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Social Network Analysis of Public Design Cases Using Recycled Waste Plastics

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ABSTRACT

Purpose: In this study, examples of recycling methods and their implementations that can apply waste plastics to public designs were investigated, and their relationships were identified. **Method:** Pinterest, an image-based social networking service and social bookmarking site was selected as a data search tool. Descriptive statistical analysis and social network analysis (SNA) were used as analysis methods in this study. **Result:** The waste plastic recycling method through modular construction combining units was most frequently applied to public designs. This method was calculated to have the strongest influence. It can be inferred that this is due to the characteristics that can derive results with various functions and forms of waste plastics. Artistic installation technique was also investigated as a frequently used recycling method. This method can express works with only design thinking and without any specific recycling processing technology; it was mainly applied to the installation of sculptures in which important ideas related to environmental protection and sustainability were visualized. Furniture and building components were found to be the most frequently appearing implementations. In the implementations regarding furniture, the methods of replacing wood with waste plastic or implementing various shapes through 3D printing were dominant. A public design has a very high waste plastic capacity; therefore, it can effectively contribute to waste plastic treatment and recycling. It is expected that the results of this study will be utilized to prepare effective alternatives for the treatment of large amounts of waste plastics during urban planning.

KEYWORD
Public Design
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1. Introduction

1.1. Research Background and Objectives

Mass production and excessive consumption culture of plastic products generated large amounts of waste plastic, and the use of plastic in the production of health supplies surged due to the COVID-19 pandemic. Owing to the indiscriminate management of plastic waste, various environmental problems have emerged [1].

In South Korea, as discussions on the publicity of design began in the early 2000s, public design-related policies were implemented, paying attention to the design of public facilities that had been overlooked compared to those in private areas. Research on recycling plastic waste has been carried out in various fields, and attempts have been made to recycle plastic waste in the manufacturing of building materials by using waste plastics as concrete composites [2, 3], plasticizers [4], and mortar fillers [5]. Moreover, a composite material that can be used as a floor coating material with improved durability was developed by mixing plastic raw materials with blast furnace dust (BFD), which is a form of metal waste from the steel industry [6]. In addition to this, a technology for producing permeable packaging blocks using PET wastes [7], a technology for using a composite material made of waste plastics filled with inorganic minerals including coal (i.e., the by-product of a thermal power plant) for railroad production [8], and a technology for replacing concrete aggregates with waste such as plastics used in electronic products [9] have also been developed. In particular, plastic waste can be easily recycled as a material with physical and mechanical properties similar to natural aggregates during the manufacturing of mortar or concrete [10]. When porous foamed plastic waste is used as an alternative aggregate, features such as heat insulation, hygroscopicity, and weight lightening can be further improved [11]. As such, waste plastics can be developed in various forms of building materials or mixed with existing construction and demolition (C&D) waste to be recycled as building materials. Waste plastics, which are easily used as building materials, can be recycled via various methods for public designs that constitute public spaces in cities. To this end, this study aims to explore the feasibility of public design that can resolve environmental problems and improve citizens' awareness by identifying the recycling characteristics of waste plastics applied to public design and enhancing the recycling efficiency of waste plastics.

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1.2. Research Method and Scope

In this study, by limiting the scope of the study to the manufacturing countries, implementation methods, and implementation results of public designs to which the waste plastic recycling method was applied, various cases were investigated, and their characteristics were identified. To obtain examples of waste plastic recycling methods implemented in actual public design areas, Pinterest, an image-based social network service and social bookmarking site, was selected as a search tool. Descriptive statistical analysis and social network analysis (SNA) were used as the analysis methods in this study. SNA was performed only on indicators of degree centrality, closeness centrality, and betweenness centrality.

2. Background Knowledge

2.1. Concept and Subject of Public Design

Public design is a value-oriented concept that can be applied to products, space, and visual media, and because all design activities that provide public benefit from public institutions are public designs, detailed items of public design are classified using terms such as public space, public facilities, public visual media, and public architecture according to the subject of application [12]. Public design is not a concept based on the outcome of design but a term created based on the value that design activities and goals pursue, namely public benefit and publicity, and it is a design conducted for the purpose of restoring the cultural value and publicity of the public domain, seeking design possibilities based on culture and coordinating and adjusting personal and social values [13].

According to the Public Design Promotion Act (shortened as the Public Design Act), the targets covered by public design are specified as public facilities, etc (Korean Law Information Center, n.d). In this Act, the term "public facilities, etc." means facilities, articles, visual images, etc. developed, produced, installed, operated, or managed by State agencies, etc. for the benefit of the general public.

2.2. Literature Review

To search for previous studies related to this study, the Web of Science database of Clarivate Analytics in the United States was utilized. Research literature search on "design" and "construction" through "recycling" or "upcycling" of waste plastics confirmed that 195 papers from 55 countries were published in international journals from 1992 as of December 2020. The number of these studies has shown an increasing tendency since 2010, and in 2020, 57 papers (the largest number ever) were published in international journals (Fig. 1). Among the published papers, 21

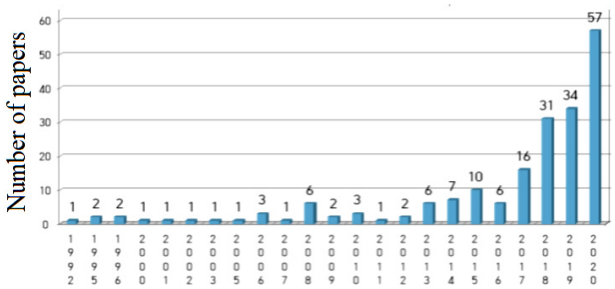


Fig. 1. Number of papers published by year

papers were published in the United States, regarded as the country with the most active research. India and China also published 18 and 17 papers, respectively, and were surveyed as countries performing active research in this field.

Research related to public design through recycling of waste plastics was conducted in various fields, and the most active research was in the engineering field, where 106 papers were published. Moreover, 77 papers in the field of environmental science and ecology, 45 in the field of materials science, and 29 in the field of construction building technology have been published, indicating that many studies have been conducted in these fields. It was found that Korea published four research papers in international journals.

Research by Ragaert, Delva, and Van Geem (2017) [14], which recorded a total of 377 citations (the highest number of citations as of May 2021) and an average of 75.4 citations per year, emphasized the role of design while explaining the mechanical and chemical recycling of waste plastics and dealing with the relationship between recycling and design. In particular, among researchers who published studies in international journals in Korea, Soohwan Ju et al. (2020) carried out a study to use a composite material in which waste plastic is filled with inorganic minerals including coal, a by-product of thermal power plants, for railroad production [8], and Byunghyun Ryu et al. (2020) developed a permeable packaging block production technology using PET waste [7].

Previous studies have mainly suggested methods to develop or utilize waste plastic design in various design fields such as industry, accessories, and furniture to solve environmental problems and recycle waste plastic into high value-added materials and products. In a similar context, this study attempted to differentiate itself from previous studies by finding answers to the aforementioned recycling problem in public design by accommodating large amounts of waste plastics in various design forms such as sculptures, furniture, and convenience facilities, thus striving for a change in civic consciousness regarding the publicity of public design to more actively deal with environmental issues.

3. Research Method

3.1. Collection and Cataloging of Research Subjects

In this study, 56 cases of recycling waste plastics from several countries applied to public design were collected from Pinterest, a social network service that posts and shares images. These cases were collected by using "plastic waste," "upcycl*," "recycl*," "public space," and "built environment" as the search words. The collected public design cases were classified by implementation method, implementation results, production country, production year, production subject, and source; they were cataloged according to the type of elements.

3.2. Social Network Analysis

The frequency of appearance of the collected and organized data by element type was identified, and the relationship between elements was evaluated using a social network analysis (SNA). The aforementioned element type was regarded as a node by extracting implementation methods, implementation results, and production countries from the list organized based on the images and descriptions of public designs registered in Pinterest and applying the co-occurrence used in data informatics. By estimating that two elements are related to each other when they appear simultaneously in a specific public design case in a file in the form of graph modeling language (GML), the link information was recorded, the number of times the corresponding element appeared at the same time was measured in all public design cases investigated, and the strength of the relationship was calculated as a weight, namely tie strength, and recorded to construct a network for the SNA. GML files containing such network configuration information were retrieved from the "Ucinet" [15] program and visualized to the network, and major indicators of SNA were determined.

1) Degree centrality

The degree centrality calculates the centrality of the local level, and not the overall level, by considering only the nodes directly connected to the node to be measured. It identifies the state in which a specific node is directly connected to neighboring nodes in the network according to the number of connection lines connected to each node. Degree centrality can be used when finding topic factors that are likely to be related to many factors [16] (Eq. 1).

$$C_D(i) = \sum_{j=1}^{n} A_{ij} \quad \text{(Eq. 1)}$$

where $C_D(i)$ is the degree centrality for node i
Aij is the state of connection between node i and j (connected: 1, disconnected: 0)

2) Closeness centrality

Closeness centrality is an indicator of the degree of closeness of the node to be measured to all other nodes in the network. It is calculated by allocating the sum of the shortest path distances between the node to be measured and all nodes (Eq. 2). This indicator is utilized to search for factors with the fastest influencing phase in the network and, unlike degree centrality, considers the relationship with not only directly connected nodes but also all indirectly connected nodes at the overall level [16].

$$C_C(i) = \frac{1}{\sum_{j=1}^{n} D_{ij}} \quad \text{(Eq. 2)}$$

where, $C_C(i)$ is the closeness centrality for node i
Dij is the shortest path distance between node i and j

3) Betweenness centrality

Betweenness centrality is an indicator that finds nodes connecting different areas of the network among nodes in the shortest path between two nodes by measuring the number of cases where the node to be measured can be placed on the shortest path between other nodes. Nodes with high betweenness centrality are interpreted as having a large betweenness influence [16]. Betweenness centrality is calculated to find factors with a high betweenness influence among factors (Eq. 3).

$$C_B(i) = \sum_{j<k}^{n} G_{jk}(i) / G_{jk} \quad \text{(Eq. 3)}$$

where $C_B(i)$ is the betweenness centrality for node i
$G_{jk}(i)$ is the number of paths passing through node i among the shortest paths between nodes j and k
G_{jk} is the number of shortest paths between two nodes j and k

4. Recycling Characteristics of Waste Plastics Applied to Public Design

4.1. Implementation Type of Waste Plastic Recycling Public Designs

1) Implementation Method

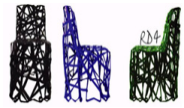
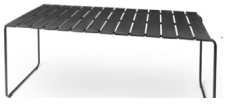
The methods of implementing the investigated public design cases were classified into 11 common types. These types were classified according to the construction method, design method, exhibition method, and the material regeneration method for implementing the public design. The construction methods included "3D printing," "floating," "modular construction," and "pavement." The design methods included "public participation design" and "style reproduction." The exhibition methods included "artistic installation" and

"collection exhibition." The material regeneration methods included "upcycling," "material replacement," and "weaving." 3D printing, which outputs public designs by inputting filaments made by recycling waste plastics, is a technology that implements public designs in response to the flow of the 4th industrial revolution by enabling customized production. Floating involves floating public designs on water using the intrinsic buoyancy of plastic. Modular construction is a method of constructing public designs by repeatedly using ready-made products such as plastic bottles and barrels or plastic unit materials made of recycled plastic. Artistic installation involves implementing waste plastic in public design artworks such as statues and sculptures by expressing it in the form of an art installation. Material replacement involves replacing existing materials such as product materials with plastic materials and applying them to products, architecture, and roads. In addition, the upcycling method aims to improve functions or performance in the waste plastic recycling process, the weaving method is used to extract threads from waste plastic and applying them like fibers, the public participation design method encourages public participation in waste plastic recycling design to manufacture products, and the collection exhibition method is used to display collected waste plastic in an exhibition space. Style reproduction is used to reproduce a specific style with waste plastic, and the pavement method involves mixing waste plastic with road pavement materials and implementing them as a general road or bicycle road. Among these implementation methods, artistic installation was the most common method with 23 cases, followed by modular construction with 22 cases; material replacement with 8 cases; collection exhibition with 3 cases; weaving, pavement, and 3D printing with 2 cases each; and floating, upcycling, style reproduction, and public participation design with 1 case each (Table 1.).

2) Implementation Results

Public designs implemented by applying the aforementioned implementation methods showed largely eight types of results: "furniture," "play facilities," "flower pots," "sculptures," "exhibition spaces," "architectural components," "artificial islands," and "roads." "Sculptures" were the most common with 18 cases, followed by "furniture" and "architectural components" with 13 implementation results each, "exhibition spaces" with 5 cases, "flower pots" with 4 cases, "roads" with 3 cases, "play facilities" with 2 cases, and "artificial islands" with 1 case (Fig. 2.).

Table 1. Public design implementation methods using waste plastics

Implementation method	Definition	Construction example
Number of appearances		
3D printing	A method of outputting with a 3D printer by inserting a filament made from waste plastics	 (Source:: The New Raw)
2 ■■		
Floating	A method of floating public designs made by recycling waste plastics on water	 (Source: Recycled Island Foundation)
1 ■		
Modular construction	A method of constructing public design by repeatedly using unit components made from waste plastics	 (Source: Jaime Navaro, 2017)
22 ■■■■■■■■■■■■■■■■■■■■■■		
Artistic installation	A method of creating public designs in the form of installation art using artistic techniques	 (Source: Matthias Desmet, 2018)
23 ■■■■■■■■■■■■■■■■■■■■■■■		
Material replacement	A method of replacing conventional materials with waste plastics	 (Source: PyraSied)
8 ■■■■■■■■		
Public participation design	A method of creating public design with the participation of the public	 (Source: COHDA, 2007)
1 ■		
Upcycling	A method of implementing public design by improving the functions or performance compared with existing ones in the process of recycling waste plastics	 (Source: cellercanroca & dezeen, 2018)
1 ■		
Weaving	A method of making waste plastics into fibers and applying them to public design	 (Source: HGTV)
2 ■■		
Collection exhibition	A method of creating public designs by displaying plastic products that have reached the end of their lifespan	 (Source: Jeremy Weihrauch)
3 ■■■		
Style reproduction	A method of reproducing a specific style with waste plastic	 (Source: The Charming Bench Company, 2021)
1 ■		
Pavement	A method of implementing public designs such as roads by laying plastic on the road	 (Source: SMC, 2020)
2 ■■		

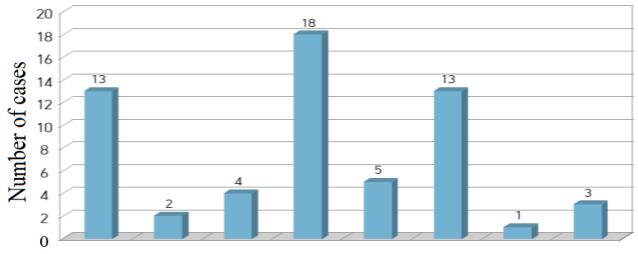


Fig 2. Number of cases of public designs using waste plastics

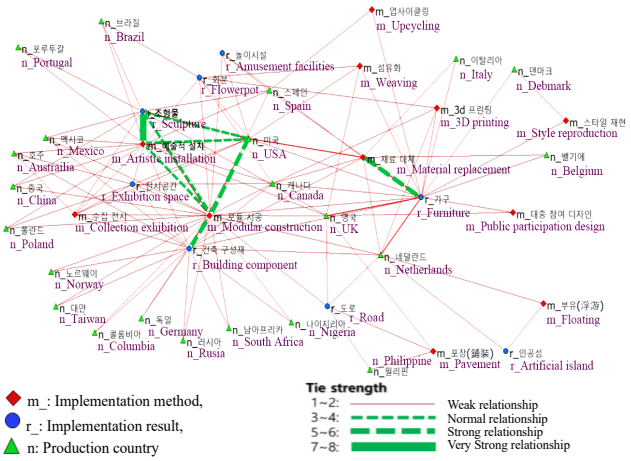


Fig. 3. Tie strengths among network components

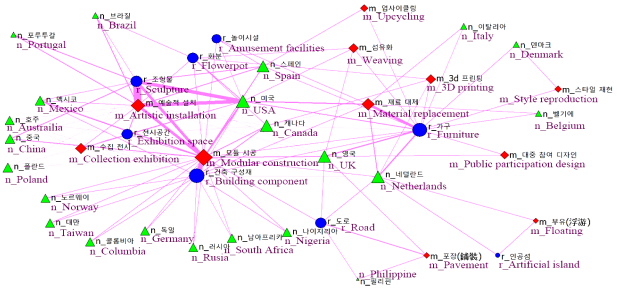
4.2. Construction of Network and Analysis of Correlation Between Components

1) Network Construction

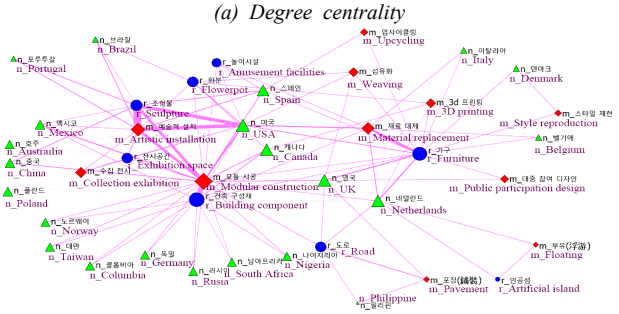
After implementation methods, implementation results, and production countries are extracted from the list of public designs that recycled waste plastics, they are visualized into nodes. The nodes are related to each other; that is, in which they appear at the same time and are connected with a link. The correlation network is constructed as shown in Fig. 3. Here, to distinguish between the types of nodes (elements), a network was constructed by attaching an identifier (Id) of m_, r_, and n_ for the implementation methods, implementation results, and production countries, in the shape of a rhombus, circle, and triangle, respectively. According to the results of the correlation analysis between network components, it was confirmed that the correlation that creates "sculptures" as a method of implementing "artistic installation" forms the strongest connection strength in "the United States." In addition to "artistic installation," the relationship formed by the implementation method of "module construction" was calculated to have a relatively strong connection with "sculptures." It can be identified through the relationship structure and strength of the connection that "module construction" is mainly used for implementing "sculptures" and "architectural components" as the implementation results. "The United States" mainly forms a strong connection with the aforementioned "module construction" and "artistic installation," indicating that "the United States" tends to implement public design using the aforementioned two implementation methods. "The United States" also implemented public design through the implementation method of "material replacement," which has a stronger connection with "UK" and "Netherlands" and has been found to be the main result of public design in the form of furniture (Fig. 3.).

2) SNA Analysis Results

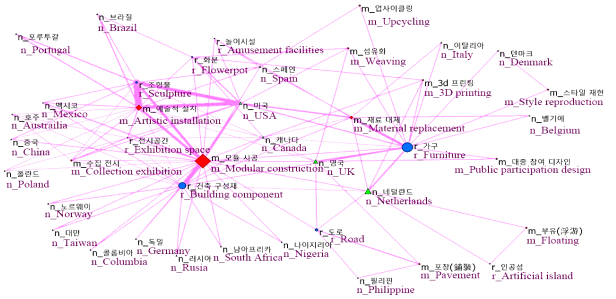
According to the results of the degree centrality analysis of the SNA, among the means of implementing public design through recycling plastic, the method with the greatest direct impact was the "module construction," which repeatedly uses unit materials to create implementation results. Next, the implementation of "artistic installation" was also found to have a centrality with a strong direct influence. The implementation results (r) of using waste plastic for public design showed that the public design in the form of "furniture" and "architectural components" had the greatest direct influence. "Furniture" is relatvely strongly related to North American and European countries such as "the United Kingdom," "Netherlands," "the



(a) Degree centrality



(b) Closeness centrality



(c) Betweenness centrality

m_: Implementation method, r_: Implementation result, n_: Production country

Fig. 4. Calculation results of the centralities of network components

United States," "Belgium," "Denmark," and "Canada." It is also directly related to the implementation methods of "material replacement" and "3D printing." The implementation results represented as "architectural components" were found to be directly related to most countries in the world, such as "China," "Taiwan," "the United States," "Canada," "Germany," "Australia," and "Nigeria," and they are mainly strongly related to the "module construction" method (Fig. 4.).

3) Comprehensive Analysis

① Analysis of Implementation Methods

According to the comprehensive analysis results of the waste plastic recycling implementation method (Table 2.), among the implementation methods of waste plastic applied to public design, "module construction" and "artistic installation" were analyzed as the implementation methods with the highest values of all three centrality indicators. This means that "module construction" and "artistic installation" have a dominant impact on the recycling method of waste plastics, directly or indirectly. Next, the "material replacement" implementation method showed high quantitative figures in the analysis of the degree centrality, closeness centrality, and betweenness centrality, suggesting that the "material replacement" method also had a relatively dominant influence on public design, directly or indirectly. For "collection exhibition," it was analyzed that the direct influence was strong owing to the low betweenness centrality and high degree centrality. It was found that the public design of the "collection exhibition" method has a weak betweenness role but acts as an implementation method with direct influence.

② Analysis of Implementation Results

In case of public design implementations, all three centrality indicators of 'architectural components' and 'furniture' appeared to be high (Table 2.). This means that the effect of 'architectural components' and 'furniture' are directly or indirectly dominant in public design. The influence of 'roads' was dominant after 'furniture' and 'building components' in betweenness centrality analysis. However, the quantitative figures of degree centrality and closeness centrality were low, indicating that the direct effect is relatively weak in the field of public design, although they might act as an intermediary for public design. On the contrary, the degree centrality and closeness centrality of 'sculptures' were calculated to be high, and hence, it was analyzed that its influence was directly or indirectly dominant in public design.

③ Analysis of Production Countries

Among the 22 countries that developed public designs through waste plastic recycling, the three analysis indicators were high for the United States and the United Kingdom (Table 2.). This means that the United States and the United Kingdom have a direct or indirect dominant centrality in the development of public designs using waste plastic recycling. In addition, the Netherlands and Canada were also found to have a relatively high influence on the development of public designs using recycled waste plastic. It was concluded that the use of recycling waste plastic in public design is being intensively pursued in North America and Europe.

Table 2. Calculation results of the centralities for the component

Id	Component	Indicators of centrality		
		Degree	Betweenness	Closeness
m_	3D printing	4	4.149	0.011
	Public participation design	2	0.000	0.010
	Modular construction	*24	*271.840	*0.018
	Floating	2	0.000	0.009
	Weaving	4	2.524	0.011
	Collection exhibition	7	2.102	0.012
	Style reproduction	2	0.000	0.010
	Upcycling	2	0.000	0.010
	Artistic installation	*16	*77.835	*0.014
	Material replacement	*8	*25.348	*0.013
	Pavement	3	4.279	0.009
r_	Furniture	*16	*193.567	*0.015
	Building component	*18	*126.372	*0.016
	Amusement facilities	4	1.050	0.011
	Road	5	*45.905	0.012
	Artificial island	2	0.000	0.009
	Exhibition space	8	4.480	0.012
	Sculpture	*10	29.565	*0.013
	Flowerpot	7	17.171	0.012
n_	Nigeria	2	0.000	*0.011
	South Africa	2	0.000	*0.011
	Netherland	*8	*90.932	*0.014
	Norway	2	0.000	*0.011
	Taiwan	2	0.000	*0.011
	Denmark	2	0.000	0.010
	Germany	2	0.000	*0.011
	Russia	2	0.000	*0.011
	Mexico	4	0.200	*0.011
	USA	*11	*30.548	*0.014
	Belgium	2	0.000	0.010
	Brazil	3	0.341	0.009
	Spain	*6	17.758	*0.013
	UK	*8	*57.537	*0.014
	Italy	2	0.000	0.010
	China	3	0.000	*0.011
	Canada	*8	15.499	*0.013
	Colombia	2	0.000	*0.011
	Portugal	2	0.000	0.009
	Poland	3	0.000	*0.011
	Philippines	2	0.000	0.008
	Australia	4	0.000	*0.011

Note: An asterisk(*) indicates a value that falls within the top three.

5. Conclusions

According to the analysis results of this study, first, there were many cases of using recycled waste plastic in public design in North America and Europe. Second, module construction and artistic installation were the most dominant means of recycling. This is because module construction can produce results of various functions in various forms through a combination of unit materials, and artistic installation of public design can be implemented through creative thinking without the requirement for special technology. Third, waste plastic was mostly applied in the form of furniture and building materials in public design, and public design in the form of furniture was mainly implemented in a way where waste plastic replaces other materials such as wood or through 3D printing.

Waste plastic can be accommodated in large amounts in public design, and thus, it will solve environmental, social, and economic problems caused by waste treatment. Therefore, recycling large amounts of waste plastic is an area that is difficult to be solved by individuals and will have a great effect if handled in the public domain, . Plastic will be highly utilized in the field of public design in the form of outdoor facilities because it is easy to maintain and manage owing to its unique durability, waterproofness, and plasticity. The research results are expected to be useful as urban planning decision-making data that provide ideas for recycling waste plastic in urban public design after the development of various designs so that public design can be an effective alternative to waste disposal.

The analysis in this study was limited to implementation methods and implementation results of recycled waste plastic in public design by country, and hence, we could not present the quantitative basis for the amount of recycled waste plastic that are consumed during the public design implementation process and economic feasibility of the process. Moreover, the symbolic and functional characteristics of the implemented public designs could not be specifically identified. Therefore, in future studies, specific and standardized indicators that can determine the effects of waste recycling in the process of implementing public design and support public design planning decisions should be developed, and information related to recycling methods suggested in this study should be systematized in more detail to develop urban public design that can materialize both practicality and aesthetics simultaneously.

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