Transforming Waste Plastic into Play

An interactive gaming installation utilizing immersive technology

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Abstract. The escalating volume of municipal solid waste (MSW) in Hong Kong, with plastic waste constituting over 20%, presents formidable challenges to the city's landfill capacities. Rather than relying exclusively on top-down governmental interventions, fostering recycling awareness at the community level emerges as a more viable strategy. This paper proposes an innovative solution through the implementation of a gamified system designed to enhance community engagement in plastic recycling by offering immersive user experiences. The study introduces a multiplayer immersive platform that synergizes physical installations with virtual gaming elements. Participants interact with these installations by collecting plastic waste, earning rewards that are both virtual and tangible. This approach not only stimulates user involvement but also provides material vendors with opportunities to recycle plastic materials. Planned experiments across several major communities in Hong Kong will employ rigorous analytical methodologies to assess the system's efficacy. Preliminary frameworks suggest that this straightforward, replicable model has the potential to bolster community recycling initiatives and invigorate demand within the local plastic recycling sector.

Keywords. MR, Waste Recycling, Phygital Spatial Design, Gamification Mechanisms, Interactive Installation

1. Introduction

Enhancing the recycling rate of municipal solid waste (MSW) is of paramount importance for Hong Kong, particularly given the substantial proportion of plastic waste and the currently low recycling rates. A critical examination of the factors influencing these rates reveals that the willingness of communities and individuals to recycle household waste and effectively sort it plays a significant role. Recent scholarly investigations have explored various passive strategies to augment participation in recycling activities, including the implementation of recycling facilities (Zhang et al.,

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2016), the development of recycling policies (Wan et al., 2014), and the creation of designated recycling spaces (Xiao, 2017). Nonetheless, there is a paucity of research on proactive measures to enhance public willingness to engage in recycling, with gamified systems emerging as a promising avenue (Helmefalk and Rosenlund, 2020). Although numerous existing games and community recycling systems have accumulated valuable practical insights, there remains substantial potential for advancement in terms of immersion and reward mechanisms. This study seeks to propose a novel, replicable recycling game model by integrating cutting-edge immersive technologies and devices with tangible reward mechanisms. This approach aims to create opportunities for the utilization of recycled plastic materials while simultaneously fostering increased resident participation in recycling initiatives.

2. Background

The management of plastic waste in Hong Kong has been challenging, with reliance on incineration and landfilling since the 1970s, and community recycling programs only starting in the 1980s. Current strategies primarily involve exportation and landfilling, but increasing restrictions and landfill saturation have renewed focus on recycling and reuse as sustainable alternatives. A significant challenge is low public participation and market fluctuations in recycled materials. The Hong Kong government's top-down policy approaches, including the "Green@Community" initiative, have seen limited success. Introducing gamification mechanisms may enhance engagement and attract a wider range of participants to the recycling process.

2.1. GAMIFICATION MECHANISMS FOR RECYCLING

Gamification, emerging in the late 20th century, gained recognition as a mainstream educational theory by 2010 (Walz and Steffen, 2015). Defined as employing game-based mechanisms to engage and motivate individuals, it has been shown to enhance learning and memory retention more effectively than traditional methods (Wouters et al., 2012). Modern gamification systems integrate reward mechanisms with user-centred design, incorporating immersive content and personalized feedback to enrich

Table 1. Analysis of Recycling Games with Gamification Elements

Analysis of Recycling Games with Gamification Elements

Recycling Game	Description	Strength	Weakness
Recyclebank	Gamified system rewarding recycling with points for rewards	Strong incentives through point-based rewards	Relies on rewards: participation may drop without them
Recycle Roundup	Teaches kids waste sorting via a scoring mechanism	Combines fun and education effectively	Limited content: time-intensive to achieve goals
Litter Critters	Players sort waste on a conveyor belt into recyclable types	Points encourage engagement	Weak real-life connection: lacks practical guidance
Eviana	Preschool game teaching correct waste bin use	Simple and ideal for early environmental learning	Lacks challenge for older or Eco-aware users
Trash Truck Simulator	Simulates garbage truck driving and city waste cleanup	Customizable trucks and diverse tasks	No focus on recycling or sorting: limited depth
Reduce Reuse Recycle Game	Sorts waste into three bins with detailed labels	Reinforces memory with clear recycling info	Time-consuming to complete tasks and learn

user experience and interactivity. Applying gamification to waste recycling can make the process more enjoyable, increase user engagement, and support sustained recycling efforts by addressing deficiencies in long-term incentives.

Table 1 highlights a range of recycling games that attempt to integrate gamification with recycling behaviours. However, these games often lean too heavily towards either gamification or recycling, failing to strike an optimal balance. While some games achieve high levels of real-world engagement and offer comprehensive reward mechanisms, they often lack sufficient gamification elements to effectively stimulate intrinsic motivation. The predominance of virtual rewards further limits their incentivizing potential, as these are generally less compelling than tangible rewards. Additionally, 2D interactive modes fail to provide adequate immersion, reducing the games' appeal and replay ability. A notable limitation of current recycling games is their low system scalability; their impact is often restricted to individual players, making it difficult to establish interactive relationships with other recycling units and limiting their role within a broader recycling ecosystem.

Online gaming platforms offer improved conditions for gamified activities, providing continuity of learning, accessibility, and flexibility. These platforms enable a comfortable and engaging experience, allowing users to complete tasks individually or collaboratively, anytime and anywhere. This networked learning format positively influences the development of relevant memories and habits.

Both the "Green@Community" initiative and existing recycling games have room for improvement in interactivity, gamification design, real-time feedback, and outcome visualization. The emergence of immersive technologies offers new opportunities to enhance user experiences, particularly in multiplayer online cooperation. The integration of augmented reality (AR) technology provides technical solutions for coordinating physical and virtual rewards, thereby increasing the overall effectiveness of gamified recycling initiatives. initiatives.

2.2. IMMERSIVE SYSTEM FOR USER EXPERIENCE

Immersive systems offer users highly realistic virtual experiences through multisensory interactions, to blur the lines between reality and virtuality, thereby enhancing users' sense of presence and engagement (Slater, 2009). The evolution of immersive technology can be traced back to the 1960s with Morton Heilig's "Sensorama," which superimposed virtual images onto real video, serving as a precursor to contemporary immersive systems. Since the onset of the 21st century, advancements in hardware miniaturization and cost reduction have rendered immersive devices more accessible to consumers, facilitating their application across various societal domains.

The primary benefits of immersive systems include the provision of authentic interactive experiences and significant capabilities for behavioural motivation. By creating three-dimensional virtual environments, these technologies enhance user focus and engagement while incentivizing users through dynamic feedback mechanisms. In the educational sector, immersive tools have been demonstrated to significantly improve knowledge retention. Their interdisciplinary adaptability extends to fields such as surgical training and architectural design validation (Paes et al., 2017).

In the domain of waste management, immersive technology can augment environmental awareness through interactive educational scenarios and motivate recycling behaviours (Stenberdt and Makransky, 2023). Specifically, immersive games utilizing virtual reality (VR) or augmented reality (AR) have been developed to simulate waste sorting, thereby aiding users in acquiring proper recycling techniques. Games such as "Trash Class VR" and "Recycle AR" primarily educate users on waste classification within VR or AR environments. These games guide users in selecting and classifying waste using user interface and button interactions, with some incorporating point systems for motivation. However, these games face challenges related to limited interaction modes and incentive systems. Handheld button interactions struggle to deliver a fully immersive experience, and virtual point systems lack tangible real-world connections, leading to diminished replay value. Immersive games employing a combined real-virtual reward model in this field remain in an early stage of development interest.

This study seeks to enhance immersive recycling systems by integrating virtual and real reward models, diverse task designs, and dynamic interactive scenarios to foster long-term environmentally friendly behaviours.

3. Methodology

The system is ultimately manifested through a combined virtual and physical interactive Installation (figure 1). Given that virtual games necessitate a secure interactive environment, the entire setup requires approximately 24 square meters of space. The device comprises two boxes of differing dimensions, each embedded with sensors. The larger box, measuring 20 x 20 x 20 cm, serves as the structural foundation for the entire apparatus, while the smaller box, measuring 10 x 10 x 10 cm, is affixed to the larger box.

During the interactive process, participants become eligible to interact with the device by collecting a specified number of plastic bottles. Subsequently, they are equipped with MR devices to engage in the game. Any of the smaller boxes can be selected as a physical reward within the game. When a small box is removed, a virtual box appears in its original location. Participants can customize the virtual model through gesture-based interactions. Ultimately, players receive a physical reward in the

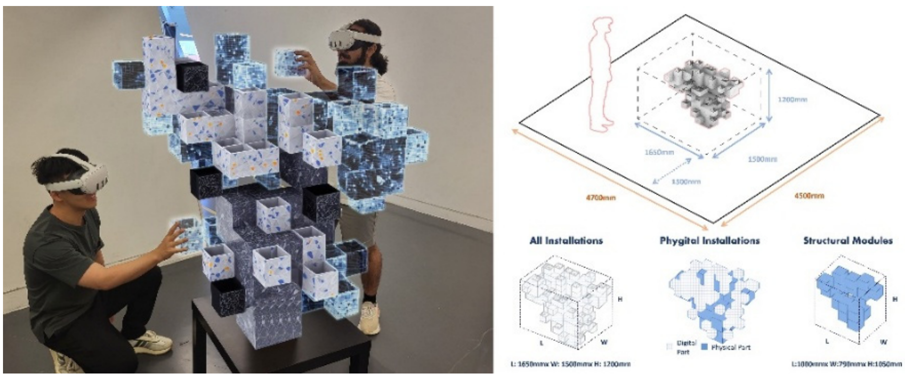

Figure 1. Phygital Interactive Installation

form of a box crafted from recycled materials, along with a customizable virtual model space.

The design of the physical device and the development of the virtual system constitute the core focus of this study. Figure 2 delineates six specific technical nodes and the overarching framework of the system. From a physical perspective, the device design primarily concentrates on utilizing locally recycled plastic to fabricate the boxes, thereby offering increased market opportunities for local recyclers. Additionally, the design addresses the rapid assembly and sensor integration on the boxes to ensure an optimal interactive experience. In the virtual system, establishing a game system framework that supports multiplayer participation and implementing sensor data streaming are critical components. These elements are foundational for collecting user experience data and enhancing the overall interactive experience.

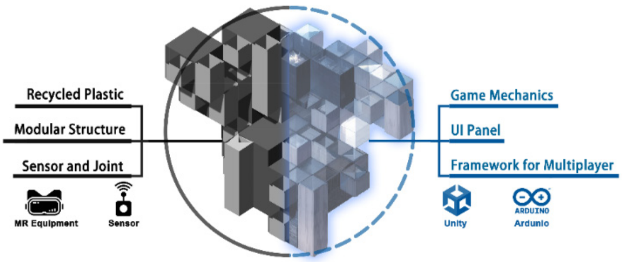

Figure 2. Technical framework

3.1. PHYSICAL BOXES MADE FROM RECYCLED PLASTIC

The boxes employed in this device are constructed from locally recycled plastic materials in Hong Kong, primarily derived from discarded polyethene terephthalate (PET) plastic bottles and high-density polyethene (HDPE) plastic bottle caps. These plastics are processed through two principal methodologies. The first method involves the collection, washing, and filamentation of discarded PET plastic bottles, which are then subjected to heating to produce filaments suitable for 3D printing. The recycled PET 3D printing material is characterized by its white, semi-transparent appearance and exceptional thermoplastic properties, facilitating the additive manufacturing of lightweight yet durable plastic containers. These containers are specifically designed to function as pen holders, serving as practical items for rewarding participants. A further advantage of 3D printing is its ability to produce intricate surface designs by configuring print paths, thereby establishing a foundation for personalized customization of future boxes (figure 3).

The second method processes discarded HDPE plastic bottle caps by washing, crushing, heating, and cutting them into granules. These granules undergo hot pressing and extrusion to produce boxes that are heavier but stronger than those made from PET additive manufacturing. Smaller boxes, requiring lighter weight to reduce stress on node positions, are printed using recycled PET with a 20% fill setting. In contrast, larger boxes, serving as structural elements, are constructed from recycled HDPE. HDPE granules are hot-pressed into sheets and then cut and assembled into boxes.

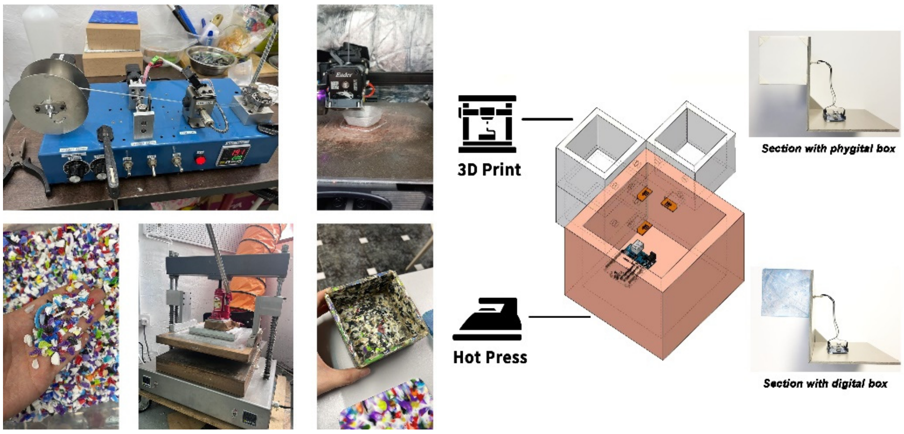

Figure 3. Plastic recycling materials and production process

3.2. INTERACTABLE STRUCTURES WITH MAGNETIC SENSORS

During participant interactions, the smaller boxes serve as tangible rewards to incentivize the collection of plastic waste. These boxes are designed to function as pen holders or flower pots, necessitating a design that allows for easy disassembly and detection when removed by participants. To achieve this functionality, a combination of magnetic snap connectors and Reed Switch sensors is employed. Magnetic snap connectors utilize magnetic force to facilitate the attachment and detachment of objects, allowing for quick and convenient connections between components and easy disconnection when necessary. Reed Switch sensors, which detect nearby magnetic fields and close the circuit upon sensing magnetism, offer high sensitivity, low power consumption, and reliability.

Additionally, these sensors have no exposed external contacts, resulting in minimal contact wear, making them ideal for frequent handling in interactive processes. As illustrated in Figure 4, an Arduino Mega development board is housed within the larger box to connect multiple Reed Switch sensors, leveraging its multiple signal interfaces. Reed Switch sensors and magnetic snap connectors are positioned on the connecting surfaces of the large box and each small box. Conversely, corresponding magnetic snap connectors and magnets are affixed to the connecting surface of the small box to activate the switch.

When an interaction occurs and a small box originally placed on the surface of the large box is removed, the Reed Switch sensor detects the absence of the nearby magnetic field. The built-in magnetic switch disconnects and the sensor's digital interface registers a signal transition from low to high frequency. Concurrently, through programming the Arduino Mega development board, the board transmits a specific signal to the computer memory based on the interface's position, indicating that a specific box has been removed.

3.3. GAME MECHANICS AND UI PANEL

To incentivize participants to engage in recycling, the system offers not only tangible rewards but also a virtual gaming environment accessible through head-mounted mixed reality (MR) devices. The Meta Quest 3 was selected for demonstrating MR effects due to its superior visual performance and multifunctional development platform. The initial design of the game draws inspiration from urban maps of Hong Kong, transforming these maps into a three-dimensional geometric installation by segmenting districts (figure 4). Each real-world street block corresponds to both a physical and virtual cube, which players can designate as a "community," "garbage collection station," or "recycling centre," to create a virtual recycling route within a mixed-reality world composed of these three building types.

In the virtual game, players earn virtual tokens based on the number of plastic bottles they collect, with entry into the game requiring a specified collection threshold. These tokens enable detailed customization of virtual cubes, allowing players to alter the form and colour of their virtual structures. During gameplay, removing a 3D-printed small box triggers the appearance of a virtual module, where participants can choose from three virtual building options. Upon customization, the system generates a transportation route to simulate waste collection paths, tracking the distance covered. The initial design of the boxes draws inspiration from Hong Kong's map, creating a virtual recycling network that mirrors reality as the game progresses.

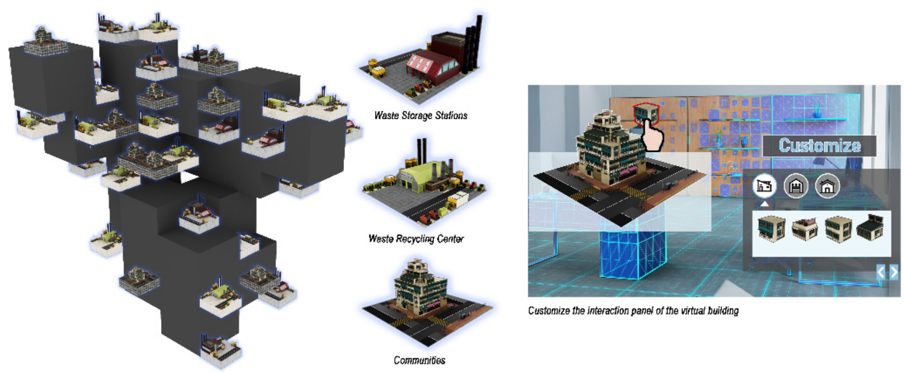

Figure 4. Game mechanics and UI panel

The user interface panel (UI Panel) of the virtual system is primarily divided into two sections: one dedicated to implementing a multiplayer online server interface, which is detailed in subsequent sections, and another, as illustrated in Figure 4, that allows players to enter a customizable interactive mode.

3.4. MULTIPLAYER GAME MECHANICS

The Mixed Reality (MR) interactive system developed in this project supports multiple participants engaging in interactive games simultaneously, thereby facilitating the collection of extensive game data. The system offers two modes for multiplayer collaboration: one for active participation in the game and another for displaying game results. In the default mode, all participants join a server to play the game. In this configuration, each participant's actions are shared in real-time, allowing all participants to view each other's virtual worlds. However, they can only manipulate and modify their own selected virtual modules, making this mode ideal for rapid multiplayer testing. In the alternative mode, any headset can be designated as a server, enabling participants in the same game to view each other's virtual worlds without interacting with or customizing their own or others' virtual models through gestures. This mode is particularly suitable for displaying the virtual world after the game concludes.

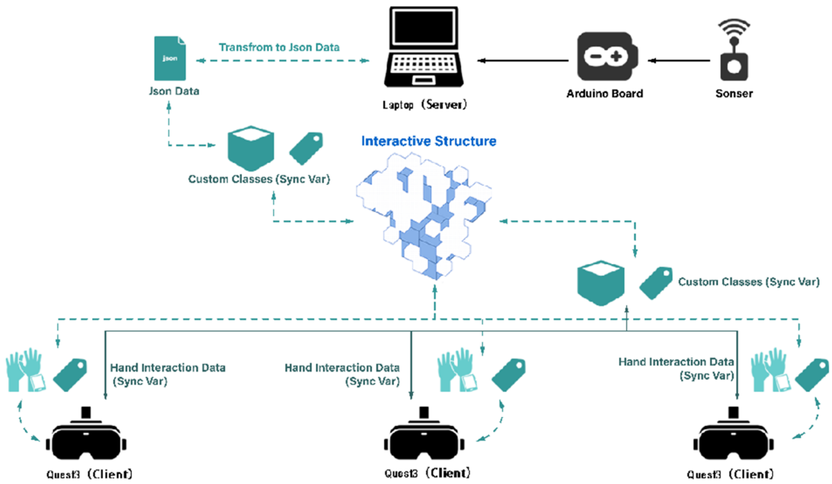

Figure 5. Multiplayer online framework

The project utilizes Unity and MetaQuest XR, employing the Mirror plugin to enable multiplayer online games across various platforms. The Mirror's client-server model facilitates server creation and connectivity among Android devices. Participants can join or initiate a server via the virtual user interface panel. Interaction data is transmitted using JSON, a standard data exchange format, and stored in a custom class. This data is converted to JSON format through the 'JSON Utility' and synchronized bidirectionally across platforms. Participants can view each other's player tags and observe virtual model customizations through head-mounted MR devices.

4. Result

This project presents a framework for interactive games utilizing immersive technologies, where both virtual and physical rewards are employed to encourage repeated engagement. The framework is currently undergoing a series of preliminary tests, yielding some promising results. In the virtual component of the game, participants expressed interest in exploring various combinations of virtual cubes through repeated play. While the expectation of repeated engagement was fulfilled, several participants noted that the limited variety of virtual building combinations reduced their motivation to explore the game further. Regarding physical rewards, the pencil holder was well-received; however, most participants expressed a desire to customize the shape and pattern of the box through 3D printing. This aspect will be enhanced in future experiments with a broader range of tests.

The experiment strategically deploys interactive equipment in neighbourhoods with high concentrations of municipal solid waste, such as the Eastern District, Yau Tsim Mong District, and Yuen Long. Over one week, data from head-mounted devices and sensors will be collected to evaluate user engagement. Participants will complete a questionnaire addressing personal information, recycling willingness, and experience feedback, using a Likert scale (1=Strongly Disagree, 5=Strongly Agree). Non-participating residents will act as a control group to compare and analyse recycling behaviours and attitudes under different conditions. Interaction data and questionnaire responses will be cross-validated to ensure consistency, informing recommendations to improve future recycling practices.

5. Discussion and conclusion

The proposed system offers substantial advantages for recycling participants and stakeholders, including plastic recycling material manufacturers and governmental agencies. By integrating game mechanics with immersive technology via physical interactive devices, the system enhances the recycling experience, enabling participants to engage in physical interactions, earn tangible rewards, and explore a customizable virtual metaverse through MR devices. Unlike traditional systems, this approach promotes recycling through repeated experiential engagement. As MR devices become more accessible, community participation is expected to increase. For manufacturers, the system provides a market for materials and enhances recycling performance through data analysis. Future studies will address improvements in data collection and box manufacturing for large-scale implementation.

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