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An Alternative Approach for the Recovery of Plastic Waste under the Concept of Zero Waste City

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Abstract

The pervasive utilization of plastic products has led to a gradual transformation of plastic waste into a significant global pollutant, their accumulation in the environment results in significant environmental pressures. Considering these challenges, the development of effective recycling methods for waste plastics and the realization of their high value has become an urgent problem. The central research question guiding this study is as follows: What design solutions can be implemented to effectively integrate recycling optimization and value-added transformation, thereby enabling the effective repurposing of waste plastics and advancing the realization of zero-waste cities? The present article focuses on the pressing issue of waste plastic management by introducing a set of innovative design solutions centered on two core objectives: recycling optimization and value-added transformation. This applied research study not only explores innovative design solutions for repurposing waste plastics but also addresses the associated challenges and environmental concerns, while emphasizing the importance of source reduction and reuse within the comprehensive zero-waste city framework.

Keywords: Plastic Waste; Urban landscape; Zero-Waste City

1. Introduction

Plastics products are widely used in our life[1], according to the World Bank, as of 2016, the global municipal waste generation has reached 2 billion tons, and it is expected to reach 3.4 billion tons by 2050[2,3]. Huge amounts of waste plastics have been produced since they are produced. The prevailing conventional methodologies for the disposal of plastic waste, primarily incineration and landfill disposal, are the subject of considerable scrutiny due to their propensity to generate secondary pollution. However, the incineration of these plastics releases toxic gases that contribute to air pollution, while the dumping of discarded plastics into surface waters can contaminate water bodies and lead to secondary contamination of subsequent water bodies[4,5,6,7]. Polyolefin plastics, which include polyethylene (PE) and polypropylene (PP), account for more

than 60% of all plastics and are the most widely used and discarded plastics and introduction for these plastics are shown in Table 1 and Figure 1[8]. The effective recycling and upgrading of waste polyolefin is of significant importance for environmental protection and resource utilization in China and worldwide. The chemical stability of waste plastics is a critical reason why they persist in the environment and also why recycling them is difficult. For example, the C – C bond dissociation energy of polyethylene (PE) is 372 kJ/mol, which makes degradation slow but also gives recycled products long durability. This dual nature underscores the central problem: plastic pollution conflicts with global sustainability goals such as zero urban waste. Chemical recycling technologies can serve as a foundation for the design of co-recycling technologies[9]. At present, the recycling of waste plastic is chiefly accomplished through three distinct methodologies: physical, chemical, and energy recycling. A comparison of the aforementioned methodologies reveals that physical recycling has the most substantial popularity. The primary reasons that support its popularity include its minimal pollution, damage to the plastic substrate, and cost-effectiveness[10].

Table 1. Properties and Applications of Major Plastic Types. Source: Designed and illustrated by the author.

Plastic Type	Chemical Classification	Main Application Areas	Degradation Characteristics
Polyethylene (PE)	Thermoplastic Polymers	Packaging film, plastic bags, containers, pipes	100–400 yrs photodegradation; low biodegradation; microplastic generation[11]
Polypropylene (PP)	Thermoplastic Polymers	Food packaging, automotive components, textiles	200–600 yrs decomposition; incineration releases CO_2 and toxins[12]
Polyvivlchloride (PVC)	Chlorinated Thermoplastic Polymers	Building materials (pipes, window frames), cable insulation	>500 yrs biodegradation; incineration produces dioxins[13]
Polystyrene (PS)	Thermoplastic Polymers	Foam packaging, disposable tableware, electronic housings	Nanoplastic generation; very low biodegradation (<5%/year)[12]
Polyethylene terephthalate (PET)	Thermoplastic Polymers	Beverage bottles, clothing fibers, food containers	50+ yrs hydrolysis; enzymatic degradation (90% in 72 hrs)[14]
Polylactic acid (PLA)	Bio-based Degradable Plastics	3D printing materials, medical supplies, food packaging	3–6 mos (industrial composting); 80% slower in nature[15]

Polybutylene adipate terephthalate (PBAT)	Petroleum-based Degradable Plastics	Biodegradable plastic bags,agricultural films	>90% decomposition within 6 mos (composting >50°C required)[16]



Figure 1. Chemical Properties of Various Waste Plastics. Source: Designed and illustrated by the author.

The widespread use and persistence of plastics have created a pressing environmental challenge, highlighting the urgent need for effective recycling solutions that can balance material durability with sustainable waste management. However, physical recycling usually produces materials of reduced quality and low added value, chemical recycling remains costly and prone to secondary pollution, and energy recovery contributes to greenhouse gas emissions. This technological fragmentation reveals a fundamental gap: no single method has yet succeeded in achieving large-scale, environmentally safe, and economically viable recycling of plastic waste. Notably, recent advances in heterogeneous photothermal catalysis have opened new possibilities for selective depolymerization of mixed plastics, using tailored catalysts to achieve high-yield recovery of valuable monomers while addressing critical challenges in multiphase mass transfer and energy efficiency17.

At the physical space level, non-degradable plastic waste now exceeds 18% of municipal solid waste. These waste materials occupy precious land resources, reducing landfill capacity by over 40%. More alarmingly, wind and water dispersal creates pervasive "white pollution" across urban landscapes. Regarding water systems, microplastics have infiltrated every component of urban waterways: wastewater treatment plant effluents contain concentrations as high as 1,200 particles per liter. These particles not only carry carcinogens like polycyclic aromatic hydrocarbons but also accumulate heavy metals, eventually entering human bodies through drinking water and seafood. For urban infrastructure, plastic waste increases drainage pipe blockage rates by 60%, causing annual direct economic losses exceeding 30 billion yuan from urban flooding. When improperly incinerated, these materials release dioxin compounds that can spike the Air Quality Index by 400% within a 3-kilometer radius, significantly elevating respiratory disease incidence. From a socioeconomic perspective, global cities incur hidden costs of $130 billion annually from plastic pollution, including waste management, healthcare expenses, and property devaluation. More profoundly, greenhouse gases (e.g., methane) from plastic decomposition contribute 3.5% of total urban carbon emissions, becoming a major climate change

driver. This complex pollution is fundamentally altering urban ecosystem material cycles. Confronting this multidimensional environmental crisis, 78% of coastal cities worldwide have developed novel geological formations called "plastistone," foreshadowing permanent plastic markers in the Anthropocene's urban stratigraphic record. These findings illustrate the multifaceted impacts of plastic waste on urban systems, underscoring the necessity for integrated approaches that address environmental, infrastructural, and socioeconomic dimensions simultaneously.

In light of these challenges, there is an urgent need to develop innovative recycling strategies that transcend traditional methods and integrate plastic waste into broader urban sustainability frameworks. This study seeks to address this need by exploring the potential of waste plastics as resources for urban landscape construction under the concept of a “waste-free city.”

To address the above issues, great efforts have been devoted to treat these plastic waste in the city by different methods. Chemical recycling is an emerging technology that converts and upgrades waste plastics into basic chemicals or fuels through thermal cracking, catalytic hydrogenation, and chemical depolymerization, among other reaction mechanisms18. In comparison to conventional physical recycling methods, this advanced technological approach exhibits a higher degree of versatility with regard to raw material acceptance. Specifically, it demonstrates an increased tolerance to diverse raw materials, resulting in the production of valuable petrochemicals. In addition, it facilitates the generation of high-calorific-value fuels, which are crucial in a wide array of industrial applications and energy production processes. This approach is poised to become a pivotal catalyst in the advancement of recycling, encompassing its three distinct categories19,20,21. The chemical recycling of polyolefin plastics has given rise to several technical branches. The process of thermal cracking is characterized by the controlled rupture of molecular chains within a thermodynamically regulated environment. In contrast, catalytic hydrogenation employs metal catalysts to expedite depolymerization reactions. Chemical depolymerization is a process that uses specific solvents to selectively break down polymers, thereby achieving targeted degradation. Co-coking technology, on the other hand, is a method in which the refining process is enhanced by the concurrent application of coking and distillation techniques22. This approach utilizes the combined effects of these two methods to achieve a treatment that is more effective than either individual technique alone. Nevertheless, the process of chemical recycling incurs substantial costs, which invariably lead to a subsequent diminution in the overall recycling value. Furthermore, the process of chemical recycling has been observed to result in environmental pollution. Consequently, large-scale chemical recycling is still in the experimental stage23. Energy recovery is achieved through the high-temperature incineration of plastic, which results in the conversion of heat or electricity24,25,26. Nevertheless, this technique is accompanied by several notable limitations. Incandescent waste disposal through incineration has the potential to generate toxic gases, which can be a contributing factor to ecological concerns. Furthermore, the process has the indirect possibility of releasing carcinogenic byproducts, including dioxins and furans, that can have a detrimental effect on human health. Furthermore, the combustion of plastics,

which is characterized by its high carbon content, has been shown to result in an increase in carbon dioxide emissions, thereby contributing to the ongoing phenomenon of climate change. Given the drawbacks associated with chemical and energy recovery, physical recycling is preferred because it rarely produces pollutants or secondary pollution. Consequently, the prevailing mainstream recycling method is predominantly physical in nature. While chemical and energy recovery methods show technological promise, their limitations in cost, scalability, and environmental impact reinforce the need for more viable alternatives that can be practically implemented in urban settings.

Physical recycling represents the prevailing mainstream technology for the recycling of single-category, clean industrial waste plastics. The process chain is comprised of five core links: The process of material sorting is undertaken to ensure homogeneity. Raw materials are then subjected to mechanical crushing, resulting in uniform particles. Subsequent to this step, a cleaning procedure is employed to remove surface contaminants. The next phase of the process involves melt regeneration, which is performed under stringent temperature control to reorganize the plastic phase transition. During this stage, the addition of toughening agents, reinforcing fibers, and other modifying materials as needed is crucial. The final phase of the process is pelletizing, which produces recycled particles27,28,29. This technology boasts two key advantages: low energy consumption and ease of operation. Nonetheless, the quality of the raw materials imposes a limitation on the process, which consequently restricts the capacity to generate products at the same level or lower. This, in turn, engenders a deficiency in added value.

The industry has a general tendency to adopt a physical modification process with the objective of enhancing the performance of recycled products. The primary technological approaches encompass toughening modification through elastomer blending to enhance impact resistance; blending modification leveraging the synergistic effect of diverse polymers to optimize overall performance; filler modification employing inorganic fillers to balance cost and performance; and enhancement modification through fiber composites to improve mechanical strength. Despite the pervasive implementation of physical recycling processes in industrial settings, significant challenges persist30,31. These challenges encompass the presence of substantial fluctuations in processing efficiency and the absence of substantial economic benefits. Despite these efforts, current recycling paradigms remain trapped in a low-value loop, failing to establish ecological connections between waste streams and urban systems. This gap motivates the exploration of alternative applications that enhance the functional and aesthetic value of recycled plastics.

To further enhance the recycling value of plastic waste, efforts are centered on upgrading equipment intelligence, implementing process standardization, and developing high-value-added recycled product production processes32. In the domain of plastic waste recycling, the prevailing approach is the "industrial closed-loop" regeneration mode. For instance, transparent PET bottles are sorted, crushed, and subsequently molded under heat to produce industrial trays or low-end daily necessities33. PP woven bags, composed of synthetic fiber textiles, undergo a melting and drawing process to be utilized in the production of inexpensive carpets or as the

base cloth for packaging34. However, these products often lack durability and weather resistance, quickly re-entering the waste stream. This perpetuates a cycle of low-value recycling and misses opportunities to integrate waste materials into urban ecological systems.

The utilization of physically recycled waste plastics in the context of urban landscape construction has the potential to circumvent the constraints imposed by conventional methodologies and thereby expand the ambit of waste plastic applications. Through the implementation of modular design and functional integration, recycled plastic products have the potential to overcome the limitations associated with single-use industries, thereby contributing to the development of urban infrastructure that exhibits both engineering performance and ecological value35. The structural porosity of these organisms facilitates the synchronized integration of two primary functions: the infiltration of rainwater and the regulation of microclimates. The assembly characteristics of these elements lend support to dynamic renewal and maintenance. This dynamic process significantly extends the service life of the elements. Furthermore, the visual transformation of these elements into components of the landscape has been shown to effect a transformation in which waste is converted into a medium that is alive, capable of being used as a tool for the education of the public in environmental concerns. The aforementioned dynamic transformation has also been demonstrated to create a cognitive interface through which the public may engage in the process of recycling resources. This cognitive interface is established through design strategies, including but not limited to, the following: material traceability and color coding36. For instance, MVRDV's "Mega Mat" installation at Bangkok Design Week and the beer bottle landscape wall at Xuchang Waste-Free Park illustrate how designers can transform discarded plastics into public art, integrating functionality and cultural narratives. This transformation serves to reduce the environmental burden and establish a cognitive bridge for the public to participate in environmental protection through strategies such as color coding and local cultural symbols. This approach represents a paradigm shift from viewing plastic waste as a problem to be managed towards recognizing it as a resource for creating multifunctional urban landscapes that simultaneously address environmental, educational, and aesthetic objectives.

Within the paradigm of the expanding circular economy, the concept of "waste-free cities" has emerged as a pivotal element, promoting the mitigation of waste generation and the facilitation of resource recycling, thereby establishing itself as a pivotal direction for the advancement of both the circular economy and sustainable development37. In accordance with this concept's tenets, the promotion of resource reuse and the cultivation of a recycling economy, in conjunction with the augmentation of integrated waste management capabilities, constitutes a paradigm of urban development that aspires to curtail environmental degradation38. The "waste-free city" concept is predicated on a novel development paradigm that seeks to achieve the effective utilization of resources and to ensure the continuous enhancement of the environment within the urban landscape. This objective is pursued by means of the implementation of recycling initiatives and environmentally sound production practices.

Moreover, this paradigm is designed to minimize the environmental impact of plastics and other waste materials39.

The "Waste-Free City" is guided by the development principles of innovation, coordination, environmental sustainability, openness, and the sharing of resources. It promotes the formation of a green development model and lifestyle, the continued reduction of solid waste at source, resource utilization, minimization of landfill waste, and reduction of the environmental impact of solid waste. This is also an advanced urban management concept. In response to this trend, the 77th United Nations General Assembly adopted a resolution declaring March 30 every year as the International Waste-Free Day. In the context of a circular economy, the construction of "waste-free cities" has emerged as a planning goal for numerous countries and cities40,41. Concurrently, the concept of a "waste-free city" has undergone a process of refinement, with its application extending to diverse urban settings, including urban landscapes and urban communities42. By employing a holistic, waste-free approach, it offers a novel perspective on the study of material flows of urban waste43. It's important to emphasize that the “waste-free city” concept encompasses a complete waste hierarchy, prioritizing source reduction and reuse before recycling. This approach aims not only to manage waste effectively but also to prevent its generation through innovative design, conscious consumption, and extended product lifecycles. In essence, a growing number of cities are pledging to pursue a comprehensive green transformation of economic and social development, thereby accelerating the promotion of green and low-carbon development, while concomitantly undertaking efforts to enhance the overall efficiency of resource recycling. The "waste-free city" represents the ultimate vision, and the accelerated construction of green cities can comprehensively promote green transformation. A comprehensive approach to urban sustainability entails the integration of several key components, with the primary focus being the establishment of ecological landscapes, ecological public centers, ecological communities, green space systems, ecological buildings, and ecological preservation44. The waste-free city concept thus provides a comprehensive framework that integrates waste management with urban development, creating a foundation for exploring innovative approaches to plastic repurposing within urban landscapes.

The transformation of waste materials into raw materials that can be utilized for other valuable purposes while achieving a cleaner and healthier environment is a key objective. The transformation of waste materials into unique urban landscapes offers novel avenues for the resourceful and sustainable utilization of waste[39]. Concurrently, plastic waste is beginning to be recognized as a novel material with potential applications in landscape design. The utilization of recycled refuse in landscape design initiatives has been demonstrated to curtail environmental degradation and promote ecosystem balance45. This recognition of plastic waste as a potential resource for landscape applications establishes a crucial link between waste management and urban design, opening new possibilities for sustainable development.

Recycled plastic is revolutionizing the way of viewing and utilization to building materials. Beyond its pragmatic applications, the product exemplifies the principles of a circular economy by repurposing waste materials and contributing to the development

of sustainable, intelligent structures46. The strategic redesign of plastic waste can facilitate the adoption of eco-friendly lifestyles and stimulate innovative thinking and creativity. The concept of "Waste-Free Cities" is predicated on two fundamental principles: the reduction and harmless disposal of plastic and other types of waste, and the provision of a more expansive source of inspiration for artistic creation. The integration of waste plastics into urban beautification and landscape design is a strategy that can facilitate the comprehensive implementation of the concept of sustainable development in both life and design. The integration of waste plastics into urban design thus represents a convergence of practical environmental management with aesthetic and cultural innovation, creating new pathways for sustainable urban development.

Therefore, the purpose of this study is threefold: (1) to identify the unresolved challenges of conventional recycling in the context of urban sustainability; (2) to investigate how recycled plastics can be transformed into valuable materials for landscape design; and (3) to evaluate their potential role in advancing the “waste-free city” concept. By focusing on design-led applications, this paper seeks to bridge the current gap between low-value recycling practices and high-value urban ecological needs.

2. Application of Waste Plastics in Urban City Construction Development

The present study examines the innovative application of waste plastics in urban construction under the concept of a zero-waste city. This section analyses ten global case studies, selected to provide comprehensive and critical evidence base for this research. The cases were chosen based on three primary criteria: their geographic and typological diversity, representing a wide spectrum of applications across different continents; their innovative value in design strategy, technical processing, or material engineering, demonstrating cutting-edge approaches to upcycling; and their replicability potential, offering valuable insights and scalable models for other urban contexts seeking sustainable waste management solutions. This curated selection moves beyond anecdotal evidence to form a robust foundation for identifying effective design solutions that integrate recycling optimization with value-added transformation, thereby directly addressing the paper's central research question. The aim of this article is to focus on the potential of waste plastics as renewable resources in urban landscapes. Through innovative design, waste plastics can be transformed into more valuable landscapes.

2.1. Plastic Road, Netherlands

In Figure 2, the Plastic Road initiative, pioneered by VolkerWessels and first implemented in 2018 as a bicycle path in Zwolle, Netherlands, represents a transformative approach to sustainable infrastructure by repurposing recycled plastics (3,000 kg per installation, equivalent to 500,000 bottles) into modular, lightweight roadways with integrated drainage and sensor systems. This innovation reduces construction time by 70%, lowers maintenance costs by 30%, and creates a closed-loop lifecycle while addressing plastic waste pollution, demonstrating scalable potential for global urban adaptation.

This is the world's first large-scale project to use recycled plastics as road paving material. The project demonstrates significant potential for global adaptation due to its modular design and functional integration, which can be tailored to diverse urban contexts. It effectively combines aesthetic appeal with environmental awareness, highlighting a scalable model for addressing plastic waste.

However, potential challenges must be considered. Long-term monitoring studies suggest that plastic-based roads may release microplastics through abrasion and weathering processes. These microplastic particles could enter surrounding ecosystems through stormwater runoff, posing potential ecological risks. Since research should focus on developing encapsulation technologies and wear-resistant surfaces to minimize microplastic release, while establishing comprehensive life-cycle assessment protocols to evaluate the full environmental impact of these innovative materials.



Figure 2. Photos of Plastic Road from Netherlands[47].

2.2. MEAN* designs 3D printed pavilion, Dubai

As shown in Figure 3, another example for waste plastic application was presented in Netherlands. The Deciduous Pavilion, a pioneering 3D-printed architectural installation in the Netherlands developed by MEAN* (Middle East Architecture Network), exemplifies the innovative reuse of plastic waste in sustainable construction. Inspired by the regenerative cycle of deciduous trees, this modular structure combines three eco-conscious materials: birch plywood flooring, robotic 3D-printed concrete bases, and structural components fabricated from 30,000 recycled water bottles. The project demonstrates significant advancements in circular construction through its off-site prefabrication system that eliminates heavy machinery requirements while enabling precise, adaptable spatial configurations for diverse functions including exhibitions and public events. By transforming post-consumer plastics into durable architectural elements, the pavilion achieves dual environmental objectives: diverting substantial plastic waste from landfills and raising public awareness about material recycling potential. The application of large-scale 3D printing technology enhances resource efficiency by minimizing construction waste and allows rapid reconfiguration of the space to meet evolving needs. This project establishes an implementable model for sustainable architecture that harmonizes ecological responsibility with functional design innovation, offering scalable solutions for urban environments seeking to reduce their environmental footprint through creative material reuse. The pavilion's success lies in its ability to merge aesthetic symbolism with practical sustainability, proving that waste materials can be successfully repurposed into high-performance architectural components without compromising design quality or structural integrity.



Figure 3. Photos of MEAN* designs 3D printed pavilion from Dubai[48].

2.3. Recycling Loop proposal on a Normandy's beach, France

As shown in Figure 4, a recycling loop from waste plastic was demonstrated in France. Vincent Leroy conceptualizes a novel iteration of his monumental halo installation. This installation represents a new paradigm, situated at the threshold of reality and constructed entirely from recycled plastics. The installation has been designed to raise awareness about the quality of our waste and to promote interest in the subject. Leroy's artistic approach entails the meticulous creation of fluid deformations, characterized by a soft, steady, and continuous flow. The system is straightforward yet remarkably effective. The game appears to be an intriguing one, characterized by its lightness, fluidity, and almost volatile nature. The project directly addresses the issue of discarded plastics and emphasizes the environmental impact of marine pollution. By establishing a system centered on plastic recycling, it raises public awareness of plastic pollution and the circular economy and encourages widespread participation and action. The project combines waste plastic recycling and art. By designing an interactive recycling system, it provides a solution for plastic recycling and creates an educational space. The project emphasizes the concept of circular economy and environmental protection and provides new ideas for other regions.



Figure 4. Recycling Loop proposal on a Normandy's beach in France[49].

2.4. The Cola-bow, China

As presented in Figure 5, the Cola-Bow is an innovative public art installation crafted from over 17,000 recycled plastic bottles collected from Beijing universities and Coca-Cola recycling points. Braided into a dynamic form inspired by the Coca-Cola logo's iconic curves, the sculpture transforms waste into a striking urban landmark. Situated in a pollution-prone area, it serves as a powerful visual statement on plastic waste recycling, merging environmental activism with artistic expression.

This project demonstrates how discarded materials can be repurposed into functional public amenities while raising awareness of plastic pollution. By converting bottles into an eye-catching design, the Cola-Bow not only revitalizes the urban landscape but also sparks community dialogue on sustainability. Its success lies in seamless integration with the local environment, enhancing public engagement through interactive appeal. The installation's dual role—as both a social catalyst and a practical space—showcases how recycled materials can improve urban utility while promoting ecological values. Beyond its immediate impact, the Cola-Bow offers a scalable model for other cities. Its design concept and implementation process provide a blueprint for adapting recycled plastic structures to diverse cultural and spatial contexts. This initiative proves that sustainability-driven art can effectively bridge environmental goals with community needs, inspiring broader adoption of circular design principles in public spaces.



Figure 5. Photos of The Cola-bow in China[50].

2.5. U.S.E. – urban safety everyday, Italy

In Figure 6, the piece, entitled "U.S.E. – Urban Safety Everyday," was an experimental furniture installation that was placed in the Italian town of Lucca in March of 2022. The 3D-printed design, conceptualized by architect Giulia Del Grande and produced by Studio R3direct, is composed primarily of recycled plastic. It functions as a "second skin" for new Jersey barriers, thereby transforming them into objects that are both aesthetically pleasing and user-friendly in urban environments. The green installation is envisioned to become an integral part of everyday life in the town of Lucca, thereby promoting eco-conscious design. The final material composition of "U.S.E." consists of approximately 75% FiberPack®, with the remaining 25% comprising PE and aluminum. These two components serve as primary and secondary raw materials, respectively, in the production of the module.



Figure 6. Photos of U.S.E. – urban safety everyday in Italy[51].

2.6. Print Your City, Greece

Print Your City is an initiative that has been conceived by the Dutch-based research and design studio (Figure 7). It is a ground-breaking program that allows citizens to participate in the recycling process by bringing their plastic waste and designing custom urban furniture. The laboratory is responsible for closing the plastic waste loop through the implementation of advanced technologies at the local level. The New Raw demonstrates the viability of 3D printing street furniture from plastic household waste or flakes from grinded recycled products by redesigning public spaces within the Greek city.



Figure 7. Photos of the Print Your City in Greece[52].

2.7. Print Your City, Greece Tulum Plastic School, Mexico

The Tulum Plastic School project, an Archstorming competition initiative (Figure 8), demonstrates innovative reuse of plastic waste through Harvard designers Daniel Garcia and William Smith's award-winning proposal. Their design transforms recycled

plastic pallets into primary structural elements, combined with steel tube frames and corrugated plastic sheets to create two herringbone-shaped buildings - a classroom and community courtyard. The scheme creatively utilizes pallets' inherent stability by slotting them into the steel framework, forming repetitive modular units that blend structure and material efficiency.

Beyond its architectural innovation, the project addresses multiple sustainability challenges. The translucent corrugated plastic cladding provides thermal insulation and waterproofing while maximizing natural daylight, transforming into a glowing community landmark at night. This "architecture of multiplicity" harmoniously combines domestic, industrial and traditional elements through its material palette and spatial organization. The design's brilliance lies in its balanced approach: avoiding energy-intensive plastic reprocessing, it instead employs straightforward assembly of intact pallets with complementary recycled materials. This strategy yields numerous advantages - rapid on-site construction with minimal disruption, excellent weather resistance, low maintenance requirements, and full demountability for future reuse. The modular system ensures cost-effectiveness and replicability for similar contexts. More than just a physical structure, the project serves as an educational demonstration of circular design principles. By visibly incorporating waste materials into an attractive, functional community asset, it effectively raises awareness about plastic pollution while providing a practical model for sustainable construction in developing regions. The design proves that environmental responsibility can coexist with architectural quality and community value.



Figure 8. Photos of the Tulum Plastic School, Mexico[53].

2.8. People’s Pavilion, Netherland

In Figure 9, the People's Pavilion is a temporary pavilion designed by Dutch architecture firm bureau SLA and Overtreders W for Dutch Design Week 2017, with a capacity of 200 seated or 600 standing individuals, making it suitable for a variety of events, including audience gatherings, musical performances, and other events. The project's fundamental innovation lies in the implementation of the "100% borrowing" concept, which entails the utilization of all construction materials sourced from local suppliers, demolition projects, and donations from residents. This approach eliminates the need for conventional construction tools and methods, such as screws, glue, saws, and drills, on the construction site. The primary structure is 8 meters in height. The roof glass utilizes the standard system employed in the greenhouse industry, while the bottom curtain wall glass is derived from the renovation of an office building. The upper façade is adorned with over 9,000 pieces of colorful tiles, crafted from recycled plastic bottles collected by residents. This arrangement ensures sufficient lighting during the day and produces visually appealing effects at night through the illumination. Subsequent to the exhibition, with the exception of the plastic tiles, which will be

distributed among the residents, all borrowed components will be returned in optimal condition, thereby achieving a zero-waste outcome. This project exemplifies the reuse principle that is fundamental to zero-waste cities, demonstrating how materials can be utilized without permanent transformation or downcycling.

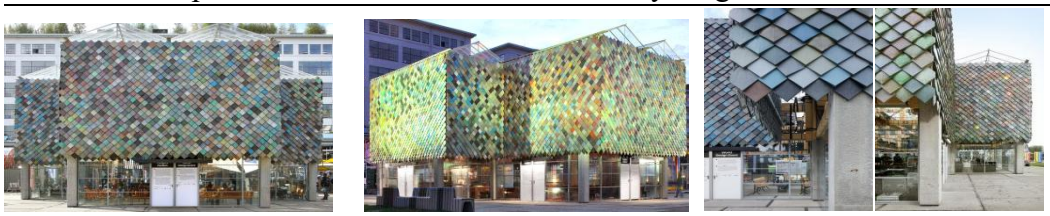


Figure 9. Photos of the People’ s Pavilion in Netherland[54].

2.9. Urban Magnetic Field, China

In Figure 10, the "Urban Magnetic Field" installation, created by Kyoko Ohoshi Design Studio to celebrate Dongguan's fifth urban anniversary in 2024, transforms Guanxiang Yinxiang Lane's green space into a dynamic public art attraction. Inspired by magnetic field dynamics, the design features concentric ring towers and radial pathways that visually symbolize urban gravitational pull, creating a striking focal point for the city center.

Constructed primarily from modular plastic baskets and lightweight synthetic materials, the installation demonstrates innovative material reuse - waterproof plastic components are later redistributed to the public through the "Food Basket Recycling Program," ensuring zero waste. This circular approach not only showcases sustainable design principles but actively engages visitors in environmental consciousness. The plastic baskets' inherent qualities - weather resistance, lightweight properties, and easy assembly - make them ideal for temporary urban installations while maintaining structural integrity. Beyond its symbolic representation of urban energy, the project creates an immersive spatial experience through its seamless integration with surrounding greenery and walkways. The modular design allows for quick assembly without specialized equipment, offering adaptable potential for various public spaces. By transforming utilitarian objects into artistic architectural elements, the installation expands possibilities for plastic waste applications in urban design while enhancing public space vitality. This temporary-yet-impactful intervention successfully merges environmental messaging with aesthetic innovation, serving as both a celebratory landmark and a practical demonstration of circular design principles in urban development. The project's afterlife through material redistribution further reinforces its sustainable mission, creating lasting impact beyond the exhibition period.



Figure 10. Photos of Urban Magnetic Field in China[55].

2.10. Toy Story Residence, India

The Toy Storey Residence (Figure 11), designed by India's Wallmakers for completion in 2024 in Vadakkara - a region grappling with plastic toy waste - reimagines sustainable housing through creative material reuse. This innovative home integrates over 6,200 discarded toys with traditional Mangalore tiles in a terracotta grille facade, creating both visual impact and commentary on plastic consumption. The design embodies circular principles through its modular, low-cost construction featuring: a cantilevered "house-within-a-house" layout adapting to existing trees and terrain; toy-supported balconies eliminating conventional facades; and quiet ground-floor spaces contrasting with playful exterior textures.

The project also demonstrates practical sustainability: the lightweight structure is weather-resistant and easily assembled, while its open-plan organization supports modern living needs. The scheme's scalability allows adaptation for community spaces or children's centers, proving waste materials can achieve both artistic and functional value. By transforming toys into architectural elements, the residence creates an interactive spatial experience that raises environmental awareness while achieving near-zero waste - a model merging ecological responsibility with innovative construction techniques and community engagement.



Figure 11. The picture of Toy Storey Residence in India[56].

The ten global case studies exemplify innovative applications of waste plastics in urban construction. Rather than presenting them in a purely report-style narrative, we have clustered these cases into three thematic categories based on their primary application and design intent:

Infrastructure and Public Space Elements, including Plastic Road, U.S.E., Print Your City, and Urban Magnetic Field, which integrate waste plastics into functional urban furniture, safety facilities, and pedestrian infrastructure;

Architectural and Structural Innovations, including MEAN* Pavilion, Tulum Plastic School, People’s Pavilion, and Toy Story Residenc, where waste plastics are used for structural components, modular buildings, and façade systems;

Art-Driven and Awareness-Raising Installations, including Recycling Loop Proposal and The Cola-bow), which employ artistic approaches to stimulate public dialogue and environmental consciousness.

This thematic clustering allows for a more structured understanding of design strategies, technical pathways, and sustainability outcomes. A comparative summary of all cases is provided in Table 2.

Table 2. Comparative Analysis of examples of the city construction from waste plastics. Source: Illustrated by the author.

Project Title	Location	Material Type	Design Objective	Technical Approach	Environmental Performance	Reuse Potential

Plastic Road	Netherlands	Recycled PET bottles	Sustainable roadway with integrated utilities	Modular prefabricated panels	Reduces construction time (70%) and maintenance (30%); closed-loop lifecycle[57]	High (modules are replaceable and fully recyclable)
MEAN* 3D-printed Pavilion	Dubai	Recycled water bottles (30,000 units)	Modular exhibition pavilion	Robotic 3D printing + off-site prefabrication	Diverts plastic waste; minimizes construction waste	High (modular design allows for reconfiguration)
Recycling Loop Proposal	France	Recycled plastics	Artistic marine pollution awareness installation	Artistic assembly with kinetic elements	Raises public awareness on marine pollution and circular economy[58]	Low (art installation, site-specific)
The Cola-bow	China	Recycled PET bottles (17,000 units)	Public art and urban landmark	Hand-braiding and structural framing	Visual statement on recycling; sparks community dialogue	Mid (durable art piece, but fixed form)
U.S.E. – Urban Safety Everyday	Italy	FiberPack® (75%), PE, Al (25%)	Urban safety furniture (barrier cover)	3D printing multi-material composites	Upcycles waste; promotes eco-conscious design	High (modular, attachable/detachable)
Print Your City	Greece	Household plastic waste	Customizable urban furniture	3D printing from plastic flakes	Closes local plastic loop; citizen participation	High (on-demand production, recyclable)
Tulum Plastic School	Mexico	Recycled plastic pallets,	Educational community building	Modular steel frame with pallet infill	Avoids energy-intensive	Very High (full material

	corrugated sheets			processing; demountable	reuse intended)
People's Pavilion	Netherlands	Borrowed materials, recycled plastic tiles	Temporary event pavilion	Borrowed material concept, no adhesives	Zero-waste outcome; all materials returned/reused	Very High (100% material circularity)
Urban Magnetic Field	China	Recycled plastic crates	Temporary public installation	Modular assembly artusing ubiquitous objects	Zero-waste through public redistribution program	High (materials redistributed for other uses)
Toy Story Residence	India	Discarded plastic toys	Sustainable residential building	Integration with traditional construction	Addresses local toy waste; near-zero waste model	Mid (building is permanent, materials not reused)

3. Conclusions

In this article it sets out to identify design solutions that effectively integrate recycling optimization and value-added transformation of waste plastics, thereby advancing the zero-waste city concept. The analysis demonstrates that successful repurposing hinges on interdisciplinary strategies that address both technical performance and socio-ecological systems. Rather than merely diverting waste from landfills, the most effective applications create new value through functional design, community engagement, and circular material flows while acknowledging persistent challenges that require further innovation.

The investigation reveals that modular design strategies consistently deliver the most effective outcomes for urban applications. This approach enables designers to accommodate the inherent variability in post-consumer plastic quality while creating systems that support repair, replacement, and eventual material recovery. Prefabricated components significantly reduce on-site construction time and costs while ensuring quality control in manufacturing environments. The flexibility of modular systems allows cities to adapt infrastructure to changing needs without generating additional waste, directly supporting the adaptive capacity required for sustainable urban development. These findings suggest that modularity should be a primary consideration

when designing with recycled plastics, particularly for applications requiring durability and long-term performance.

Material performance emerges as both a critical challenge and area for innovation. The chemical stability of plastics, particularly polyolefins like polyethylene and polypropylene which constitute the majority of plastic waste, presents both advantages and limitations. While this stability enables long product lifespans, it also complicates reprocessing and leads to variability in material properties. Weathering resistance remains a particular concern, with ultraviolet radiation, temperature fluctuations, and mechanical stress causing surface degradation in many applications. Advanced stabilization methods through material compounding and surface treatments show promise in addressing these limitations, though they must be carefully balanced against recyclability considerations. The development of standardized material grades and performance specifications appears essential to build confidence among engineers and architects, particularly for load-bearing applications.

Public acceptance levels vary significantly based on application type and community engagement approaches. Functional urban amenities that address clear community needs, such as seating, shelter, playground equipment, and safety barriers, achieve substantially higher adoption rates than purely artistic installations. The research indicates that acceptance increases when residents perceive direct benefits from these installations and understand their environmental value. Participatory design processes that engage community members in collection, design, or fabrication stages foster stronger senses of ownership and environmental responsibility. However, concerns about material safety and longevity persist in many communities, highlighting the need for transparent communication about testing protocols and maintenance plans. These findings underscore that technical success must be matched by social adoption to achieve meaningful impact.

From an economic perspective, the research identifies several persistent barriers to scalability. The absence of standardized material specifications and certification protocols creates uncertainty for specifiers, particularly for structural applications. Current market conditions often disadvantage recycled materials due to fragmented collection systems, processing costs, and the persistent low price of virgin plastics. Lifecycle cost analyses reveal that while initial costs for recycled plastic products can be higher, modular systems often provide long-term savings through reduced maintenance and easier repair. However, these economic benefits remain poorly captured in conventional procurement processes. Strategic policy interventions, including extended producer responsibility regulations, recycled content mandates, and green public procurement criteria, prove essential to create stable market conditions and stimulate investment in advanced recycling infrastructure.

Environmental assessments reveal complex trade-offs that necessitate careful management. While repurposing plastic waste reduces landfill burdens and conserves virgin resources, certain processing methods introduce new impacts through energy consumption, emissions, or water use. Applications that combine plastics with other materials may complicate future recycling, potentially perpetuating linear material flows. Lifecycle assessment methodologies must evolve to better capture these trade-

offs, particularly regarding microplastic generation and ecosystem impacts. The findings suggest that design strategies should prioritize mono-material constructions, reversible connections, and easily separable components to maintain material value through multiple use cycles.

The research identifies several emerging opportunities that could enhance future applications. Digital technologies including artificial intelligence for sorting and robotic fabrication enable more precise transformation of waste materials into high-value products. Urban mining approaches that localize waste streams and reprocessing facilities reduce transportation impacts while strengthening community resource awareness. Bio-based compatibilizers and additives offer pathways to enhance material performance without compromising recyclability. These innovations, combined with circular business models that maintain ownership and responsibility through product-service systems, could significantly advance the field.

Systemic challenges require integrated solutions across multiple domains. The development of circular economy ecosystems demands collaboration between waste management systems, design disciplines, manufacturing industries, and urban planning authorities. Educational institutions have a crucial role in developing the interdisciplinary skills needed for this transition, while financial institutions must create new instruments that support circular business models. Policy frameworks need to align across local, regional, and national levels to create coherent signals that support investment and innovation.

The repurposing of waste plastics within urban environments represents a promising yet complex pathway toward zero-waste cities. The most successful approaches integrate technical innovation with social engagement and supportive policy frameworks, creating solutions that are not only environmentally beneficial but also functionally valuable and socially inclusive. While challenges remain regarding material performance, economic viability, and environmental trade-offs, these can be addressed through continued research, collaborative governance, and design innovation. By viewing plastic waste as a resource rather than refuse, cities can transform an environmental problem into an opportunity for creating more sustainable, resilient, and circular urban systems. Future work should focus on developing standardized material protocols, enhancing public participation models, and creating policy frameworks that support circular economy transitions across urban systems.

The findings demonstrate that the transition to zero-waste cities requires rethinking not only material flows but also design processes, business models, and governance approaches. No single solution will achieve the necessary transformation; rather, progress will come through the cumulative impact of multiple innovations across different systems and scales. By learning from the insights generated through this research, cities can develop more effective strategies for transforming waste plastics from environmental burdens into valuable urban resources.

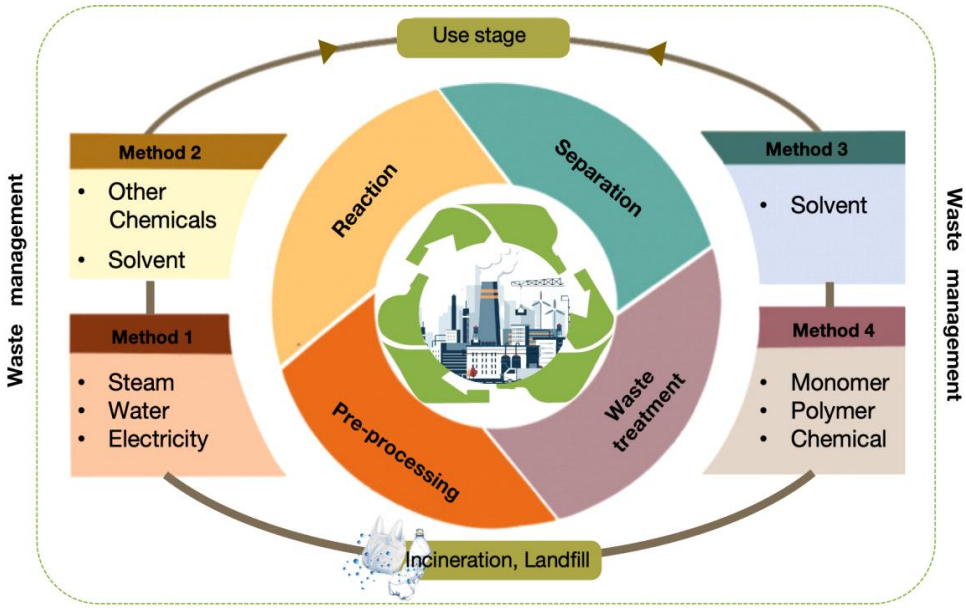


Figure 12. Current Recycling Methods for Waste Plastics and Their Process Flows.

The aforementioned discussion illuminates the dynamic interplay and continuous evolution of waste plastics within the context of urban landscape design (Figure 12). The diagram illustrates the interconnection between diverse components, encompassing the collection and recycling of waste plastics, material modification and design, construction and implementation of landscape facilities, public participation and feedback, and policy support and advocacy.

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