RAE2026

The Development of A Gamified Interactive XR Structure to Increase Participation of Recycling

MCO1

Dr Sky Lo Tian Tian

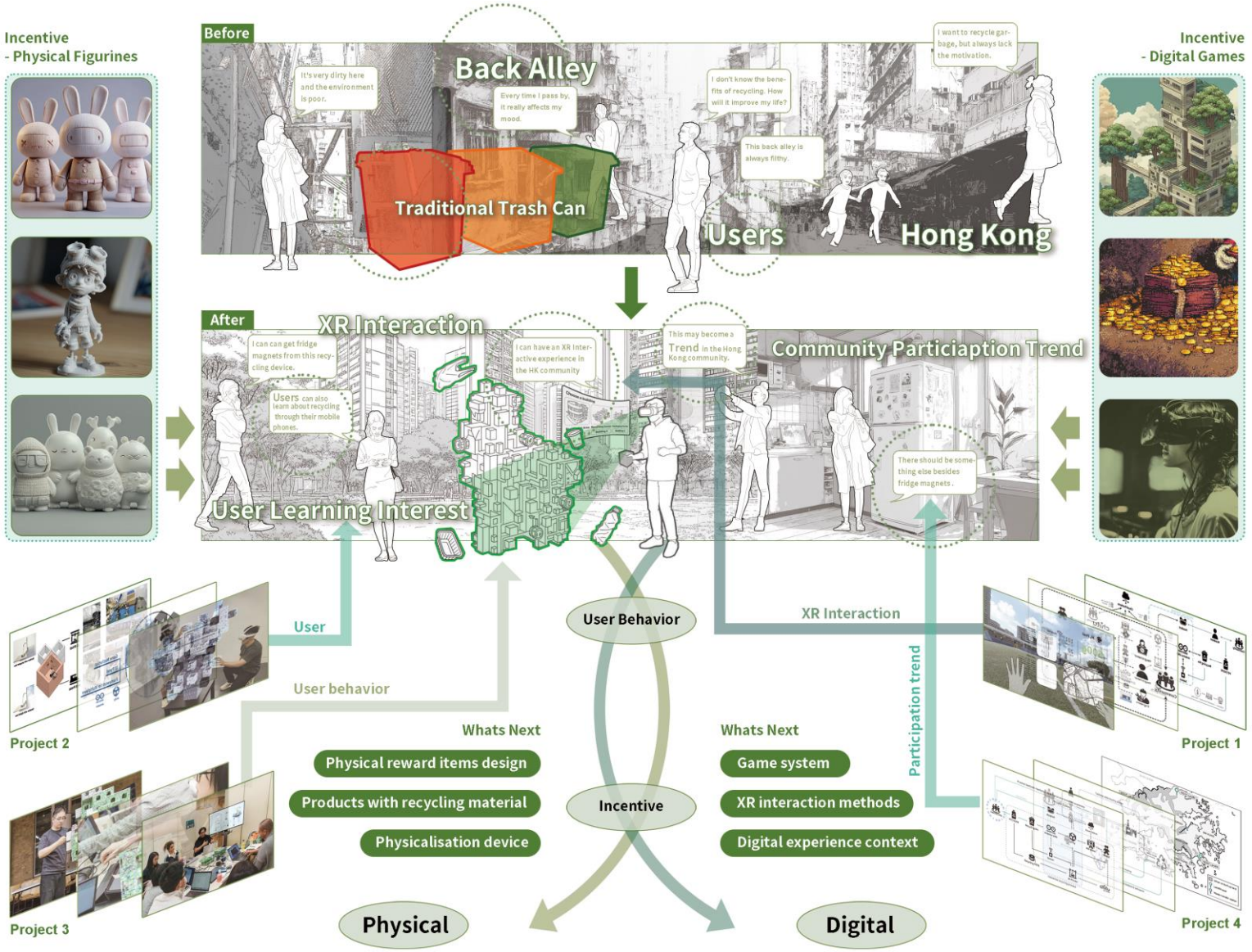
Contents

1 Research Descriptor

This research (Phygital Recycling) is supported by a two-year (2023–25) start-up grant from PolyU for HK$350,000). This research explores ‘phygital’ practices, a term that has emerged from marketing c.2007. It refers to the building of customer relationships with the physical and digital worlds. For this study, phygital practices were deployed in four experiments targeting enhanced recycling management in Hong Kong. Dr Lo’s interactive interdisciplinary methods integrate design, environmental engineering, gamification, behavioural economics and HCI to address these challenges and establish an extended reality recycling (Xrecycling) platform. Yu-kai Chou’s Octalysis Framework for gamification is employed to foster recycling awareness and influence behaviour, and Slater’s (2009) immersive technology theory is adopted to provide virtual, multi-sensory interactions that reshape recycling habits. This research adopted a hybrid approach, integrating VR, 3D printing, sensors and spatial design to create a 3m x 3m immersive, gamified recycling prototype within a phygital systems framework. Six-month longitudinal tracking and qualitative interviews assessed changes in behaviour, engagement and environmental self-identification. Key measures included continued participation, user perceptions of ownership and material reciprocity. Findings show that incorporating Hong Kong’s socio-cultural context into an interactive phygital system enhances recycling practices and understanding. Recycling is explored through physical-digital interactions, challenging traditional models and promoting sustainable, community-centred engagement. Approximately 40 college students participated in the year-long experiment. Given that young people are key to reducing plastic consumption and the ‘blind box’ culture, the next phase will expand to community recycling points for broader testing among 12–35-year-olds.

Research outcomes have been disseminated through academic papers, workshops and exhibitions. This study underscores the importance of physical space and spatial narratives in encouraging recycling behaviour and environmental awareness. Future research aims to develop collaborative virtual storytelling, developing design principles for decentralising sustainability initiatives, giving ecological agency to communities and challenging top-down extractive mandates.

1 Research Map – Relationship of Different Outputs



2 Personal Profile: Prof Sky LO Tian Tian

Dr Lo's research explores spatial phygital interaction and the relationships between virtual and physical spaces through transdisciplinary methods that combine design, VR technologies, gamification and digital tools. His work emphasises multi-level sharing and collaboration, from basic data to deep intelligence using mixed reality (MR) technologies to enhance interaction, transfer knowledge and foster innovation in the design process. In his research, he uses the IoT and virtual visualisation to advance interactive fields and human VR interaction (HVRI) and open up the potential for future hybrid interactive experiences. His MCO 1 (Gamified Recycling) and MCO2 (XR Bamboo) demonstrate the outcomes of this research.

Dr Lo joined The Hong Kong Polytechnic University as an Assistant Professor in 2022. He has organised several workshops for DigitalFuture, CCD-ASC and POLAR and published over 30 papers on transdisciplinary research and interactive design. He contributes to the leadership of organisations including CAADRIA (The Association for Computer-Aided Architectural Design Research in Asia), eCAADe (Education and research in Computer Aided Architectural Design in Europe), WORLD16 (a working group of 16 professors from around the world that engage in collaborative research on VR technologies) and World CAAD PhD (https://research.polyu.edu.hk/en/activities/world-caad-phd-forum-2/).

3 Research Questions

1. How can phygital experiences enhance recycling efficiency among young users through gamification in Hong Kong?

Hong Kong is currently characterised by low recycling efficiency and insufficient community participation, but research has shown that the combination of VR (phygital) and gamification mechanisms can be used as incentives to improve recycling efficacy. Phygital gamified experiences can be introduced into existing recycling spaces in Hong Kong by analysing the user experience of existing recycling spaces, identifying their strengths and weaknesses and exploring the potential of phygital experiences to improve the current state of waste recycling.

2. What user needs and behaviours should be identified to integrate gamification and digital tools effectively into recycling activities in Hong Kong?

To enhance user awareness and attraction to recycling activities in Hong Kong, this project will examine how to identify user needs and behavioural patterns. Specific measures include examining existing interaction methods (not limited to the waste recycling field), identifying innovative interaction methods from different disciplines and fields and exploring the possibility of their integration into the existing recycling system to encourage wider participation.

3. How can interactive spatial models be designed for refuse collection points in Hong Kong to transform them into engaging public spaces?

This can be achieved by exploring the design of collection points in Hong Kong to create more attractive public spaces and by analysing and generating different spatial design models for waste recycling. Recycling can be designed to be more than a process and become an interactive spatial experience with the potential to increase enthusiasm for waste recycling. This could transform the role of the refuse collection point and transform it from an unappealing element of urban life to an activity space where citizens enjoy participating.

4 Research Outputs

1. Basic technology: Exploring the potential of XR gamified interactions for recycling in Hong Kong

– Phygital Recycling: Development of a gamified interactive XR structure to enhance the participation of recycling

Peer Reviewed Paper, DOI: https://doi.org/10.52842/conf.ecaade.2024.2.485

2. Interactive experience deepening: XR gamification and interactive recycling system design

– Transforming Waste into Play: An interactive gaming installation utilising immersive technology

Peer Reviewed Paper, DOI: https://papers.cumincad.org/cgi-bin/works/paper/caadria2025_227

3. Participation model innovations: Exploring user behaviors and needs related to recycling

– Workshop: Phygital modular structure, CAADRIA 2025 Tokyo

Link: https://www.caadria2025.org/phygitalmodularstructure

4. Urban spatial integration: Research on XR gamification mechanics and user engagement trends in Hong Kong community

– Enhancing Urban Vitality through Interactive XR Installations: fostering engagement and environmental awareness

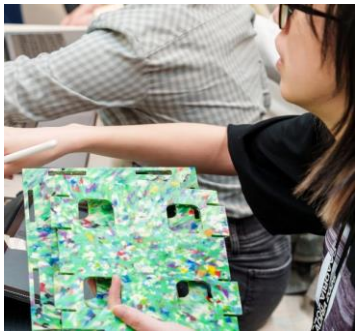
Peer Reviewed Paper, CAAD FUTURES 2025 (Accepted/In press).

Link: https://research.polyu.edu.hk/en/publications/enhancing-urban-vitality-through-interactive-xr-installations-fos/

4 Research Outputs

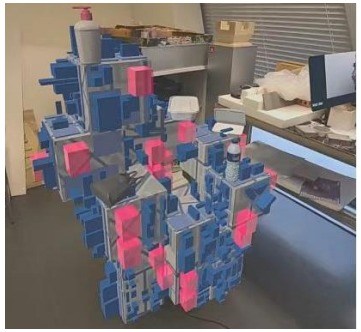
1. Interactive physical device

This uses recycled plastic, 3D printing and CNC machining to create a modular interactive physical recycling device, currently measuring 1.5m × 1.5m. The device has undergone preliminary user experience data and opinion collection and was exhibited at the CAADRIA 2025 conference in Tokyo. Users can trigger virtual information by interacting with the physical device through gestures.



2. Virtual platform of phygital recycling structure

The project has involved designing preliminary mobile app interfaces and UI/UX interfaces for XR interactions. The simple and attractive interfaces encourage target users to participate and are continuously optimised based on user feedback.



3. 3D-printed incentive rewards

This project uses recycled plastic bottles for 3D printing and has already produced the first set of pen holders cum fridge magnets for use in the reward system. These pen holders can be connected to the Arduino and Unity systems to trigger virtual information when users engage in XR interactions.

4 Research Context

This MCO is a series of studies with the XR virtual recycling experience and Octalysis Framework as its theoretical core, which systematically deconstructs the synergistic mechanism of gamification and phygital interaction.

Octalysis is a comprehensive gamification framework for designing and optimising user experiences by understanding and applying the core drivers of human motivation. The framework emphasises human-focused design, rather than functional and focuses on systematically optimising human motivation and engagement. This fits with the design logic of this MCO, which focuses on the internal motivation behind human activity and stimulates public interest and environmental responsibility through virtual experiences and physical rewards.

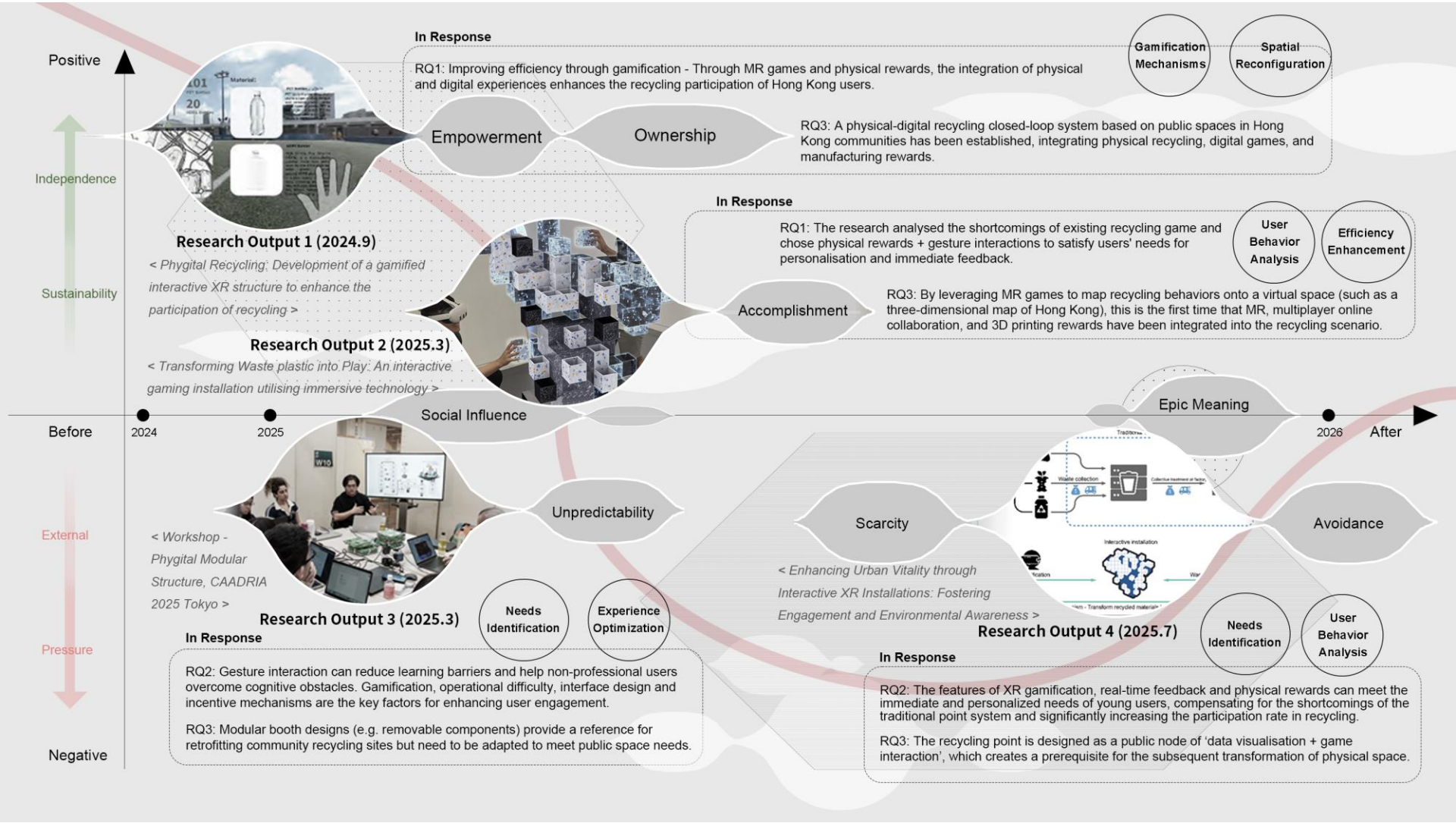
This study is ongoing and currently consists of a total of four components (see previous page): technology development and validation, interaction model deepening study, participation model innovation study and urban spatial integration.

In component 1, ‘Empowerment' and ‘Ownership’ in the Octalysis Framework helped the researchers realise that a pure VR model lacks the driving force of physical interaction, which leads to a decrease in participation. In component 2, ‘Social Influence’ and ‘Accomplishment’ guided the refinement of gamification interactions and reward mechanisms. In component 3, ‘Social Influence’ and ‘Unpredictability’ underpinned the promotion of engagement through the analysis of user behaviour. In component 4, ‘Scarcity’ and ‘Avoidance’ promote design inclusiveness and environmental significance.

The next page is a summary map of the MCO's core research, and how the Octalysis Framework assists in the design of behavioural motivation (gamification) and the phygital (interaction). The four components of the MCO are iterative, resulting in a solution of Technology Validation – Behavioural Change – Public Co-Creation – Spatial Reinvention.

Chou, Y. (n.d.). The Octalysis Framework for Gamification & Behavioral Design. *Yu-kai Chou*. https://yukaichou.com/gamification-examples/octalysis-complete-gamification-framework/

4 Research Timeline



4 Research Output 1

Phygital Recycling: Development of a gamified interactive XR structure to enhance participation in recycling (2024)

This was originally published in the proceedings of eCAADe 42 conference titled '42nd Conference on Education and Research in Computer Aided Architectural Design in Europe (eCAADe 2024)', which was held in Nicosia in 2024. The paper is included in Volume 4 of the conference proceedings, pp. 485–494.

The focus is on enhancing the participation in and efficiency of plastic waste recycling in Hong Kong through the phygital system that combines MR technology and a gamification mechanism. Specifically included are the following: 1) a sensor-based recycling box designed to collect the weight, volume and colour data of plastic waste; 2) an MR game based on the Unity platform, where the user interacts through gestures to transform the recycled data into a virtual model; 3) 3D printing technology that transforms virtual models into physical rewards for plastic recycling and 4) community-driven collaborative ecosystems.

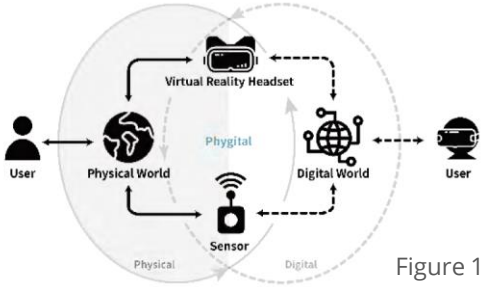
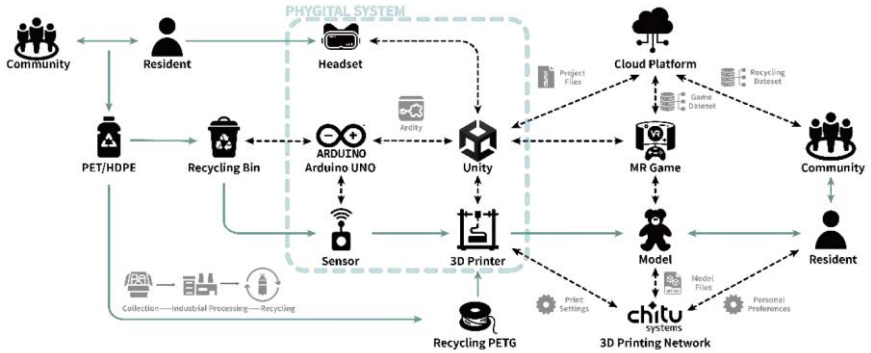


Figure 1: The phygital recycling system

Figure 2: Recycling process based on the designed phygital system



(Lo, T. T., & Bao, H. (Published). Phygital Recycling: Development of a gamified interactive XR structure to enhance the participation of recycling . In *Education and research in Computer Aided Architectural Design in Europe*, https://papers.cumincad.org/cgi-bin/works/paper/ecaade2024_40

4 Research Output 1

Phygital recycling: Development of a gamified interactive XR structure to enhance participation in recycling (2024)

A phygital recycling closed-loop system was constructed, connecting physical recycling, digital play and manufacturing rewards (Figures 1 & 2). Researchers used Arduino sensors (HX711 weighing module, TSC230 colour sensor, ultrasonic module) to collect plastic waste data (Figure 3). MR game (Figure 4) interactions were developed through the Unity platform, which supports gesture interaction and virtual model generation. In addition, 3D printing technology was utilised to transform the user-designed models into physical rewards (the material is recycled PETG plastic).

The intention was to analyse the shortcomings of existing recycling systems in Hong Kong, verify the technical feasibility and evaluate impact on user behaviour. The results show that the phygital recycling system has the potential to improve the recycling experience compared to the current traditional ones.

Users are less motivated to engage with VR or AR due to their lack of connectivity and limited interactivity. In this research, we chose MR technology + physical rewards because they can combine physical and digital interactions and enhance engagement. Limited sensor accuracy, MR equipment popularity and 3D printing costs may also limit implementation and represent the technical challenges for future research.

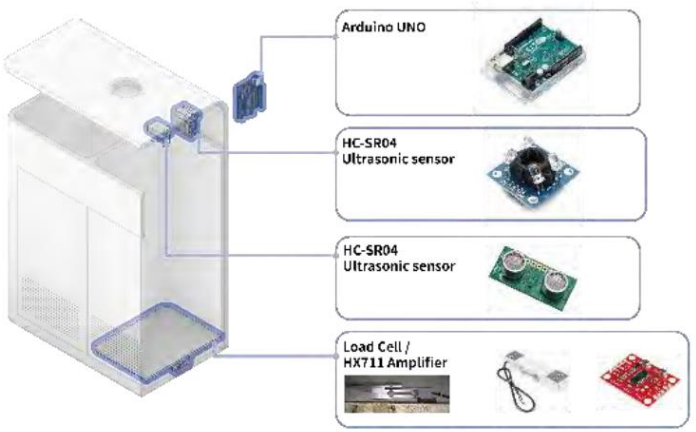


Figure 3: Recycling bins and sensors

Figure 4: Visual recycling interface

4 Research Output 1

Phygital recycling: Development of a gamified interactive XR structure to enhance participation in recycling (2024)

Relationship between the research content and the research questions

This study validates that a phygital (physical-digital fusion) experience enhances user engagement through MR games and physical rewards, directly responding to the question of how to improve efficiency through gamification. There is then an analysis of the shortcomings of the existing recycling system and the potential of innovative interactions such as gesture interaction and personalised design to satisfy user's needs for fun and immediate feedback. In the preliminary phase of the research, the potential of turning recycling boxes into interactive public spaces was explored by transforming recycling into a virtual creative activity through MR technology.

This study established a complete "sensing data → virtual creation → physical feedback" phygital link in the recycling scenario, breaking through the previous limitation of VR/AR's single-point interaction lacking a real touchpoint. This paper is at the foundational stage of a series, proposing a "interactive public collection point" prototype, laying the technical framework for subsequent experiments.

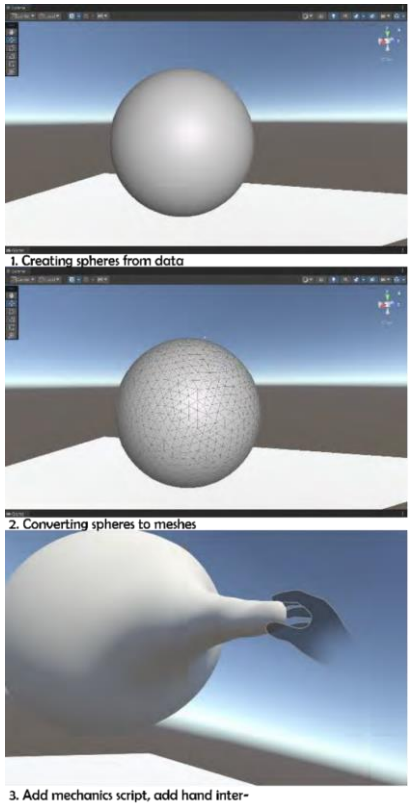


Figure 5: Using interactive gestures to build virtual creation models during recycling process

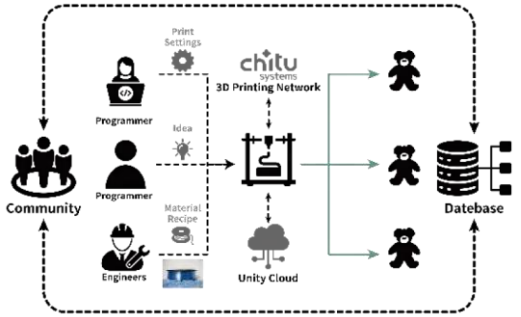


Figure 6: Additive manufacturing-based recycling networks – for stakeholders

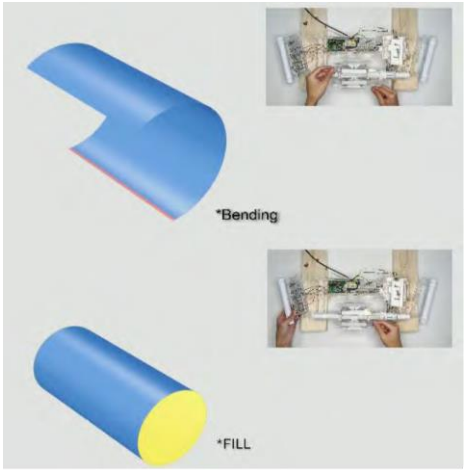


Figure 7: Phygital modelling system – MR virtual and physical interaction tools design

4 Research Output 2

Transforming waste plastic into play:

An interactive gaming installation utilising immersive technology (2025)

This research was published in the proceedings of the 30th CAADRIA (the Association for Computer-Aided Architectural Design Research in Asia) Conference held in Tokyo in 2025. The paper is included in Volume 3 of the conference proceedings, pp. 437–446.

In this step, we designed a phygital interactive game device to enhance the efficiency of plastic recycling in Hong Kong. In the physical part, recycled plastic (PET/HDPE) 3D printed boxes were used as rewards (e.g. pen holders). The box has a built-in magnetic sensor (Reed switch) to detect user interactive behaviour. The virtual part offers immersive gaming through MR devices, which allow users to customise a 3D map of Hong Kong and participate in multiplayer interactions.

The aim is to incentivise young users to participate in recycling through gamified rewards (physical + virtual) while creating a local market.

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	Customisable 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

Figure 1: Analysis of recycling games with gamification elements

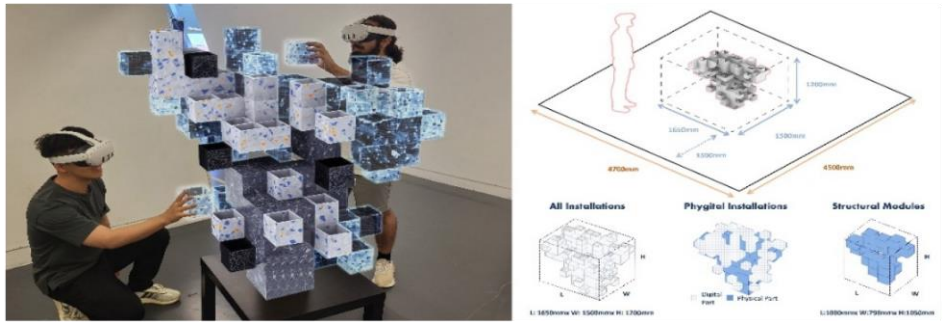


Figure 2: Phygital interactive installation

Bao, H., **Lo, T. T**., He, Y. & Li, Y. (2025). Transforming Waste Plastic into Play: An interactive gaming installation utilising immersive technology. In 25th International Conference on Computer-Aided Architectural Design Research in Asia: Architectural Informatics, CAADRIA 2025. https://papers.cumincad.org/data/works/att/caadria2025_227.pdf

4 Research Output 2

Transforming waste plastic into play:

An interactive gaming installation utilising immersive technology (2025)

Relationship between the research content and the research questions

The study confirmed that phygital integration enhances engagement through MR games + physical rewards. The research analysed the shortcomings of existing recycling game and chose physical rewards + gesture interactions to satisfy users' needs for personalisation and immediate feedback. By mapping recycling behaviours to virtual spaces (e.g. a 3D map of Hong Kong) through MR games, it was possible to explore the social potential of recycling points.

This research is the first to integrate MR, multi-person online collaboration and 3D printing rewards into a recycling scenario. The design of this device is replicable and suitable for community dissemination. However, further testing of the feasibility of large-scale deployment (e.g. recyclables sorting accuracy) is needed. This research is in the "social diffusion" stage of a series, providing a replicable hardware form and traffic entry point for subsequent community deployment and recycling economy.

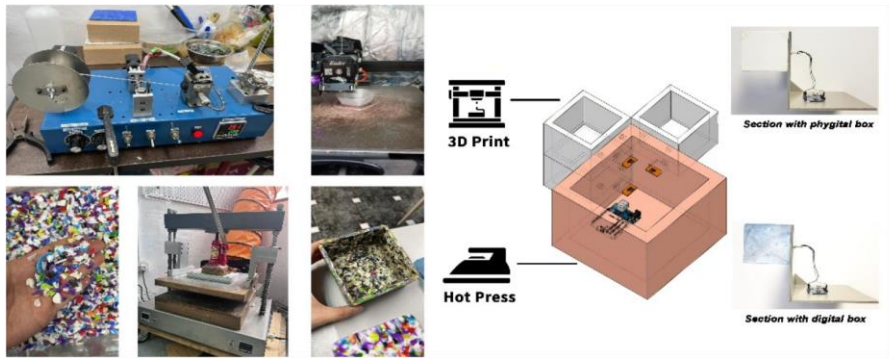


Figure 3: Plastic recycling materials and production process

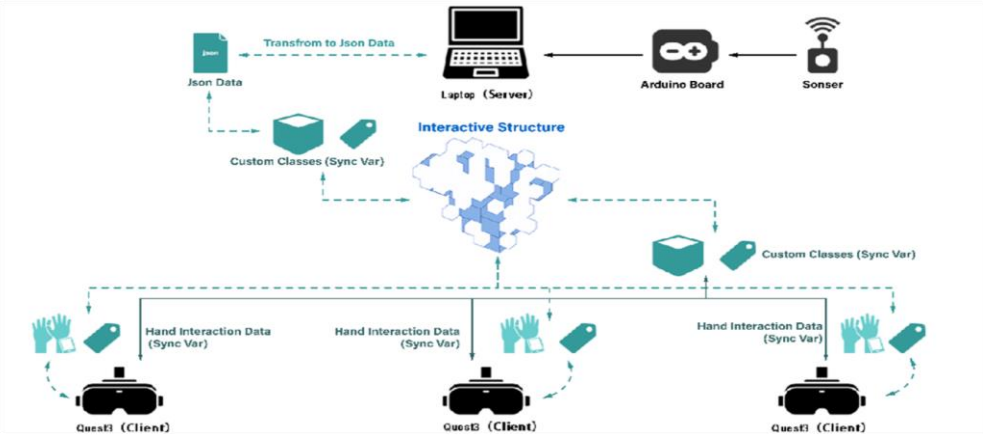


Figure 4: . Multiplayer online framework of the phygital recycling system

4 Research Output 3

Workshop – Phygital modular structure, CAADRIA 2025 Tokyo

This study is the third step of the current research process and was submitted as a workshop proposal for CAADRIA 2025. It falls within the framework of the workshop program and is an experimental practice of the first two phases to collect key data and feedback from target users. Therefore, this workshop is also included here as an important output of this study.

The study proposes a phygital modular structure system that combines gamification and extended reality (XR) technologies to achieve the following system practice goals: first, enhancing design collaboration by engaging non-expert users in modular design through gestural interactions (e.g. Meta Quest devices); second, using digital twin technology to synchronise the physical model with the virtual scenario (designing a 165cm x 150cm modular exhibition stand). Finally, incentivise user participation in the design process through reward points, real-time feedback and personalised experiences.

This research breaks away from the one-way model of "expert design - user participation" in Study 1-2, and defines "property" as modular hardware + gesture-based XR + digital twin synchronization.

(https://www.caadria2025.org/phygitalmodularstructure)

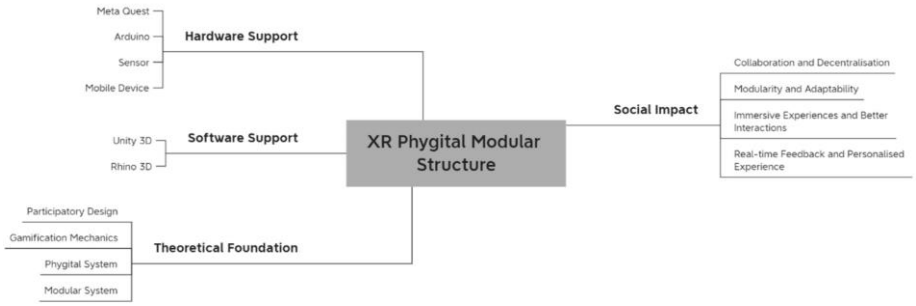


Figure 1: XR phygital modular structure system

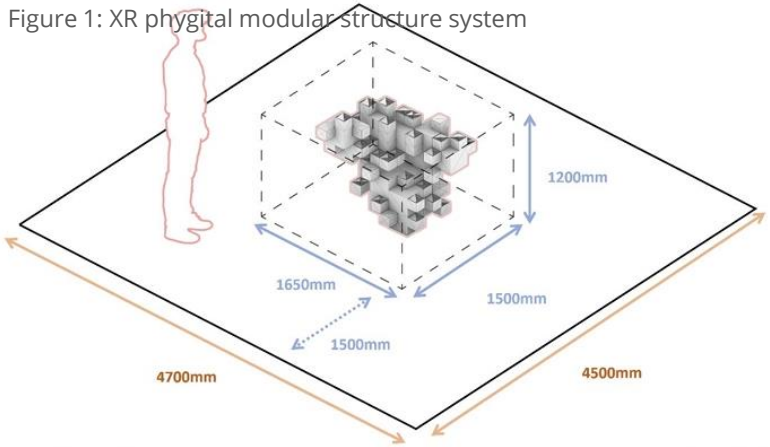


Figure 2: Exhibition stand design

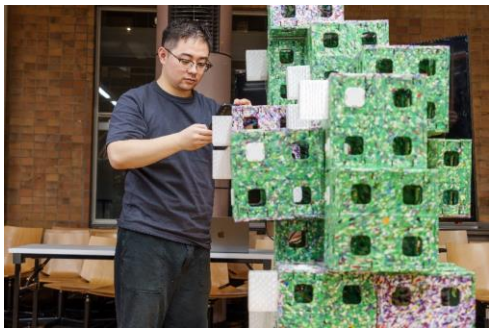
4 Research Output 3

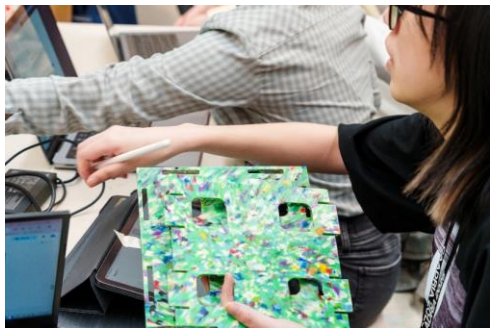
Workshop – Phygital modular structure, CAADRIA 2025 Tokyo

Relationship between the research content and the research questions

The workshop is an experimental exercise in the framework of 'Phygital Interaction + Gamification'. The study proposes that gesture interaction reduces learning barriers and overcomes the cognitive barrier for non-expert users, and this logic can be applied to the interaction design of recycling activities. Modular booth designs (e.g. removable components) provide a reference for retrofitting community recycling sites but need to be adapted to meet public space needs.

This integration supports rapid design modifications through modular construction, enhancing design communication and output capabilities. The project enables designers to rapidly create customisable XR interactive game scenarios by integrating physical models with digital interfaces. However, implementation faces the challenges of device penetration and user experience optimisation.





4 Research Output 4

Enhancing urban vitality through interactive XR Installations: Fostering engagement and environmental awareness (2025)

This research was published in the proceedings of the CAAD Futures 2025 Conference, to be held at the University of Hong Kong.

The study proposes a phygital recycling system to transform the traditional recycling system by exploring Hong Kong's participation trends through XR technology and gamification mechanisms. This includes designing smart recycling bins equipped with sensors to track plastic recycling data in real time. Refinement of the XR interactive game design, where users participate in virtual recycling tasks through MR devices to promote carbon reduction. In addition, printing user-designed items from recycled plastic (PETG) serves as an in-kind incentive. Later, through urban analysis, recycling points can be deployed in high-traffic areas such as parks and transportation hubs to promote public space activation.

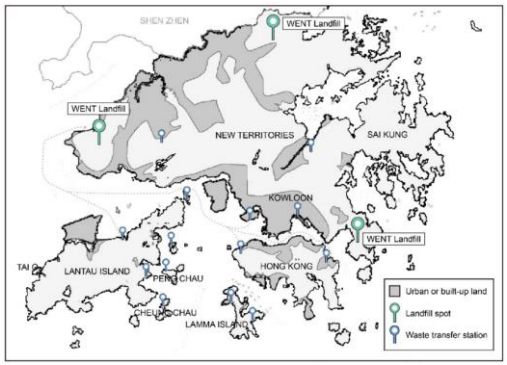


Figure 1: Mapping showing the separation between urban areas (shaded) and waste management facilities, including landfill spots (green) and waste transfer stations (blue) in Hong Kong

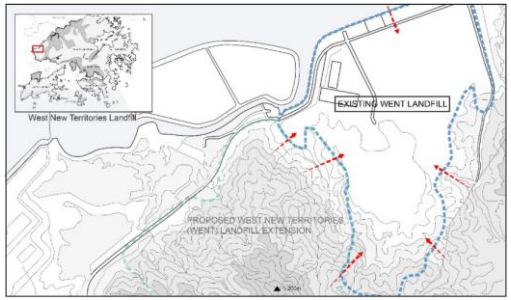


Figure 2: Relative isolation of landfill sites and surrounding environments

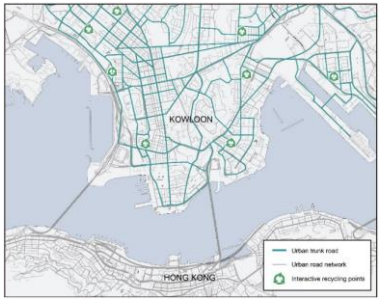


Figure 3: Urban road network and interactive recycling points

Lu, X., Bao, H., & **Lo, T. T**. (2025). (Accepted/In press). ENHANCING URBAN VITALITY THROUGH INTERACTIVE XR INSTALLATIONS: FOSTERING ENGAGEMENT AND ENVIRONMENTAL AWARENESS. In CAAD Futures 2025, the University of Hong Kong.
https://research.polyu.edu.hk/en/publications/enhancing-urban-vitality-through-interactive-xr-installations-fos/

4 Research Output 4

Enhancing urban vitality through interactive XR installations: Fostering engagement and environmental awareness (2025)

Relationship between the research content and the research questions

The study confirms that XR gamification can significantly increase recycling engagement rates and directly motivate younger users through its technology. Real-time feedback and physical rewards satisfy user need for immediacy and personalisation and to compensate for the shortcomings of traditional point systems. The recycling point is designed as a public node of 'data visualisation + game interaction', which creates a prerequisite for the subsequent transformation of physical space. This phase attempts to insert the phygital recycling system into high-traffic public spaces, realising the double enhancement of recycling behaviour and urban vitality. Meanwhile, it develops a real-time system of visualising carbon footprints, which helps move this project onto the next stage of spatial remodelling.

This research is currently in the "urban scale study" phase, providing a highly visible entry point for the next step of integrating with policies, business, etc., and completing the practical transition from "experimental prototype" to "community co-creation" to "urban infrastructure".

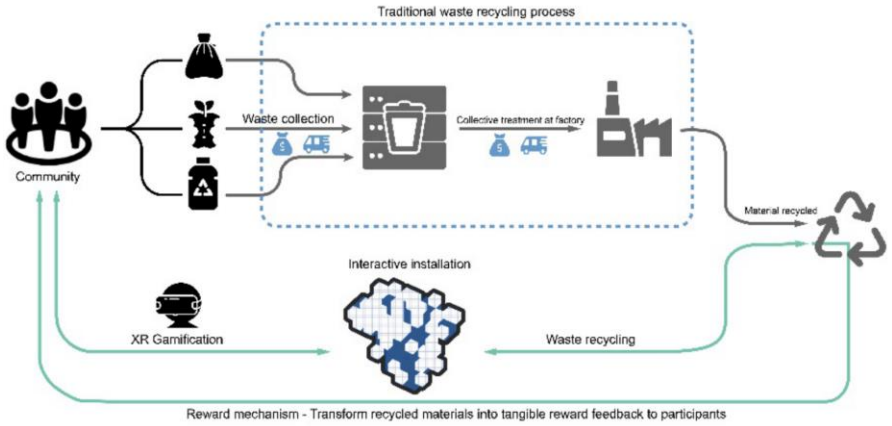


Figure 4: Illustration of user interaction with the Phygital Recycling System, showing the visible user engagement (solid line) and the hidden recycling process (dashed line).

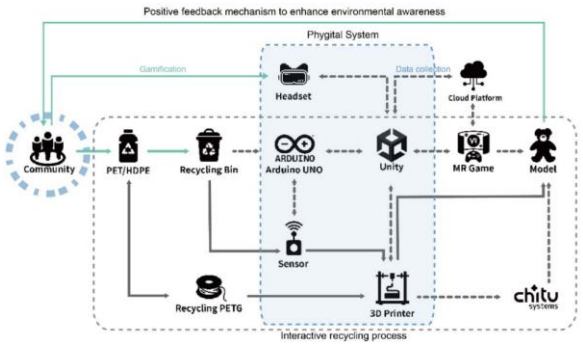


Figure 5: Recycling process based on the phygital system

5 Research Field & Key References

Cross-disciplinarity – Design, interactive technology and plastic recycling

This research area focuses on the integration of design, interactive technology and plastics recycling.

Key References:

Helmefalk, M., & Rosenlund, J. (2020). The effectiveness of the use of gamification in recycling is presented, but the lack of deep integration of immersive technologies provides an initial theoretical foundation for this study.

Steuer, B., & Chen, P. (2023). The current situation and potential of plastics recycling in Hong Kong are discussed, pointing out the limitations of the existing recycling system.

Slater, M. (2009). 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.

Paes, D., Irizarry, J., & Pujoni, D. (2021). Explored the use of immersive design in education to inform the use of immersive technology in recycling education in this study.

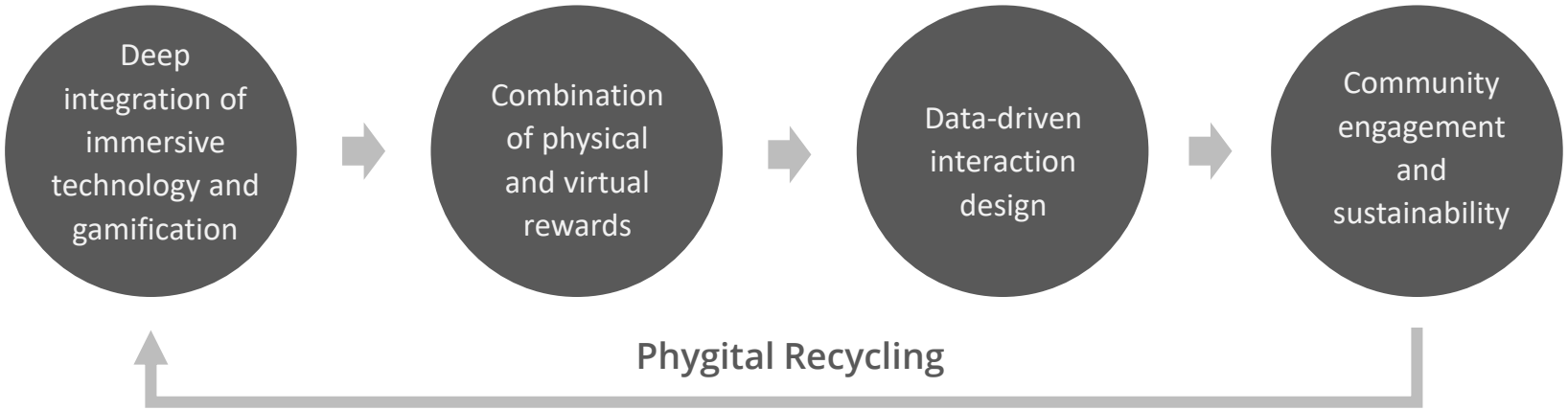
Stenberdt, V. A., & Makransky, G. (2023). In the domain of waste management, immersive technology can augment environmental awareness through interactive educational scenarios and motivate recycling behaviours.

Van Dooren, M. M. M., Visch, V. T., & Spijkerman, R. (2018). The effect of virtual versus physical rewards on behavioural persistence.

5 Research Field & Key References

Cross-disciplinarity – Design, interactive technology and plastic recycling

The originality of this study lies in the deep integration of MR technology and gamification mechanisms and the seamless interaction between virtual and real through the phygital system, which provides a more attractive (virtual-reality fusion of gamification experience and instant physical rewards) and immersive recycling experience. Unlike previous studies, this concept not only incentivises users through virtual rewards but also incorporates physical rewards (e.g. 3D-printed recyclables), which enhances the user's sense of participation and achievement. The combination of game mechanics and a city-wide system also greatly increases user engagement and participatory attraction. In addition, this study also collects physical world data through sensors, further optimising the interactive virtual-real experience and providing new solutions for sustainable plastic recycling.



6 Research Methods, Prototypes & Materials

The primary research objective is to explore ways to improve participation in waste recycling by integrating spatial design, game mechanics and phygital experiences. The study has two main components: identifying design methods that combine virtual technology and game mechanics with physical environments and then analysing user feedback to refine these methods.

Specific research methods include:

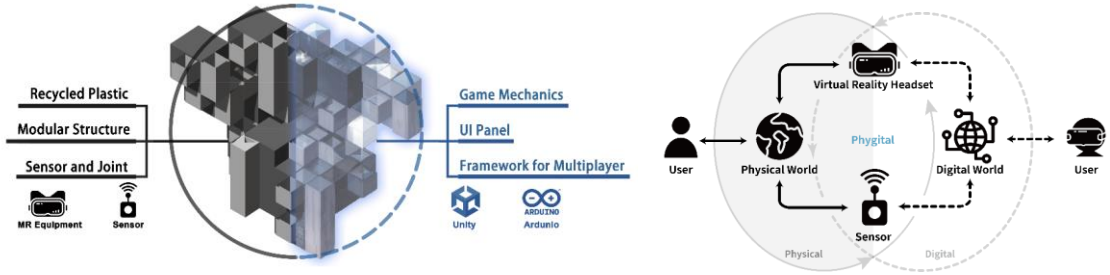
1. Conducting research and establishing partnerships between immersive technologies and recycling systems, gaining a comprehensive understanding of waste recycling through a literature review. **(Research output1, 3)**
2. Site study of recycling corners in Hong Kong that includes indoor and outdoor spaces for people to engage with the recycling process. **(Research output2, 4)**
3. Establishing a framework based on the research to develop a phygital experience to enhance recycling participation. **(Research output1, 3)**
4. Selecting a site that best fits a try-out to reshape the environment with a certain level of physical installation or modification to provide a specific spatial experience. **(Research output2, 4)**
5. Developing a gamified XR experience that responds to the physical design and site. **(Research output1, 2, 4)**
6. Engaging the public to collect observed behaviour data and user feedback. **(Research output1, 2, 3, 4)**
7. Re-examining the framework based on public engagement and summarise the structure of designing phygital interactive experience. **(Research output3, 4)**

6 Research Methods, Prototypes & Materials

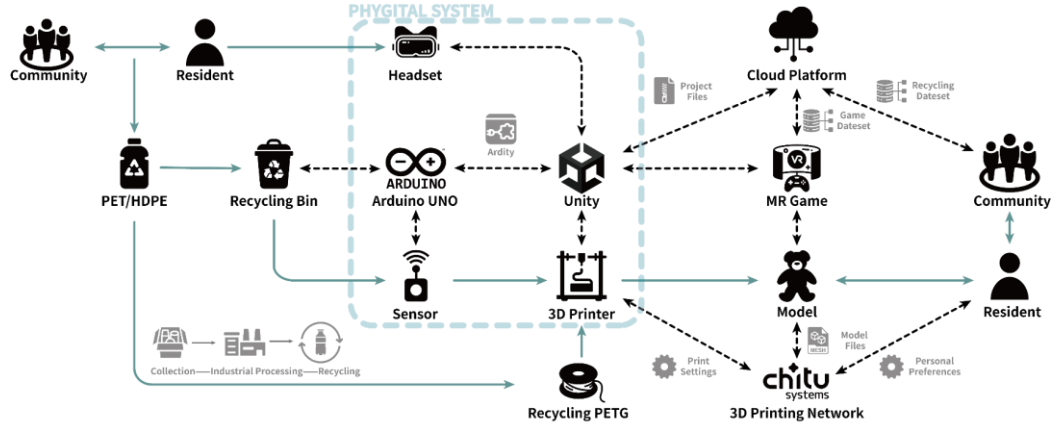
Definition of ‘phygital’ in this MCO project

Phygital is a portmanteau combining ‘physical’ and ‘digital’. It was coined by Chris Weil, the Chairman and CEO of Australian marketing agency Momentum Worldwide, to describe the seamless integration of the physical and digital worlds (What is phygital marketing?, 2024). Phygital was first used in the field of marketing to describe how brands integrate online and offline experiences. Its core concept is to break down the boundaries between the virtual and real worlds and create immersive, data-driven interactive experiences.

The phygital system is an interactive platform that amalgamates physical sensors and virtual reality technology to facilitate bidirectional real-time interaction between the virtual and real worlds.



Framework – Phygital system



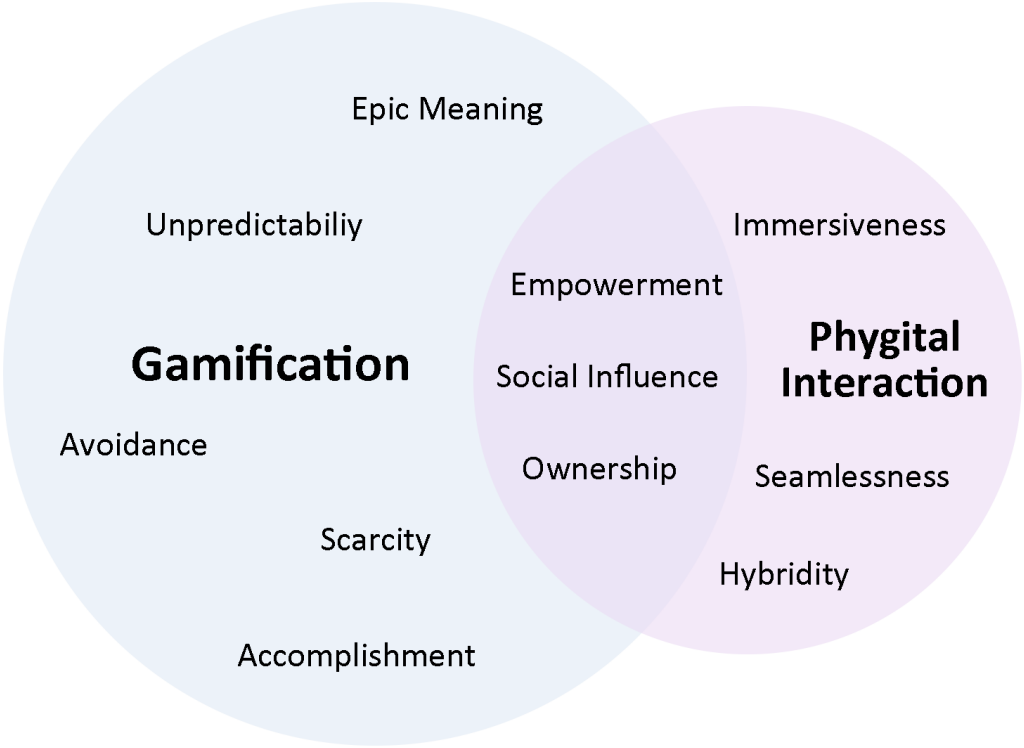
What is phygital marketing? (2024). *Amazon ads*. https://advertising.amazon.com/library/guides/phygital#:~:text=Phygital%20is%20a%20term%20invented,exciting%20and%20unique%20customer%20experiences.

6 Research Methods, Prototypes & Materials

Theoretical foundation

The Octalysis Framework is a comprehensive gamification framework to design and optimise user experiences by understanding and applying the core drivers of human motivation. The framework emphasises human-focused design, rather than functional and focuses on optimising human motivation and engagement in a system.

Octalysis Framework provides a theoretical foundation for phygital interaction through its eight core drivers (Epic Meaning, Empowerment, Social Influence, Unpredictability, Avoidance, Scarcity, Ownership, Accomplishment), helping researchers to create more engaging interactive experiences, while phygital interaction expands the framework's application scenarios. Phygital interaction blends physical and digital elements to provide an immersive experience that goes beyond traditional gamification methods, emphasising the seamless interaction between physical and digital spaces.



Chou, Y. (n.d.). The Octalysis Framework for Gamification & Behavioral Design. *Yu-kai Chou*. https://yukaichou.com/gamification-examples/octalysis-complete-gamification-framework/

6 Research Methods, Prototypes & Materials

A – Interactive installation of phygital recycling interactive gamification system

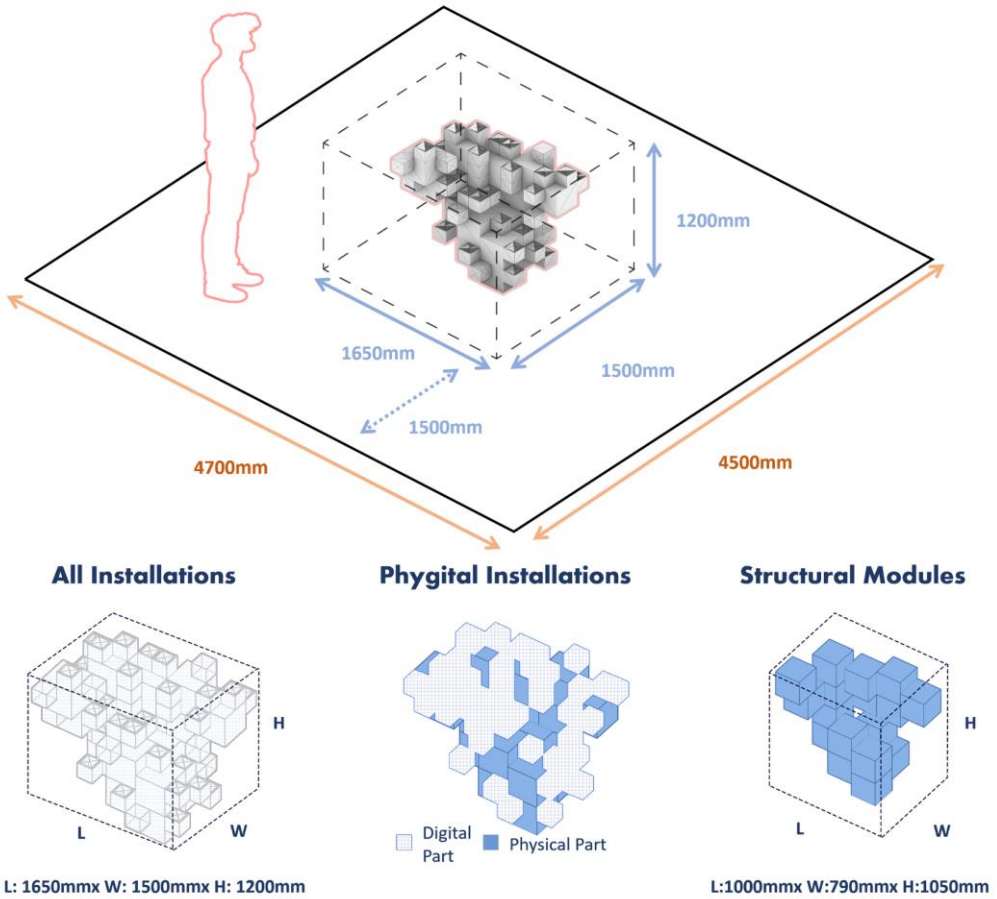


Figure 1: Phygital Interactive Installation

The participant is escorted to the game venue, where they can begin by selecting any plastic box. The game officially starts when the participant picks up their first plastic box. At this moment, a virtual model appears in place of the removed physical box, signalling the commencement of the game. The game will primarily be played using the Meta Quest.

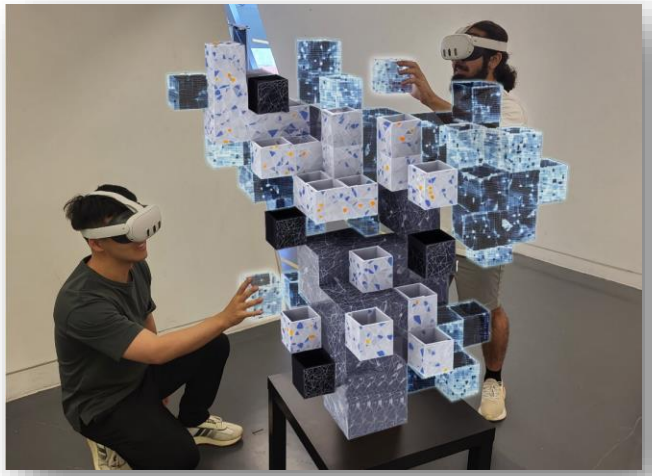
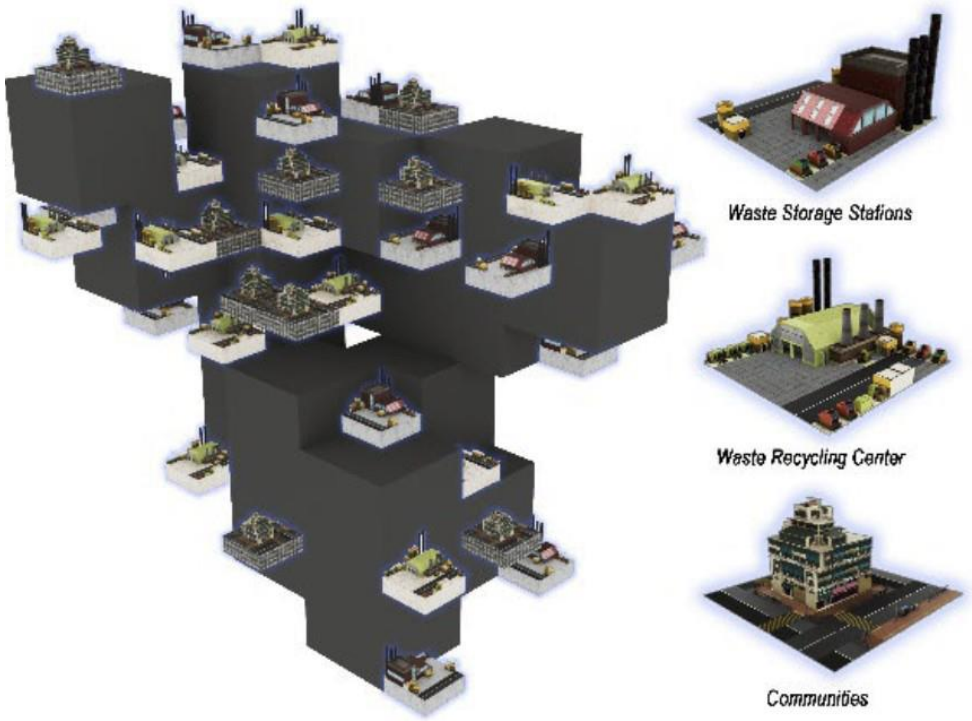


Figure 2: Prototype of phygital interactive installation

6 Research Methods, Prototypes & Materials

B – Gamification of MR G virtual experience interface



Customise the interaction panel of the virtual building

The phygital recycling virtual experience uses a 'Data-driven MR Achievement System' – using MR/XR devices to transform recycling behaviour into an interactive experiential game, where users use gestures to complete challenges, unlock achievements and accumulate virtual points that can be exchanged for physical rewards, transforming waste sorting into an immersive experience.

6 Research Methods, Prototypes & Materials

B – Gamification of MR virtual experience interface

Plastic Waste Recycling Station Collects plastic waste and sends it to recycling centres

Recycling Centre Recycling of plastic waste

Community Generating Plastic Waste

Figure 1: Three types of virtual models

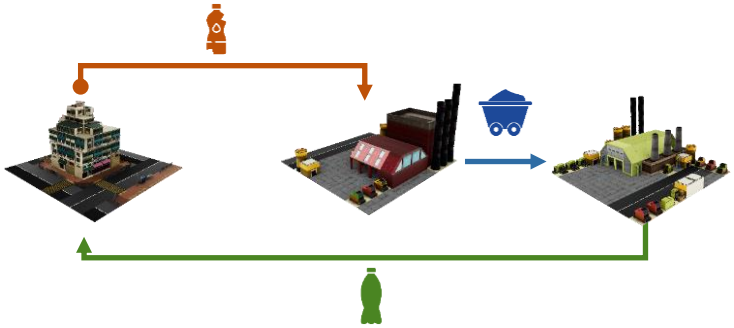


Figure 2: Different rules and play methods for virtual models

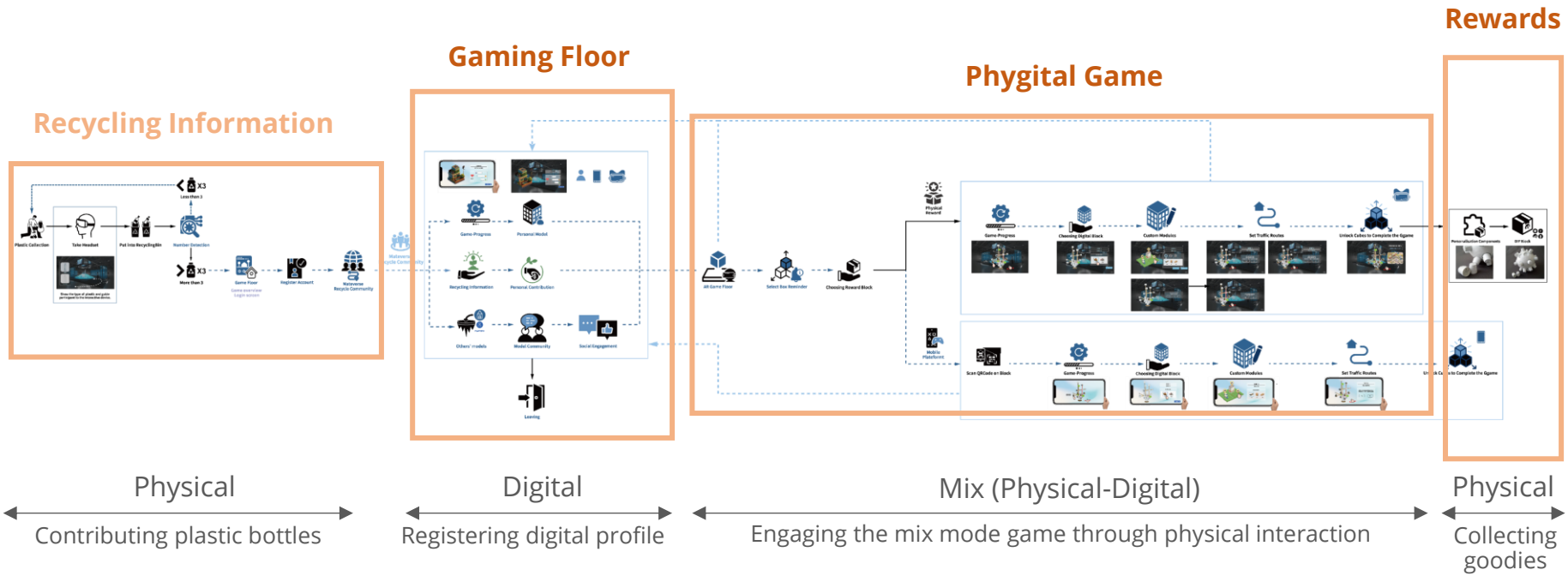
Figure 3: Unlock the virtual map through the game

Gamification is the transformation of recycling behaviour into an immersive experience with a sense of purpose, immediate feedback and social dynamics through game mechanics such as reward points and achievements, and interactive devices are the physical carriers, which visualise the abstract rules of the game through the interaction design of virtual and real, and thus using gamification to enhance public participation.

Within the game, players can choose from three types of virtual models: the community, the plastic waste recycling station and the recycling centre. These units must be coordinated effectively to regenerate plastic waste resources. Players must collaborate and strategically place virtual models to unlock different parts of the map. By completing the recycling and reclaiming cycle in one area, players can gradually unlock new sections of the map. The game is completed when all plastic waste in the area has been recycled.

6 Research Methods, Prototypes & Materials

B – Gamification: Introducing the complete phygital recycling structure game flow

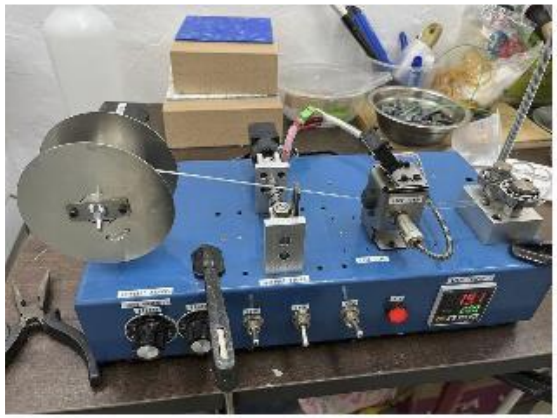


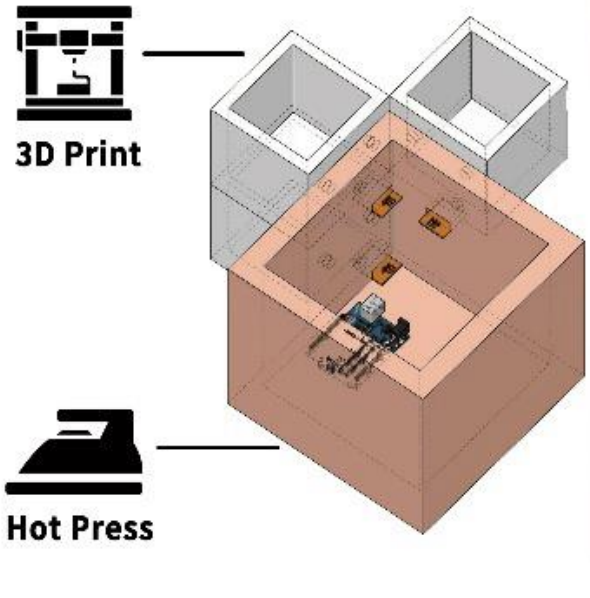
The complete phygital recycling structure gaming process **(1)starts with putting plastic bottles into the device [Physical]**, **(2)followed by self-service gaming in mobile app mode [Digital]**. Then, the user plays the XR interactive game through the **headset** to complete the entertainment and learning process in **[Mix] mode**. Finally, **the user** will receive **[Physical] rewards** for 3D printing based on points earned from recycling behaviours and games.

This is a summary of the **entire Phygital Recycling Structure game flow**. Players can conduct recycling activities through their headset devices, and the platform obtains recycling information. Players can **earn points and rewards** through the online mobile platform and offline experience device and exchange their physical rewards through virtual game interactions.

6 Research Methods, Prototypes & Materials

C – Recycled material used in 3D printing device and modular customisation rewards

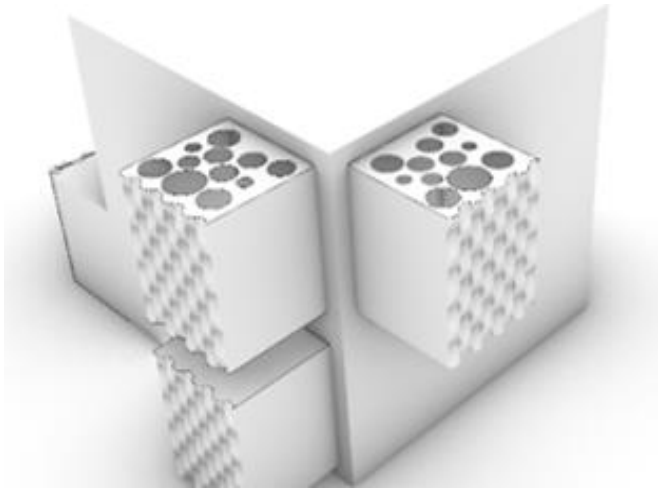


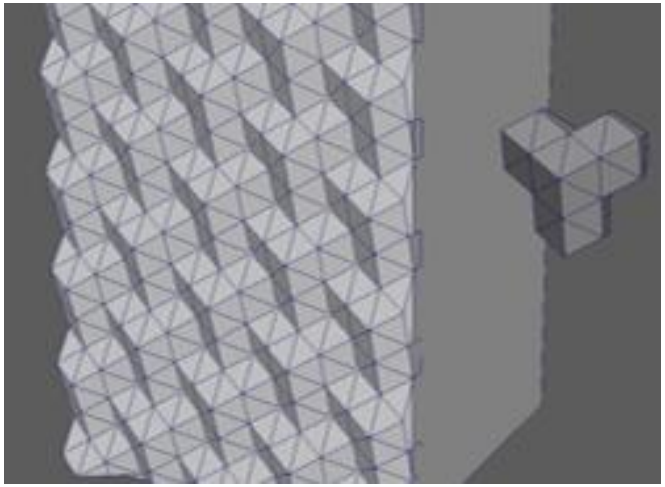


A demo of a sensor-smart recycling bin experienced through an MR interactive device has been created and exhibited. We collected plastic bottle caps for recycling and CNC to create the main box of the device (see left). Simultaneously, we recycled PET plastic for 3D customised reward printing (see white box on the right).

6 Research Methods, Prototypes & Materials

C – Recycled Material used in 3D printing of modular customisation rewards





Recycled Material Box design

3D customised reward printing (PET plastic)

The raw material required:
Big Box (15), Small Box (48)

PET: 1500g–2000g

HDPE: 20000g–25000g

6 Research Methods, Prototypes & Materials

D – Prototype of the project (mixed mode interaction)

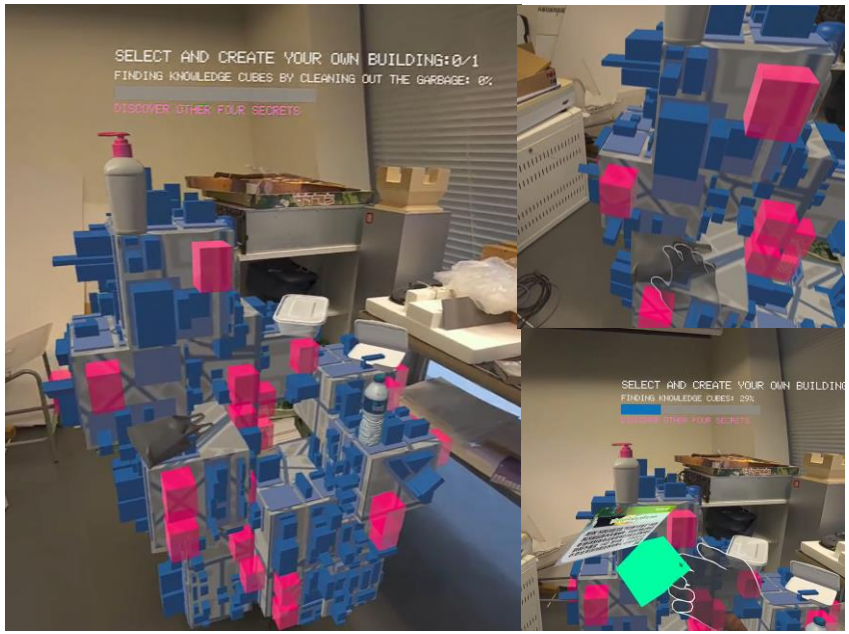
Video 1: Coffee interactive prototype Link: https://ira.lib.polyu.edu.hk/video.jsp?id=115344

This is a pre-design prototype of the phygital recycling structure for immersive technology testing and user experience analysis using the process of learning to make coffee. The immersive technology uses a combination of physical and digital methods, where the user can see virtual images through the headset and interact with them through gestures for the purpose of experience and learning. The real world can also be seen through the headset, so that users are still aware of the real world. Users can interact with the physical and virtual world simultaneously.

6 Research Methods, Prototypes & Materials

E – Immersive technology of the phygital recycling system (delivery-game-co-creation)

Device installation process



Virtual-Physical (Phygital) recycling system

Centred on immersive technology (MR device, Unity, Arduino), the project transforms the physical act of recycling plastics—detected in real time by a sensor-equipped box made of recycled material—into a gamified virtual experience, where users interact through gestures within a 3D game environment. The process culminates in the creation of 3D-printed rewards made from recycled PET plastics, completing a closed-loop cycle of ‘delivery–game–co-creation’. This integrated system makes recycling behaviour tangible, engaging, and interactive, linking physical action, digital participation, and material outcome in a seamless experience.

7 Research Outcomes

This MCO Research designed a complete physical-digital recycling loop game process. (1) Place plastic bottles in the XRecycling community interactive device and participate in the XR recycling activity through a headset device to obtain points. (2) Obtain points through the self-service game on the mobile app. (3) Users receive physical rewards based on their recycling behavior and game points.

This MCO asks the central question through a series of studies:

How can we design an actionable recycling education system through XR technology to empirically improve users' recycling knowledge and long-term behavioural motivation?

Therefore, our previous four work components developed a phygital recycling structure (which I would like to call the XRecycle Platform) – an XR recycling educational system that combines physical devices with digital gamification mechanisms.

XRecycle combines virtual environment creation, recycling behaviour simulation, real-world smart recycling bin interaction and XR game knowledge experience. This research breaks through the sensory limitations of traditional VR and AR, enhances the realism of virtual interactions through sensors and motion recognition and allows physical recycling bins to be linked with virtual data, which is advanced and state-of-the-art.

Through a two-year mixed-methods study (quantitative experiments + qualitative interviews), we found that the XRecycle system significantly enhanced Hong Kong youths' knowledge of and behavioural motivation towards plastic recycling through the XR immersive experience and gamification mechanism, and the combination of real and virtual rewards design was a key motivator.

This research provides a collaborative creation platform for the recycling system, encouraging users to actively participate and contribute to sustainable development. In the future, we need to optimise the diversity of interactions to enhance long-term participation and expand the linkage with community recycling policies.

7 Research Findings

Containing gamification incentives means the XRecycling System promotes engagement in young users.

Research has shown that immersive experiences incorporating XR technology can significantly increase the interest and engagement of young users. According to Bangor's (2013) adjective rating scale, the XR recycling education platform designed in this study scored a ‘good’, which implies that the designs of the interactive interface and mechanism effectively promote users' willingness to recycle.

The XR recycling interactive installation is significantly effective in facilitating participants' acquisition of knowledge about plastics recycling.

The comparative experimental analysis of the learning outcomes before and after the experience showed a significant improvement in the post-experience test results ($M=7.10$, $SD=2.27$) compared to the pre-experience test results ($M=3.45$, $SD=1.23$), $p<0.001$.

Activities and interactive platforms related to the Hong Kong community can markedly enhance user engagement and sense of belonging.

Post-study interviews indicated that transforming garbage collection stations into engaging public spaces through the XR interactive spatial design could enhance users' connection to the community. Virtual environments and experiential installations related to Hong Kong's culture enhance users' attention and can authentically encourage them to learn. The ‘collaborative creation’ mode also enhances users' desire to explore and communicate in the virtual world. The interviews revealed that the majority of the young users recognised the collaborative creation and interactive learning experience in the XR recycling platform. Some people commented that repetitive gameplay and level settings might cause interaction fatigue, thereby reducing the appeal. The low efficiency of knowledge acquisition caused by the gameplay, the insufficient attractiveness of the interface system and insufficient motivation will become the primary challenges for future research.

7 Further Research

- **Data Collection and Manufacture**

  Future studies will address improvements in data collection and box manufacturing for large-scale implementation.

- **Technical improvements and testing**

  To further enhance interactivity and user experience, the accuracy and stability of the sensors need to be improved.

- **Community applications and assessments**

  This research emphasises the importance of applying the system to communities. Future research needs to explore specific community recycling locations and evaluate recycling data based on different areas to improve product feasibility.

- **Personalisation and Interactivity**

  Despite interest shown by users in the customisation of the virtual model, the lack of diversity in the combination of virtual city spaces limits further exploration. Future research could further enrich the design options of the virtual model to improve long-term user engagement.

- **Optimisation of incentives**

  Reward mechanisms need to be further optimised to enhance user acceptance and participation.

- **Global Communication and Promotion**

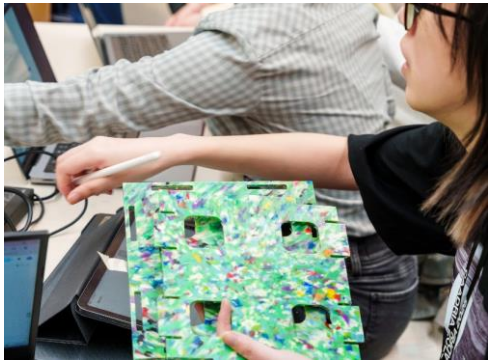
  Establish a globally transferable and deployable recycling model to promote the adoption of recycling frameworks outside Hong Kong, providing a new paradigm for resource recovery and utilization in other regions.

8 Research Dissemination – Projects and Paper Publication

Year	Project
2024	**Lo, T. T**., & Bao, H. Phygital Recycling: Development of a gamified interactive XR structure to enhance the participation of recycling . In Education and research in Computer Aided Architectural Design in Europe, https://research.polyu.edu.hk/en/publications/phygital-recycling-development-of-a-gamified-interactive-xr-struc (Open access)
2025	Bao, H., **Lo, T. T**., He, Y. & Li, Y. (2025). Transforming Waste Plastic into Play: An interactive gaming installation utilizing immersive technology. In 25th International Conference on Computer-Aided Architectural Design Research in Asia: Architectural Informatics, CAADRIA 2025. https://papers.cumincad.org/data/works/att/caadria2025_227.pdf (Open access)
2025	Lu, X., Bao, H., & Lo, T. T. (2025). ENHANCING URBAN VITALITY THROUGH INTERACTIVE XR INSTALLATIONS: FOSTERING ENGAGEMENT AND ENVIRONMENTAL AWARENESS. In CAAD Futures 2025, the University of Hong Kong. https://caadfutures2025.hku.hk/conference_papers.html (Accepted/In press).

8 Research Dissemination – Workshop

Year	Project
2025	**Phygital Modular Structure, CAADRIA 2025 Tokyo** (https://www.caadria2025.org/phygitalmodularstructure) **Instructor:** **Sky Lo Tian Tian** Assistant Professor, School of Design, PolyU **Other Key Instructors:** Hanzhe Bao, Research Assistant, School of Design, PolyU Yuhao He, PhD Student(HKPFS), School of Design, PolyU Yuhao Li, Research Assistant, School of Design, PolyU



8 Research Dissemination – Exhibition

Year	Project
2025	**Phygital Modular Structure, CAADRIA 2025 Tokyo** (https://www.caadria2025.org/phygitalmodularstructure) **Instructor:** **Sky Lo Tian Tian** Assistant Professor, School of Design, PolyU **Other Key Instructors:** Hanzhe Bao, Research Assistant, School of Design, PolyU Yuhao He, PhD Student (HKPFS), School of Design, PolyU Yuhao Li, Research Assistant, School of Design, PolyU