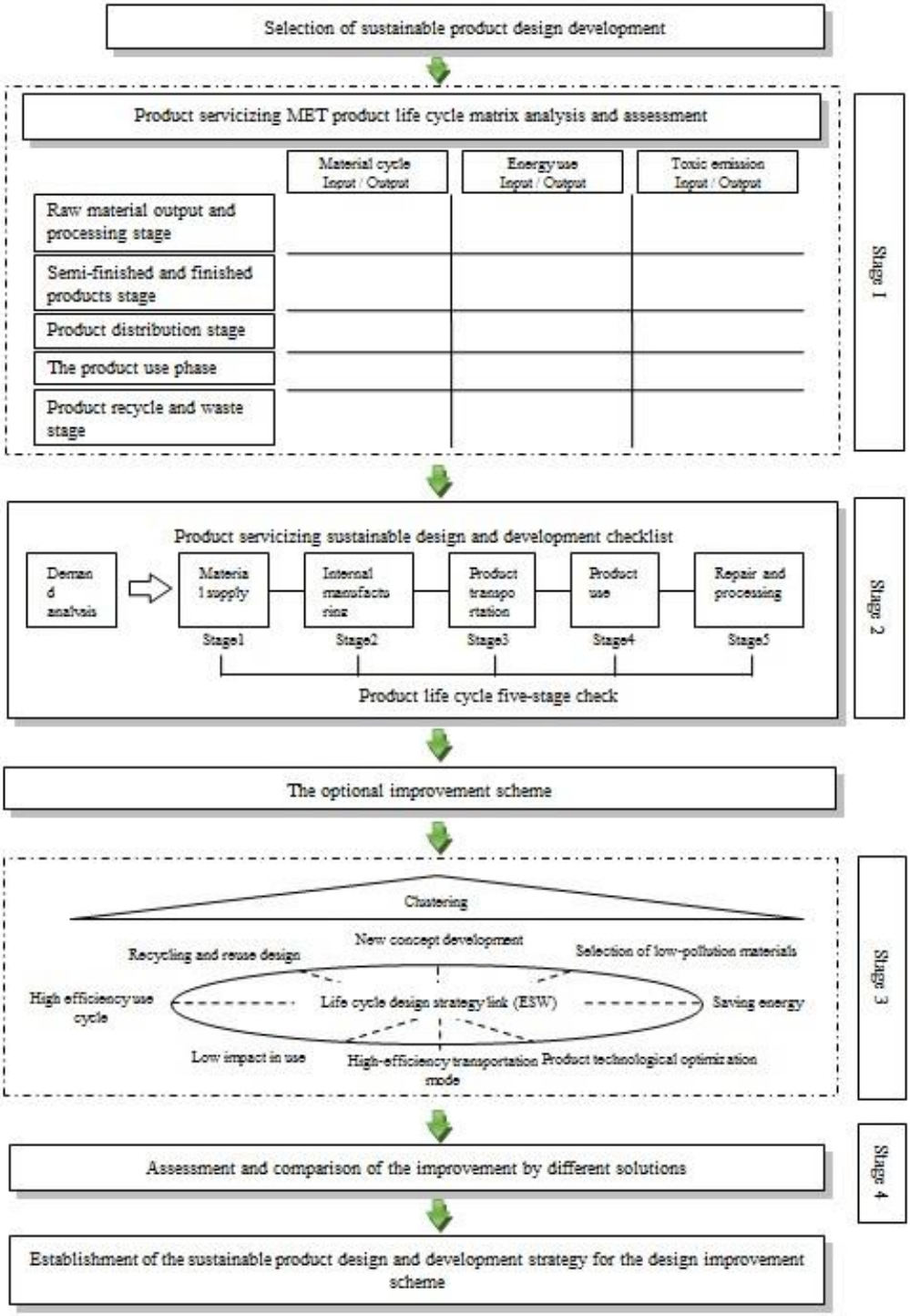

Figure 5. The decision model for sustainable design and development of product servicizing

method, which designs checkpoints and identifies problems of environmental impact (Graedel, 1996; Weinberg, 1998). The Materials, Energy, and Toxic (MET) emissions matrix is a basic analytical method. The MET product life cycle matrix represents material cycle, energy use, and toxic emissions, and its purpose is to obtain the statistics of the outflow of substances and emissions during the product life cycle process. The greatest function of this method is to help R&D teams to focus on environmentally friendly products. With the steps adopted in the product life

cycle as the vertical axis, and the variety of effects on the environment as the horizontal axis, this method aims to understand the improvement issues in the subsequent steps of life cycle in product development (Kusz, 1992). This research tool is currently widely used in Europe and America to evaluate a variety of green products, and assess products with different properties, such as computer products with greater emphasis on assessment of the energy sector, as well as living furniture products with greater emphasis on green assessment (Tu, 2002).

(2) Stage II: product servicizing sustainable design and development check: first, demand analysis should be conducted before product functional design issue identification and classification. Each category is checked according to the five stages of the life cycle, and focuses on the major and secondary functions of the product. The problems and environmental bottlenecks arising from the checking process should be immediately improved and solved at various stages.

(3) Stage III: product servicizing life cycle strategy design wheel analysis: according to the Smart Ecodesign, Environment, and Development Foundation (EDF) by Karlsson, and Luttropp (Karlsson & Luttropp, 2006), the "Green Design Survey" by Tseng, et al. (2013) and Miller, et al. (2015), and the Life Cycle Design by Behrendt (1997), the Life-cycle Design Strategy Wheel, (LiDS Wheel) can summarize all the problems considered by green design, and develop new design concepts by taking advantage of these strategy results (Tu, 2002). Developed by the Delft University of Technology in Holland, this assessment and analysis method mainly depends on 33 green design principles, and refers to the eight design strategies

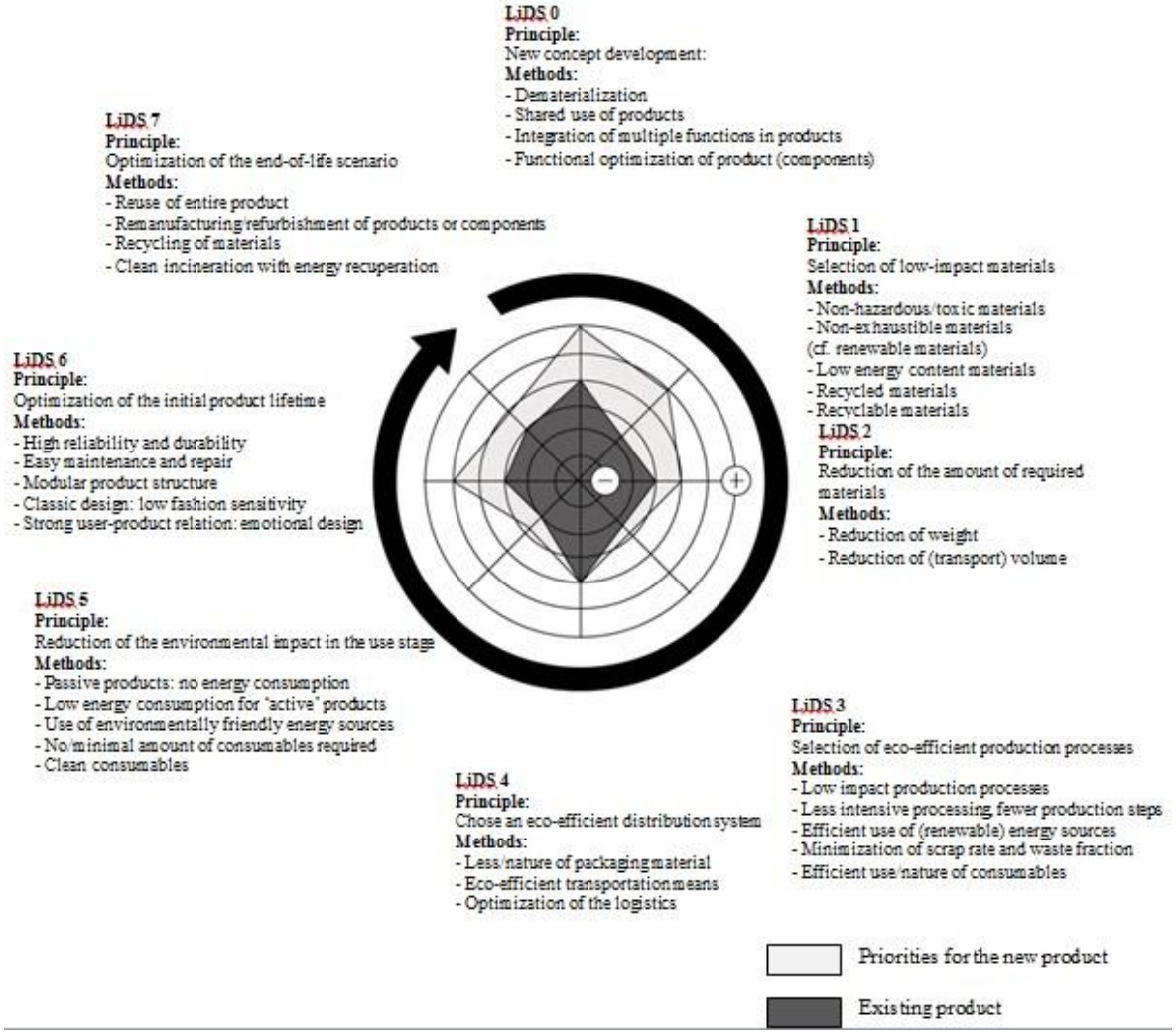

Figure 6. LiDS Wheel

summarized on the basis of the stages of product life cycle (Chulvi & Vidal, 2011). The eight strategic analysis results are displayed by a wheel-shaped radar diagram to clearly identify the differences before and after product design improvement, as well as the key points to be improved in the future (Figure 6).

(4) Stage IV: after obtaining the improvement schemes according to the analysis of the life cycle design strategy wheels, technological and structural feasibility should be conducted, and environmental, economic benefits, and marketing probability should be assessed. The focus of this stage is research and development. The research and development team should develop the priority sequences of sustainable product design processes, and obtain the cooperation of management, marketing, sales, purchase, research and development, and manufacturing sectors in order to ensure the implementation of sustainable product design and development.

Empirical application of the case study

The "Executive Desk" furniture is a necessary item of a corporate office, and due to the transformation of the modern work model and disparity in user habits, as product replacement increases, it indirectly results in a reduced product life cycle, creating the issue of how to dispose of old office desks. This item must be resolved and inspected by enterprises in terms of cost reduction. Thus, the materials selection, structure, appearance design, and color configuration, requires that designers must understand the working demands of office desk users during the design stage.

In order to gain profound understanding of market trends and user demands for office desks, this study uses Aurora Office Furniture Manufacturers as the individual case study object, which is one of the largest manufacturers in sales and leasing of office furniture in Taiwan, and uses "Ping Qinghe" director office furniture as the individual case for verification of research results. First, analysis determines the product assembly parts to understand the overall main parts, assembly structure, and application of various materials, then conducts material collection and investigation of the largest office furniture manufacturers in Taiwan.

Then, we focused on the case product to conduct MET Matrix analysis of the case product in stages in order to understand the impact of the product on the environment before introducing the decision model for sustainable design and development of product servicizing under a low carbon society. The development checklist was implemented by two experts, two senior managers, and one industrial engineer, to comprehensively understand the environmental protection issues of the product life cycle, as well as design and development checks to propose more effective design development improvement schemes. Afterwards, coupled with the life cycle design strategy wheel analysis, sustainable product design and development guidelines for the furniture of the "executive desk" furniture were developed.

Finally, the empirical application of the sustainable product design development of the "Executive Desk" furniture is conducted, and an improved sustainable product design plan is proposed. Moreover, an assessment comparison of the sustainable product design development of the "Executive Desk" furniture is made, and any disparity between the original products and the improved sustainable product design are determined by the test sheet of product servicizing, as well as the life cycle design strategies. The case study empirical study procedure is as shown in Figure 7.

MET Matrix analysis of the "executive desk" furniture

The case study product was "Ping Qinghe", made by the Aurora Group, as shown in Figure 8 and Table 4. MET Matrix analysis illustrates the key points of

environmental impact of the case product during its life cycle. The developmental direction for sustainable product design can be further explored accordingly.

According to expert interview regarding MET Matrix analysis, the environmental impacts at various stages of the product life cycle are, as follows:

1. Raw material output and processing stage: the focus should be on the selection of low environmental impact materials and energy conservation, in order that the case company can be implemented within the EPA standard specification range, and the pollution problem can be controlled.At this

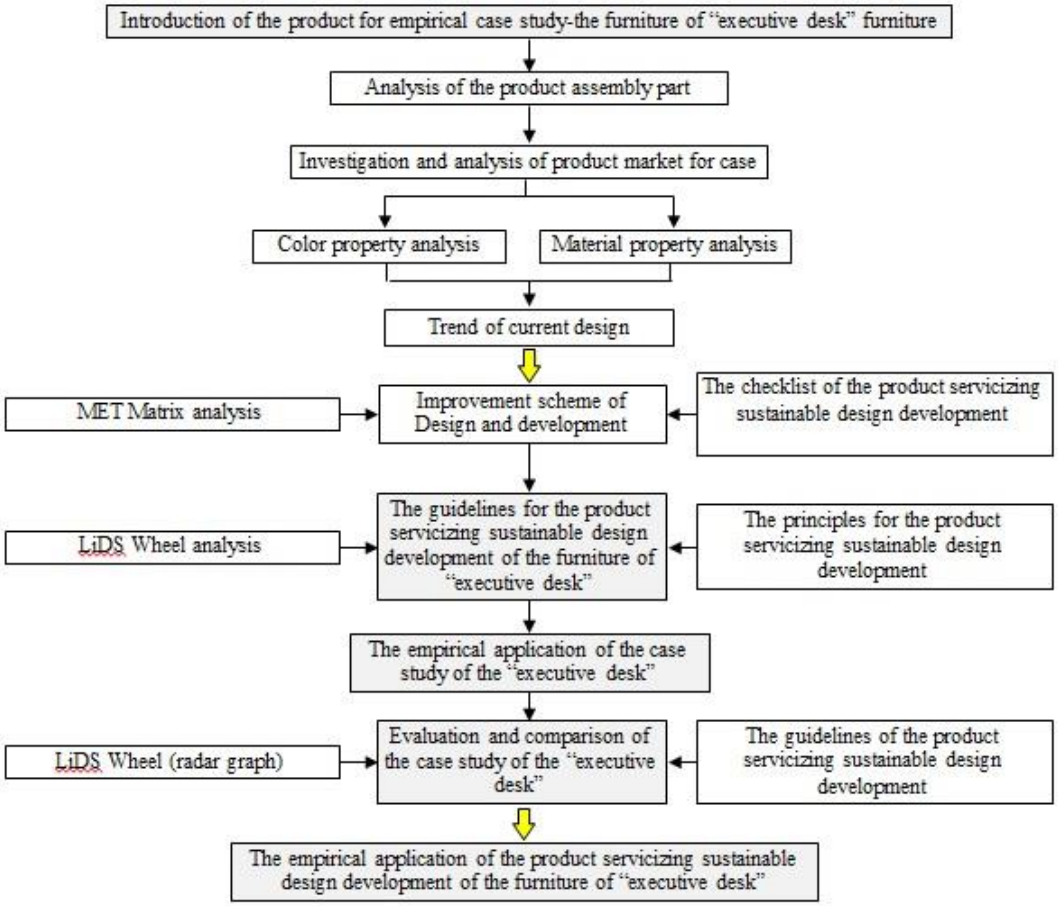

Figure 7. Empirical study process of the furniture of the "executive desk" furniture

Figure 8. Executive desk furniture

stage, it was learned that the materials employed in the executive desk furniture include metallic and non-metallic materials: the metallic materials include stainless steel, iron, and aluminum; and non-metallic materials include ABS / PC, rubber, wood, leather, glass, marble etc. This stage is prone to formaldehyde toxin release.

2. Semi-finished and finished products stage: the case company was in line with the criteria of the manufacturing process, and thus, there are no security doubts. However, the production technology can be further optimized.This stage focuses on the production of semi-finished products and product design ease of assembly. As the executive desk furniture is designed with a variety of housing functions and side tables, disassembly ease should be considered. If these issues are considered in the product design stage, in addition to increasing product design integrity, it can better avoid the reoccurrence of other problems, such as difficulty in assembly.
3. Product distribution stage: recyclable packaging material or anti-crash materials are used to effectively reduce the environmental impact.The product design should consider weight reduction, volume reduction, or choosing more non-toxic recyclable packaging materials, and other methods, to effectively reduce the impact on the environment. Such measures can streamline the manufacturing process, reduce resource waste, increase recycling convenience, reduce waste volume, help ease transport requirements, and save transport space, thereby, reducing costs.
4. The product use phase: at product life cycle stages, there should be highly efficient ways of thinking that focus on the use of low-impact methods.Product designs should be directed by modular, standardized, and multi-functional approaches in order to reduce the loss of resources. Moreover, increased product functionality can be achieved under the considerations of balancing use demands and environmental loads.
5. Product recycling and waste stage: during the initial product design, components should be clearly marked for easy classification, as clearly marked material types will facilitate safe disassembly design, design commonality components for reuse, and easy disassembly, which can reduce environmental injury. The product design at this stage should consider the

Table 4. MET Matrix analysis of the furniture of "executive desk" furniture

Executive desk product life cycle analysis matrix				
MET Matrix **Life cycle stage**	Material cycle Input / Output		Energy use Input / Output	Toxic emission Input / Output
Raw material output and processing stage	1. Metallic materials 2. Non-metallic materials	Stainless steel, iron, and aluminum ABS/PC, rubber, wood, leather, glass, and marble	Manpower, utilities, machinery and alternative energies	Formaldehyde
Semi-finished and finished products stage	Semi-finished product: 1. main desk: wood, stainless steel, leather 2.side desk: wood		Manpower, utilities, machinery and alternative energies	Carbon emission
	Finished products: Front piece+ rear piece	executive desk finished product	Manpower, utilities, machinery and other power (to make semi-finished products assembled)	Carbon emission
Product distribution stage	Pulp, ink, plastic, foam, cardboard, bubble bags		Manpower, utilities, machinery and alternative energies	Carbon emission
The product use phase	Wood, stainless steel, and leather		Manpower, utilities, machinery and alternative energies	None
Product recycle and waste stage	Wood, stainless steel, and leather		Manpower, power (transportation)	Waste

ease of disassembly and assembly to facilitate transportation.Some products cannot be reused due to maintenance problems or difficulty in disassembly. Therefore, in the design of a product, such problems can be addressed by saving materials, extending product life, design of easy disassembly, and recyclable components.

The guidelines of sustainable product design and development of "executive desk" furniture

After identifying the key points of user demand and environmental protection according to MET Matrix analysis, the checklist method of the decision model for sustainable design and development of product servicizing under a low carbon society is applied to check environmental protection issues, including product demand analysis, material production and processing check, semi-finished product

Table 5. Check and analysis of various environmental issues

Item Type		Questions	Solutions	
Product demand analysis	Consumer demand	Q1: Will there be product problems regarding use, operation, maintenance, or repair time?	Design strategy	Sustainable design principles
		➢ Executive desk, whether it is acceptable to consumers? ➢ Whether the main function of the product can give full play? ➢ Whether the product is easy to operate? ➢ Whether the product is safe in use? ➢ Whether the product can meet the needs of consumers? ➢ Is there great difference in product application with existing products? ➢ Whether the strengthening of product features can meet the needs of users? ➢ Whether extended product life can meet consumer expectations?	1.New concept development	➢ The strengthening and expansion of new product features. ➢ The use of environmentally friendly materials. ➢ Convenient and safe products. ➢ Reducing material surface machining.
Material production and processing check	Environmental issues	Q2: Will there be problems of material and component production?	Design strategy	Sustainable design principles
		➢ Product material is easy to identify? ➢ Recyclable material is easy to identify? ➢ Hazardous substances or components are easy to identify? ➢ Whether it can reduce component size in design? ➢ Are products properly functioning in the case of omitted or smaller volume component replacement? ➢ Whether a component, or other components, can reduce the volume? ➢ Whether to use rare, difficult to obtain materials? ➢ Material used has been minimized in the extraction process? ➢ Whether suppliers adopt pollution prevention measures in the material extraction process? ➢ Whether there is a major conflict between the materials used and ecological conservation? ➢ Whether materials are recyclable? ➢ Whether recycled materials are used to produce components? ➢ Whether energy can be recovered in high percentages when the product is recycled? ➢ Whether recycled materials can reduce energy consumption? ➢ Whether there are any potentially hazardous materials harmful to human health used in the components? ➢ Whether the management or control of the hazardous substances used in the material extraction process is easy? ➢ Whether special equipment is required to remedy the event of material spill or accident?	1. Selection of low environmental impact materials 2. Saving energy	➢ Use suitable and standard materials. ➢ Recyclable materials indicated in a prominent place. ➢ Hazardous substances or components labeled clearly. ➢ Using high compatibility component materials. ➢ Use high recycled materials. ➢ Avoid using materials causing environmental pollution. ➢ Reduce use of designed components. ➢ Uses easy to obtain materials to replace rare materials. ➢ Check the processing process of the supplier to simplify the process and reduce levels. ➢ Application of low energy demand materials.

		➢ Whether the management or control of the hazardous substances used in the material extraction process is easy? ➢ Whether special equipment is required to remedy the event of material spill or accident?		➢
Semi-finished product and finished product production check	**Environmental issues**	Q3: Will there be problems of product assembly, disassembly, distribution, or consumption?	Design strategy	Sustainable design principles
		➢ Reduce the release of toxic substances in the manufacturing process? ➢ Whether the manufacturing process has measurement and control equipment of hazardous substances? ➢ Whether the environmentally sound processes are used? ➢ Easy to disassemble and assemble? ➢ Complicated product manufacturing processes? ➢ Whether other energy-saving production methods can be applied to the manufacturing process? ➢ Whether the manufacturing process contains substances that will cause harm to humans or the environment?	Production technology optimization	➢ Try to choose energy-saving production methods. ➢ To remove and assemble with simple tools or semi-automatically remove and assemble. ➢ Avoid the release of toxic materials in the manufacturing process. ➢ Avoid the use of contaminated materials in the manufacturing process. ➢ Avoid unnecessary assembly parts. ➢ Unified model parts. ➢ Modular design, assembly latch homogenization. ➢ Avoid unnecessary surface processing.
Product distribution check	**Environmental issues**	Q4: Will there be any problems arising from the manufacturing process?	Design strategy	Sustainable design principles
		➢ Is it easy to assemble and disassemble? ➢ Is it easy to see the status of the assembly and disassembly? ➢ Is there any physical or chemical danger when assembling and disassembling components? ➢ Whether there is any voice or illustrated instruction assistance for assembly and disassembly? ➢ Whether packaging size, material, weight, and reuse have been optimized? ➢ Excessive packaging design? ➢ Whether recyclable packaging materials are used? ➢ Whether packaging design makes transport easily handled? ➢ Transportation mode? ➢ Transportation efficiency?	High-efficiency transportation mode	➢ Simplified product structure ➢ Detailed operating instructions. ➢ Assembly using simple tools or semi-automatic assembly. ➢ Lightweight product. ➢ Moderate strengthening in product design to avoid damage during shipping. ➢ Light and thin product, reduced packaging materials, and increased transportation volume.
Product use check	**Environmental issues**	Q5: Will there be problems regarding the product in use, operation, maintenance, or repair time?	Design strategy	Sustainable design principles
		➢ Is the product in compliance with the security benchmarks executive desk? ➢ Whether the product can be reused? ➢ Whether parts can be used directly for other purposes? ➢ Whether products can be returned to the upstream and reused? ➢ Whether energy consumption is improved? ➢ Whether product repair and maintenance is easy? ➢ Whether products can be easily disassembled? ➢ Whether the components can resist impact and abrasion, and extend life? ➢ Whether it is convenient for the consumer to perform regular maintenance? ➢ Whether dangerous or harmful substances will be generated when consumers are implementing the maintenance process?	1. Low impact in use 2.High efficiency use cycle	➢ Use materials in line with the safety benchmarks of the executive desk. ➢ Improve the functions of the executive desk. ➢ Use materials of longer service life and reduce the waste of raw materials. ➢ Easy maintenance and repair design. ➢ Design of clear operational instructions or appropriate instructions for the product. ➢ Regular maintenance provided by service personnel.

and finished product production check, product distribution check, product use check, and product recycle and waste check (Table 5). Through such checks and

Product recycle and waste check	**Environmental issues**	Q6: Will there be problems in product recycling and waste gas stages?	Design strategy	Sustainable design principles
		➢ What are the product disposal options when it is abandoned? ➢ Whether product parts or materials can be reused and reproduced? ➢ Can component parts be dismantled under safe conditions? ➢ Are materials labeled on the product for easy identification? ➢ Whether parts can be separated quickly? ➢ When the product is disposed of, whether contamination can be controlled within the specified range? ➢ In the recycling process, whether there are easily produced and released harmful substances?	Recycling and reuse design	➢ Parts easy to disassemble and separate. ➢ Parts must be clearly marked for easy classification. ➢ Parts with clearly marked material type. ➢ Safe disassembly design. ➢ Design commonality and reuse of components. ➢ Recycled materials design. ➢ Recovery system composition contact. ➢ Energy consumption of product recovery.

analysis of environmental issues, coupled with the life cycle design strategy wheel architecture, guidelines in response to environmental issues, which consider sustainable product design and development can be the basis for the design and development of sustainable products in the future.

CONCLUSIONS

This study developed a decision model for the sustainable development of product servicizing under a low carbon society. The analysis results showed that the current "executive desk" furniture should be improved, as it has barriers to be overcome. According to the assessment results of the checklist of product servicizing sustainable design and development, the "executive desk" furniture was not in line with the criteria in terms of materials, assembly, usage, or recyclable items. Moreover, the overall assessment of sustainable product design and development found that the current design had poor checking results regarding the high efficiency transportation mode, high efficiency use cycle, and recycling design.

The proposed decision model for the sustainable development of product servicizing under a low carbon society, when applied in planning prior to sustainable product design, can consider the sustainable product criteria and modularization of product component design specifications, in order that the product in use can be more easily assembled and disassembled. Moreover, when easily accessible materials are selected, it can reduce transportation costs, and items can be reused to improve or modify the impact of subsequent manufacturing, production, use, and transportation on the environment, which can achieve the ideals of dematerialization.

In addition, this study comprehensively considered impact on the environment to help companies incorporate dematerialization product servicizing sustainable design and development principles into the initial conceptual product design stage. Therefore, it can guide companies to consider environmentally friendly and easily recycled materials, as well as reducing material surface processing procedures. As a result, materials use can be streamlined to reduce the release of toxic substances and achieve better environmental benefits, which can help companies rethink product design procedures and change the consumption behaviors of people to realize the beneficial cycle of co-existence with the environment. In addition to the environmental considerations of product life cycle, this method focuses on the use, ease of use, and safety of products to achieve the vision of cherishing raw materials and reducing energy consumption.

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