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A Study of Product Design using Recycled Materials

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Abstract

Plastics that we use and simply throw away have a life span of about 500 years and barely decompose. The practice of producing and using common plastics needs to be challenged. Until now, they have been useful in the industrial structure of mass production, but it can be said that there is a lack of research into new materials to introduce and apply in terms of material recycling. As a result of this, we have come to the uncomfortable realization of the fact that we cannot incinerate or reuse these precious resources indiscriminately. No matter how well-designed a product is, it has a competitive advantage if production and consumption activities, waste, collection, sorting and treatment are considered in terms of a continuous cycle, and in this respect, Extended Producer Responsibility (EPR) can help. We are implementing the EPR system, and active industrialization in the field of recycling is required, which is also a challenge for producers to participate actively in recycling and seek to save and recycle resources in design and manufacturing. Against this backdrop, We would like to examine the possibilities, through various studies and developments on product design of recyclable materials, which is being conducted mainly in Europe. In particular, we would like to examine the methods, and value of solving environmental problems and the active efforts to achieve this in the design world, and in particular the case of product design using recycled plastics.

Keywords: *ERP System, 3D Printing, Recycle Plastic, Product Design.*

1. Introduction

In the past, Southeast Asian countries, such as China, the Philippines, and Thailand, which had operated businesses that imported waste, reprocessed it, and exported it as raw materials, thereby creating environmental problems of their own. Now, there is a movement to end this practice. In Korea, some companies exported more than 6,000 tons of waste to the Philippines, but there was a problem with bringing domestic waste back

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to Pyeongtaek port in the Philippines because of the considerable mixing of foreign materials such as waste wood, vinyl, and steel. The situation of recycling waste has to be resolved by revitalizing the waste industry. In this study, we researched the case of product design that reuses recycled plastic processed in foreign countries by searching the contents of blogs and articles online. In the initial literature search, the process of addressing new environmental issues centered on Europe and the case studies were analyzed to identify the related products. In addition, the process of reprocessing waste plastics was examined through a step-by-step investigation, and the contents that should be reflected in the design of the product, focusing on what is considered a fundamental problem. Specifically, we reviewed the recycling status of recycled plastic materials, the reuse process of plastic materials, types of plastic used in the manufacture of recycled products, and recycling policies. In addition, we reviewed the development cases and characteristics of recycled product design, analyzed the patterns of the overall solution process, and examined the value of new product design in response to environmental problems.

2. Recycled Material and Design

In the United States, 8.2%of plastic household waste is collected and recycled. The European Union, by comparison, collects 24% of its plastic packaging waste and recovers 77% of the plastic waste in Japan. Social Trends in Korea 2018. Generation and Recycling of Waste Plastics, Lee, Hee-Sun (Korea Institute for Environmental Policy and Evaluation). In addition, waste is classified as flammable and non-flammable waste, and the largest proportion of flammable waste is plastic. This amounted to about 5 million tons in 2011, about 6.9 million tons in 2015, and has increased exponentially by 19% since 2011 [1]. Figure 1 shows social trends in Korea 2018 that is Generation and recycling of waste plastics.

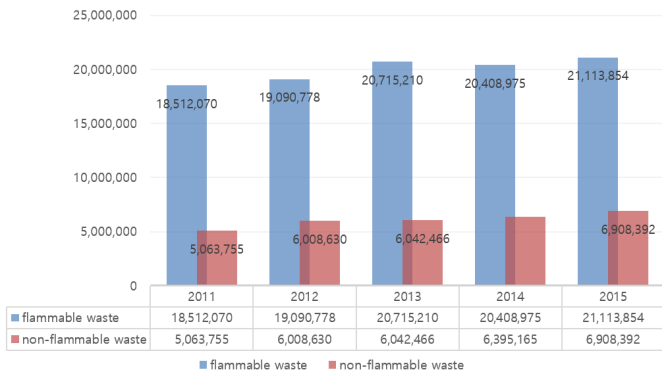

Figure 1. Social trends in Korea 2018. Generation and recycling of waste plastics

Waste plastics can be recycled, incinerated, or landfilled. Incineration is the burning of combustible plastic waste and poses a number of problems. In the case of landfill reclamation, the depleted condition of the reclaimed area makes it increasingly less useful. If plastics can be recycled through recycling methods appropriate to the resource, new possibilities will be found. Statistics show that recycling increased from 52% in 2011 by 8% to 60% in 2015, and incineration decreased from 41% in 2011 by 6% to 35% in 2015.

2.2 Recycled material reuse process

In the 3D printing system, the processing of a material used for recycling has been largely divided into four stages. This is similar to the recycling operation of the existing industry. The first is washing and drying. Since

all recycled materials are unclear in which environment, waste plastics are sorted by type of material and then washed. There are many difficulties in this process due to foreign objects and other contents. In particular, if POP printed items consisting of different materials and band-type advertisements shrinking in heat attached to PET molding are processed together, problems in processing raw materials must be eliminated before the next step. This also depends on the state of the raw materials immediately after the cleaning and drying. Figure 2 shows cleaning and drying process.

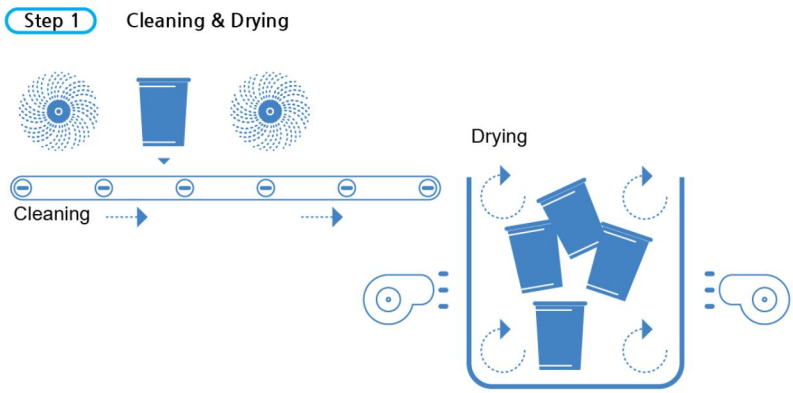

Figure 2. Cleaning and drying process

Second, the dried material is put into a grinder and subjected to the grinding process. During the grinding process, there is a case of re-injection in order to regrind the non-uniform size, and the material that is uniformly ground through the filtering is classified by the characteristics of the material. At this time, grinding is performed separately by color, and materials such as Acrylonitrile Butadiene Styrene (ABS) are separately classified and crushed separately from polycarbonates (PC). Figure 3 shows grinding and filtering process.

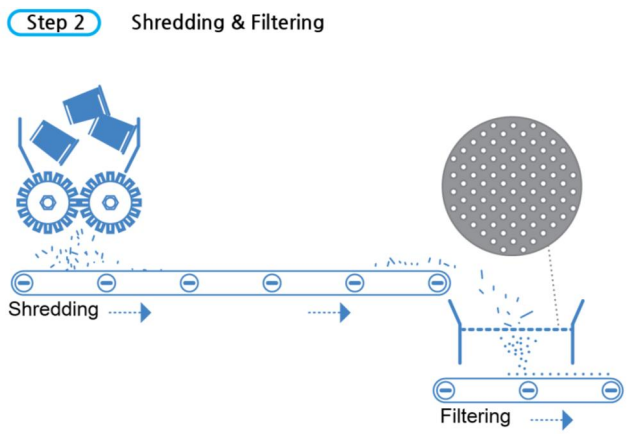

Figure 3. Grinding and filtering process

Third, the pellet is pulverized to extract the filament, as shown in the following figure. The melting point for extruding is set for each material and the filament is extracted and spooled. At this time, a certain drying process is required, and the rotation RPM of the screw is set at a constant pressure to discharge the diameter of the corresponding filament uniformly. If the thickness of the filament is not kept constant, a significant

problem arises in the next step for 3D printing. This thickness is precisely maintained because the thickness is closely related to the size of the three-dimensional object discharged at the time of output. Figure 4 shows Extruding and Spooling Process.

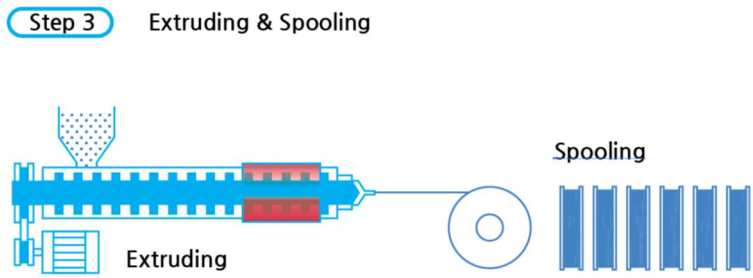

Figure 4. Extruding and spooling process

Fourth, as a 3D-printing output step, the designed result is set as desired material and the property value of layer thickness material is set and output. The most important point is the melting point of the raw material. This is because even if the material is uniform, a small amount of another material may be added or another treatment may be performed for the surface treatment of the product according to the purpose of the product as produced by various companies. However, the melting point is not a big problem in the distribution, but it is necessary to determine the physical properties of the material to be reused and set the melting point accordingly. In addition, in the industrial field is cut to a certain size to be used as pellets as an industrial raw material. Figure 5 shows design and 3D printing process.

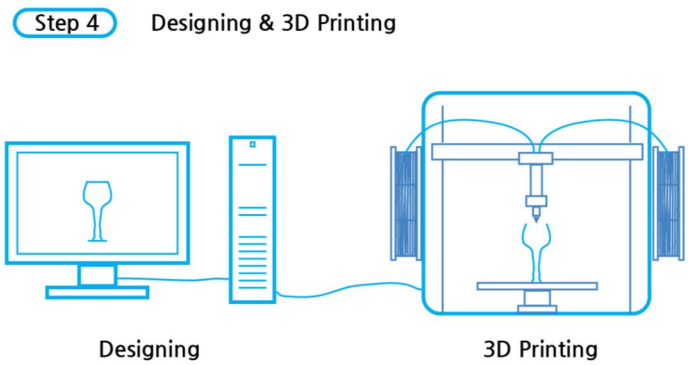

Figure 5. Design and 3D Printing Process

2.3 Recycled plastic material

Plastic materials are generally thermoplastic resins that are melted by heating and then cooled to room temperature, and thermosetting plastics, which are plastics that are cured once they are hardened by heat. Thermoplastics are melted by heating to produce products using molds. Table 1 Shows thermoplastic, thermosetting plastic.

Table 1. Thermoplastic, Thermosetting plastic

Thermoplastic	General purpose resin	Polyethylene (PE), Polyvinyl Softened Polypropylene (PVC), Polypropylene (PP), Polystyrene (PS), Polyvinyl Chloride (PVDC), Polyvinyl Alcohol (PVA), ABS Resin, AS Resin, Methacrylic Resin (PMMA))
Thermoplastic	Engineering plastics	General Purpose Enfra Special Enpta
Thermosetting plastic	Phenolic Resin(PF), Melamine resin(MF), Alkyd resin, unsaturated polyester resin, urea resin (UF), epoxy resin (EP), silicone resin, diallyl phthalate resin, polyurethane resin (PUR),	

The possibility of achieving separate collection of everyday plastics, types of application and characteristics are as follows. Table 2 shows whether plastic can be collected separately, application cases and features.

Table 2. Whether plastic can be collected separately, application cases and features

No	Separate collection	Application Types	Characteristic
High-density polyethylene (HDPE)	Separate collection possible	Detergent containers, kitchenware, toys, water bottles, shampoo bottles, etc.	Rigid and durable plastic, microwave available
Polyvinyl chloride (PVC)	Recycling difficult	Industrial goods, toys, interior goods, household goods, plastic wrap, wire covering, water and sewage pipes, hoses, etc.	Flexible, soft plastic, hard, and water resistant. Use for household and medical supplies Dangerous plastics such as phthalate (DEHP), lead, cadmium, etc.
Low density polystyrene(LDPE)	Recycling difficult	Food containers, kitchen utensils, plastic bags	
Polypropylene(PP)	Separate collection possible	Water bottles, kitchen utensils, fuel boxes, yoghurt containers, packing materials	Resistant to repeated bending forces
polystyrene(PS)	Recycling difficult	Noodle cups, insulation such as styrofoam, toys, spoons, forks, packaging vinyl, reagent bottles	Good heat shielding and easy processing. It is light and cheap, so it is used as food container. Heat releases hazardous carcinogens styrene
Others	Separate collection possible	Smartphone cases, water bottles, large items, PCs, ABS included	Heat resistance and durability are strong
ABS	Separate collection possible	Automotive parts, electrical appliances, trunks, helmets	
Polycarbonate(PC)	Separate collection possible	Discs, car accessories, milk bottles	
Epoxy	Recycling difficult	Electronic products, IC encapsulation materials, printed wiring boards, automotive paints, adhesives	

In addition, there are G10 epoxy glass, Bakelite, various insulation boards, lightweight high-strength composites, and peak polyetheretherketone (PEEK). PPS, PAI (TORLOMN), PEI (ULTEM Ultem), PI (VASPEL Vespel), PBI (Celazola cerazole), Fluorine Resin (Teflon), PPSU (Ladel). In addition, there are various special materials such as metal fiber aramid carbon fiber, carbide fiber, silica glass, quartz fiber, PBO xylon, PTFE fiber, Basalt fiber, etc., which are based on high-performance fiber materials [2].

2.4 Recycling design

In the face of environmental problems, global companies are currently designing with a variety of shared values for recycling, and are raising corporate value through efforts and practices in minimizing wastage of resources and harm to user environments. By pursuing extraordinary values in the design concept (CMF) of product design, such as smart interactive materials and environmental response materials, we are building an image that consumers use and share the value of recycling and sustainable materials [3]. Shared value design and sustainable resource use are already generalized social responsibilities expected of companies. Therefore, it is time to restructure the market based on recycling and redefine the material value chain in product design. Currently, General Electric (GE) is one of the companies that successfully implements these values. GE introduced the concept of ecology into its corporate philosophy in 2005 with the philosophy of Ecomagination, its breakthrough strategy to design clean devices that produce clean energy, reduce greenhouse gases, use clean water, and save on costs. A decade later, Ecomagination had generated more than $200 billion in revenues. For example, GE's Evolution Series Tier 4 locomotives meet emissions standards, resulting in a 70%reduction in particulate matter emissions over the past with North America's first diesel electric rail engine. Tom Szaky, who started out in 2001 while attending Printer University with the idea of eliminating waste, founded Terracycle, which now has offices in 21 countries and numerous collection programs, with numerous program participants. It recycles large amounts of waste and provides new disposal options. It is a new social enterprise for recycling; its interiors are decorated by artists using recycled waste, graffiti, and LP records. It is based on upcycling values of reusing waste without incineration and landfill, and promotes valuable waste to the value of new assets, transforming the vertical consumption ecosystem into a cyclical system, taking new benefits through the environmental sustainability of the new circular economy.

2.5 Recycle design type

There are three types of recycling designs: rebirth of similar products, recycling of parts, and re-extraction of crushed materials. First, the rebirth of similar products is a recyclable design that plans and develops a variety of products using the pattern of its shape. The design of the watch using the LP plate as it is, the case of using the LP plate as a material to express the bird on the tree branch and cut it with a laser to assemble various watch parts to develop the product. As a visual expression, it can be said to be a style that reflects old fashioned tastes. There are also examples of plastic bottles, candlesticks, and various poems and magazine hangers. This is an example of finding an object that can be applied to a type from an existing product rather than designing a new form and making a product that matches the shape. This type is a result of temporary campaign activity, and its use is not time-tested, but it is meaningful that it is trying to implement, think, and put into practice various ideas for environmental problems. Second, recycling of parts corresponds to recycling of resources. The use of old, discarded banners was popular, but recently, they are no longer made, due to material hazards. After all, indiscriminate recycling is another example of the problem, and it is important to regenerate the value of discarded items by means such as upcycling. Successful examples include fashion designs using airbag materials from Craig Green, CEO Kang of Kang-hyuk, and Grace Wales Bonner. Currently, for example, it is evaluated that the car's airbag tracking number and barcode are uniquely produced by expressing exquisite

harmony by using the sensory feeling as it is. This shows that the designer needs various experiences and knowledge about materials. Third, crushed re-extraction of materials is a generalized method of recycling that has emerged in recent years and has not received much attention from individuals and organizations in the recycling field, but it is now appearing in various research activities because of its widespread use and because it confronts social and environmental problems. Japan's Choda Design, for example, is an example of how recycled plastic bottles can be transformed into beautiful designer chairs, allowing participants to experience the amazing recycling design process interactively. Participants bring in plastic waste and participate in its recycling and extrusion to recognize it as valuable raw material for the packaging of waste [4].

2.6 Recycling policy

The Good Recycled mark is awarded to excellent recycled products developed and produced in Korea after experiment analysis and evaluation. This was introduced in July 2005 with the enforcement of the Act on Promoting Green Product Purchasing for the Sustainable Society. Companies, under which consumers voluntarily purchase green products, while central government, local governments, and other public authorities are required to purchase green products. In addition, the government is implementing green information products to encourage more users to participate. The environmental labeling certification system, which is a recycling certification system, is acquired in the same way as the Mutual Recognition Agreement by utilizing private and government cooperative systems in consideration of the situation in each country. Currently, Korea has joined the Global Ecolabelling Network to implement the environmental labeling system. Table 3 shows domestic recycling product certification system, overseas recycling-related environmental mark.

Table 3. Domestic recycling product certification system, overseas recycling-related environmental mark

Domestic recycling product certification system			
Excellent recycling certification	Carbon labeling		Environmental labeling system
Environmental mark related to overseas recycling			
Eco-Emballages	Recycled Mark	ECO Mark	EU Ecolabel

The domestic recycling product certification system was introduced by the Ministry of the Environment to promote the recycling of resources through the separate collection of product containers or packaging materials displaying information on different emissions and operated by the Resource Reclamation Corporation. It is mandatory to mark cosmetic cases, medicine containers, metal cans, glass bottles, and foamed resins. Each product will be marked with a material on the product or packaging and collected in a separate collection bin. The excellent recycling certification system is the responsibility of the Ministry of Knowledge Economy's Institute of Standards and Technology and the Korea Resource Recycling Industry Promotion Association. It is a system of certification, to improve the quality of recycled products, that consumers are not currently aware

of, and to expand the demand base of consumers. A waste paper quality rating is given to the certified products for recycled products. Carbon labeling is a certification system that converts greenhouse gas emissions generated during the entire process, such as the production and transportation of product services, into carbon dioxide emissions, and labels them. The environmental labeling system comprehensively verifies eco-friendliness in all processes of products implemented since 1992 and selects and certifies products with excellent quality and performance. It is a system implemented by the Ministry of Environment based on Article 17 of the Law on Environmental Technology Development and Support. Eco-Emballages, a European environmental mark system, is attached to the products of companies that recycle French containers and packaging. Such a scheme is the German Green Dot scheme, and since 2001, France and Germany have used the same logo as a coalition. A recycled paper mark has been used for a long time as a labeling program for the mixing ratio of paper such as office paper and toilet paper. Eco Mark is an environmental mark that is a nationally recognized mark for eco-friendly and superior products. It is an environmentally friendly product certification mark that minimizes the emission of The European Ecolabel was established in 1992 and is a recognized system in Europe and around the world. It is an excellent labeling system that accredits the entire process from the extraction, production, distribution, and disposal of raw materials to product designs and services that meet high environmental standards. The EU Ecolabel encourages producers to produce less waste and CO_2 during the production process and encourages the development of products that are durable and easy to repair and recycle.

3. Recycling Product Design Development Cases and Characteristics

3.1 Recycling product design development case

In the 3D factory, there is a development case that produced outdoor benches using a large 3D printer and received the quality certification (Q) mark of industrial products from the Korea Institute of Construction and Environmental Testing. The outdoor benches have been recognized for their quality in terms of materials, robustness, tensile strength and corrosiveness responding to the external environment and time changes, and have been produced commercially. In addition, the material can be said to be environmentally friendly because it can utilize composite materials such as waste plastics and waste wood. By comparison, the residents of the Solomon Islands were unable to access safe drinking water with a lot of plastic waste. There is also an example of eco-printing in which water pipes have been repaired. Precious Plastics is a campaign that changes the concept of plastics that we use once and throw away into precious plastics. Dave Hakkens has open-sourced related technologies such as injection, extrusion and crushing, and plastic recycling campaigns are appearing around the world. It is a good example of addressing the economic aspects of the country, which made easy-to-use products first and based on this, recycled from the resource point of view the difficult waste plastics coming to developing countries. Figure 6 shows precious plastics [5].

Figure 6. Precious plastics

The Zero Waste Lab in Thessaloniki, Greece, recycled the waste plastic into pellets and produced the outdoor furniture directly by the industrial robot arm 3D printing technique. At this time, 3D-printed furniture has increased compression and tensile strength through a new method of outputting diagonally, and more than 3000 designs have been produced since December 2018, and plan to recycle 4 tons of plastic in the future. Figure 7 shows zero Waste Lab [6].

Figure 7. Zero waste lab

Circulaire Expositie (Recycling Exhibition) Circulaire Expositie is a recycling program for millions of plastic products in the Netherlands. As part of the Recycling Exhibition, the company unveiled a sofa (Stadhuis sofa) made by 3D printing method using 300 plastic bags. New product designs with designs are emerging by recycling sustainable materials from urban construction. Filament recycling companies such as Filabot are appearing, and there is a lot of interest in new recycled materials and new 3D-printed product designs using them. Figure 8shows circulaire expositie [7].

Figure 8. Circulaire Expositie

London-based designer Charlotte Kidger showed her work of multicolored furniture by recycling the pieces and dust from CNC machining. CNC machining, or Subtractive Manufacturing, involves cutting off chunks of material, resulting in a significant amount of waste plastics from cutting. It is disposed of by incineration or landfill, and multicolored furniture is designed based on the idea of recycling these undervalued materials. Figure 9 shows multicolor furniture [8].

Figure 9. Multicolor furniture

In the case of the production of recycled plastic toys and furniture, Dirk Vander Kooij recycled waste plastics to design furniture, expressing the product's softness better than before and techniques that could not be tested in mass production. He exhibited at Hemkade Shoreum in Zaaandam and presented a new 3D printing product design technique for recycled materials. The colorful pattern of the stand, which looks like an abstract picture, is a natural phenomenon that appears as a mixture of various materials of plastic, and old toys and video tapes are reimagined as circular lights. The overall design style is produced once and the shape is composed, and the colors of various materials appearing on the surface of the object are applied in different states. In addition, the 3D-printed RvR chair is a bubble-shaped soap cabinet with a new method of output, consisting of recycled composites with three wood plates: Chuby, Coat, and Raack. Figure 10 shows plastic toys and furniture [9].

Figure 10. Plastic toys and furniture

Rezign is a chair design made from discarded jeans and military uniforms, recycled coffee bags and leftover textile waste, introduced as a result of innovative and sustainable design by Anton, Denis and Joris at the Dutch Design & Innovation Studio Planq. Their concept is a creative product that utilizes material waste around design principles of people, planet and profit, and participated in the Fabric Start exhibition by designing products with new ideas. By scrapping the old fibers and using waste plastic to create a new seating method, they utilize recycled materials that are stronger and less expensive than the plastic used in existing chairs. It was introduced as a “design that can”. Figure 11 shows innovation studio planq [10].

Figure 11. Innovation studio planq

3.2 Types and Modeling of Recyclable Product Design

Most of the types of recycled product design have emerged as examples of making large quantities of recycled materials into newly designed products. In addition, new formative characteristics with product value and aesthetic measurement are emerging, highlighting recycling design and differentiation from the existing product design type. The company is pursuing new modeling with new aesthetics and functionality by applying a method different from the existing production method. It is creating a new paradigm by increasing the value with new molding elements different from the existing production method and giving value that could not be

realized in the existing production. Recently in Europe, the concept design of an automated robotic beach cleaner design for 3D printing on the coast has been introduced [11]. The SUV-style car has the idea of two robotic arms installed to recover plastic recycled materials along the coast. The Altogether Recycling plant in Adams County, Colorado, has been testing since September 2018, using an artificial intelligence system robot that identifies plastics with a camera's light to a recycling separator called Clarke for the separation of problematic waste. The Deltabot-style robot, researched and developed by AMP Robotics, has the ability to identify and separate paper and plastic and can extract at speeds of 60 boxes per minute. In addition, Smile Plastics is attracting attention as a multicolor sheet using plastic waste, and it takes advantage of naturally occurring phenomena to produce building plates and finishing materials that are separated from current typical and standardized composites. This type of case is represented by the reuse of recycled materials, maximizing the application of recycled materials, recycling of recycled materials, and upgrading. The molding elements of recycled product design are attracting attention as a parametric design technique using Voronoi Polygon and Delaunay triangulation molding unlike the existing methods. The new modeling paradigm is emerging as the transition from the existing production method to the lamination method and the limitations of the various design processes are resolved. When it comes to recycling product design, it is common to express a new formative element that is different from the existing method of mass supply through mass production. Voronoi Polygon [Boronoi Polygon] Voronoi Polygon: When a point is placed in space, it is a Voronoi Polygon obtained by dividing the space in the area closest to each point [Reference: Naver Knowledge Encyclopedia] Delaunay triangulation Delaunay triangulation: Triangulation obtained by connecting two points corresponding to all adjacent Voronoi polygons in a Voronoi diagram for a set of points on a plane. Encyclopedia] Telone triangulation (Computer Internet IT Glossary, January 20, 2011 Iljinsa). This is a great feature of the method of making the modified parameters using a computer. These methods originate from the study of mathematical algorithms to represent all things as points, but they are currently attracting attention as a means of expressing new forms. This method uses design elements inferred from the following natural objects as the main concept and uses them as design elements. New types of design in Europe and the United States can be produced individually by applying new 3D printing techniques unlike the past methods, and the formative contents that appear in various phenomena through the proper production and supply methods that enhance the satisfaction of individual consumers are applied to a design. For example, there are two types of moldings based on plant shape and cell structure. FloraForm is an algorithm that implements the change of shape that appears when the formative elements of plant leaves grow in the surrounding environment. Cell structure is a method that expresses the combined structure of cells by using a mathematical algorithm to express the tension, thickness, and structure between polygonal cells. Recently, many cases have been applied to product design development using new materials. Examples of natural objects are also observed and analyzed. Natural products react with the environment and grow over time. Therefore, they observe and expand the appearance of natural objects, and examine the changes in constituents such as petals and the shape of plants and apply them to the design. Also unique is the way in which biological components for adapting to different environments, such as animals, insects, and natural creatures such as seaweeds and sea creatures, are examined and applied. In particular, in recent years, new robot designs and mechanisms have been realized and applied using the structure and overall shape of tree climbing in life using natural phenomena of reptiles such as iguanas and lizards. In addition, there were cases of actual product identification by mathematically identifying naturally occurring phenomena and structures in algae living in the sea.

4. Formatting your paper

Disruption of waste vinyl and styrofoam collection during recent recycling process has caused confusion. In

view of excessive usage of disposable packaging materials in Korea, regulations are being made. First of all, efforts to improve consumption behavior will be important. Korea is a disposable plastic bag that generates 23 million tons of carbon dioxide per year, and about 80% of the waste dumped at sea is plastic waste. Recently, at Electrolux Design Lan 2014, PET bottles were recycled and put into 3D Printing Cloth in the home to showcase the concept design. This is a concept that can be used immediately by giving color and design to your own clothing design through knitting and pulverizing and using fiber recycled PET material through personal 3D Printing Cloth that can be used in your own home in the future [12]. This suggests the interest of developed countries in materials and interprets plastic that is difficult to disassemble in terms of materials. This is to solve social problems by interpreting and reflecting them from the design point of view. In terms of environmental burden, which is an issue in recent years, designing and providing plastic products from raw materials is another big challenge for designers and producers, but designers recognize plastic as a useful material. It is necessary to approach from a recycling point of view. In other words, if a useful material is approached from the point of view of forming a natural cycle from recycling to virtuous recycling, many companies and designers will be able to solve the environmental problem and come up with a new design point of view. Recently, developed countries have invested considerable resources for research into improving the quality of packaging containers, and prefer recycled materials with improved quality as raw materials. On the other hand, waste plastics in Korea contain many different foreign substances and various other substances, which makes it difficult for the selection process. Reflecting these perspectives in the planning of actual product production, new processes that can be understood by new processes and consumers can be designed based on clearer recycling.

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