

A Gamified Tool for Monitoring Construction & Demolition Solid Waste Data to Support Circular Economy

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ABSTRACT

An interactive Unity framework for simulating construction and demolition waste operations to support education and research in circular economy workflows.

- Focuses on collection, logistics, and facility processing.
- Helps to easily understand complex waste-management workflows.
- Supports training, stakeholder understanding, and research.
- This project develops an interactive Unity simulation for construction and demolition waste operations
- Combines first-person and top-down perspectives.
- Uses timed tasks and progress feedback to measure efficiency.
- Reduces efficiency for mistakes instead of using hard fail states.
- Models key stages like weighing, stockpiling, screening, and separation.
- The framework supports research on process comprehension, compliance, and circular economy decision-making.

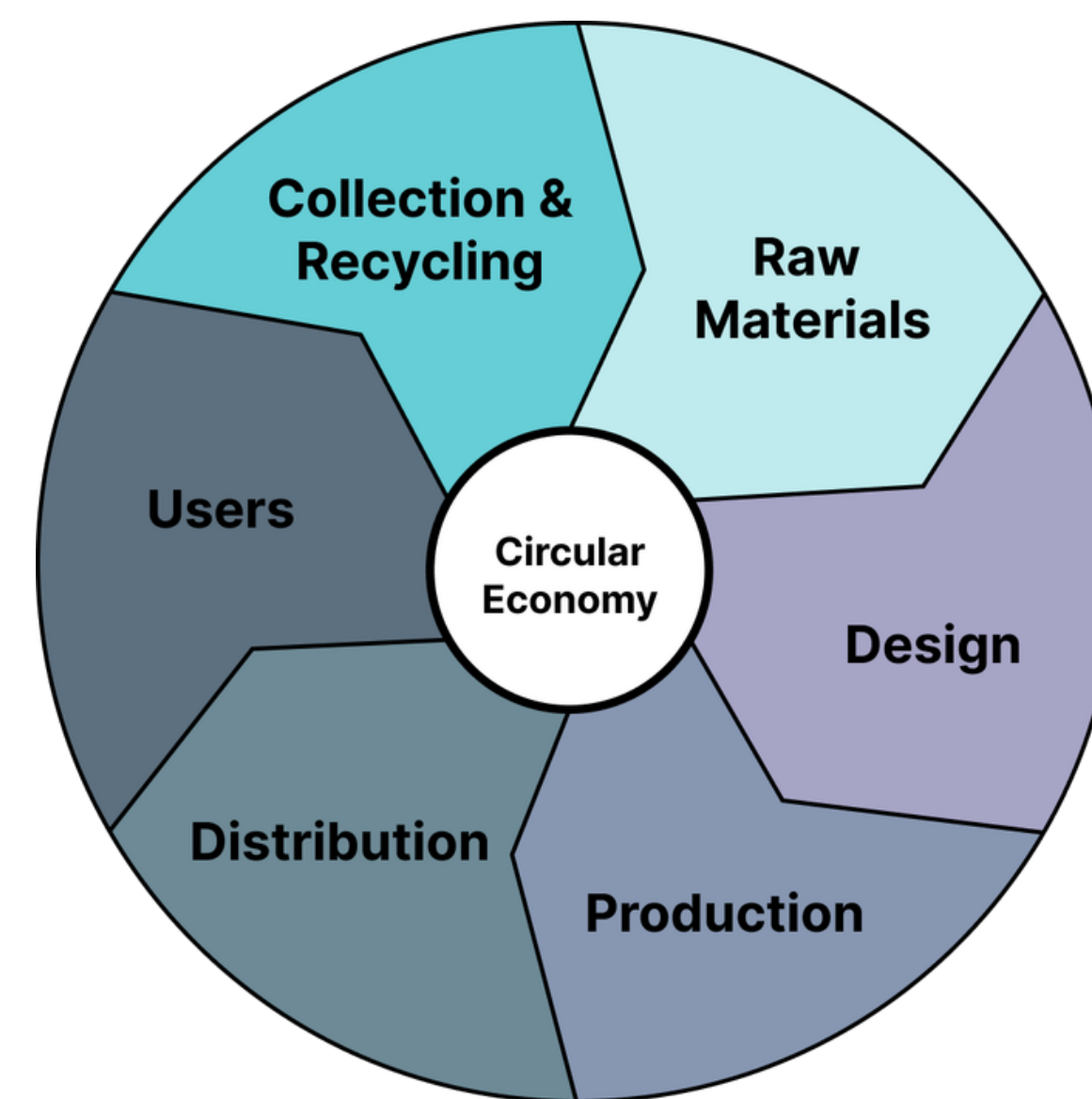


Fig 1: Circular Economy Pipeline

RELATED WORK

- **Serious games and C&D waste.** Zhuang et al. show that a metaverse serious game can be used to study green nudges and their effects on on-site construction waste management, including participation, collection behavior, and sorting performance—demonstrating that interactive environments can go beyond static training to shape how workers respond to waste-handling cues in a simulated site context.
- **Circular-economy framing.** Papamichael et al. synthesize how construction and demolition waste fits a circular-economy framework, highlighting barriers that are not only technical but informational and educational—i.e., stakeholders need clearer pictures of full-cycle material flows and recovery logic.
- **Interdisciplinary need.** Designing C&D waste “serious game” tools sits at the intersection of waste/circular-economy domain knowledge, construction and logistics process structure, learning and behavior, and interactive / game design. A single discipline rarely owns all of that at once, which is why integrated simulations are useful: they force the workflow, constraints, and trade-offs to be expressed in one coherent, playable system—something static briefings or siloed tools usually do not provide.

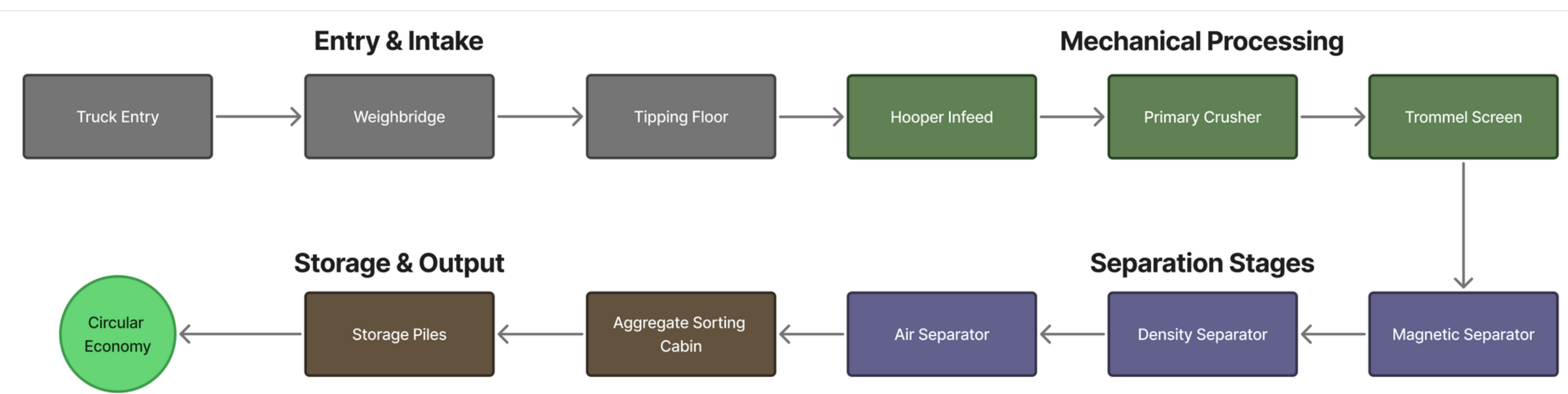


Fig 2: C&D Waste Management Process Flowchart

DESIGN METHODOLOGY

- **Goal Definition:** Collaborated with an industry professional to align the game’s objectives with circular economy principles and waste management systems.
- **Primary Research:** Conducted initial research and gathered reference materials to represent the appearance of real-world waste management sites accurately.
- **Asset Development:** Utilized Blender 5.0 to model two primary environments: a Demolition Site and a C&D Waste Management Plant based on original site references.
- **Design Validation:** Completed and verified the 3D layouts with the industry professional to ensure technical and structural accuracy.

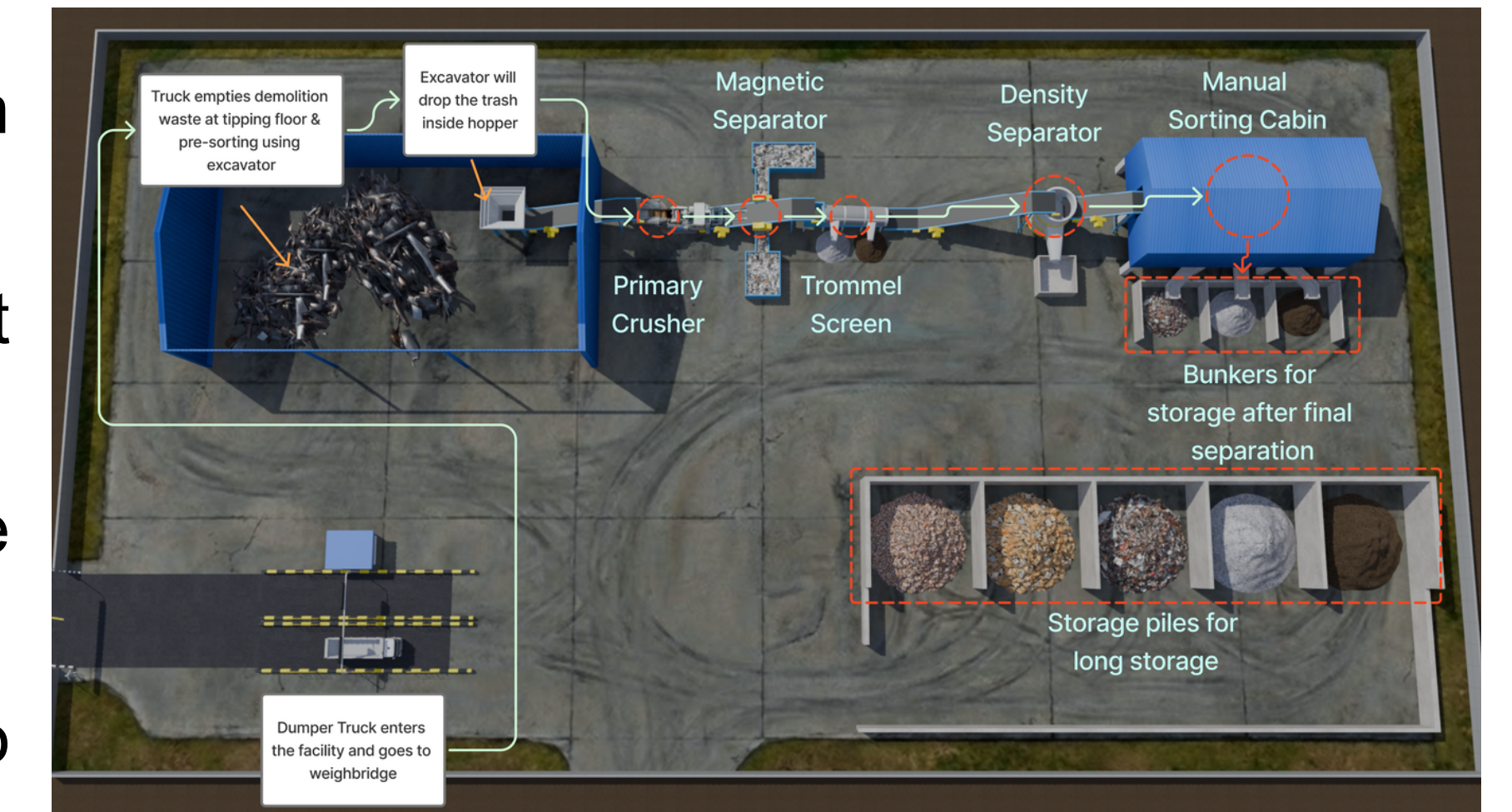


Fig. 3: C&D Demolition Waste Management Facility Game Layout

DEVELOPMENT PROCESS

With the 3D environment validated, we focused on architecting the underlying game logic and interaction that drives the simulation. We developed a modular Mode Switch System within Unity. This allows for seamless transitions between FPP (task execution) & Top-Down (logistics management) views, ensuring users can navigate the distributed nature of a waste management site.

- **Intelligent Wayfinding:** Using a centralized Instruction Manager, the system guides users through the C&D process from initial vehicle weighing at the weighbridge to final material sorting.
- **Feedback Loops:** We implemented a State-Check architecture that monitors user compliance with process constraints.
- **Procedural Event Handling:** The system manages complex interactions, such as hopper infeed, magnetic separation triggers, and density classification logic.

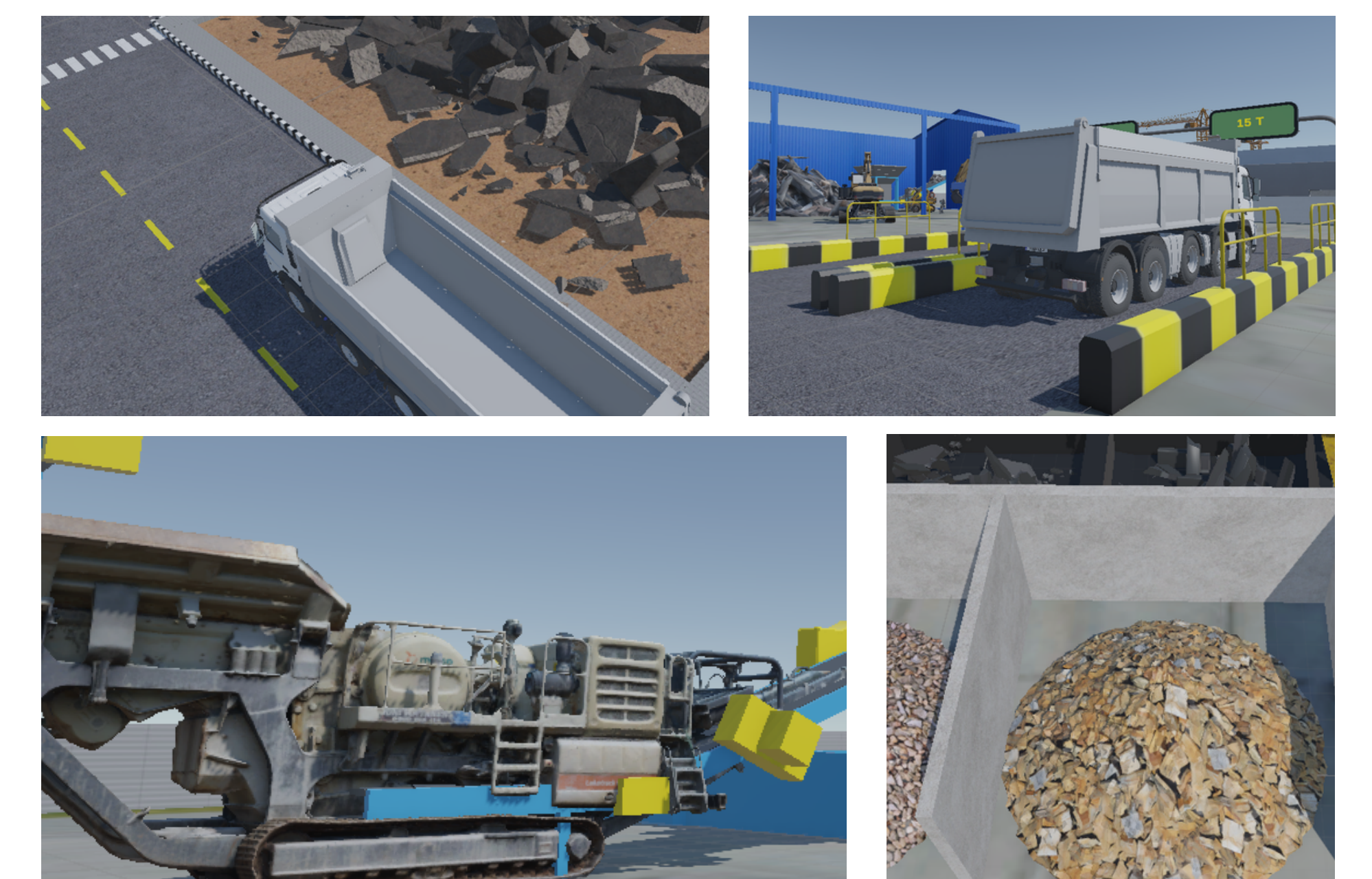


Fig. 4: Game Environment Snapshots

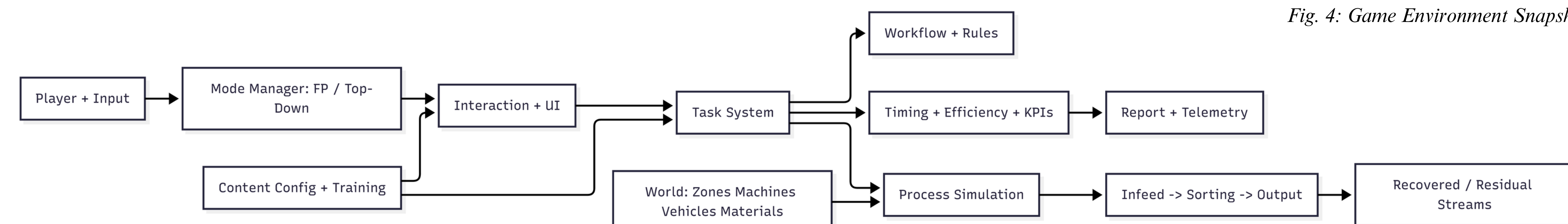


Fig. 5: Game Mechanics Flowchart

DISCUSSION AND FUTURE WORK

The simulation framework presented here establishes a functional and extensible foundation for studying how users perceive, interpret, and engage with construction and demolition waste management workflows in an interactive environment.

- **User Perception & Interaction:** Evaluate how participants engage with and interpret the interactive simulation environment.
- **Process Comprehension:** Assess whether users accurately understand the function and sequence of each stage in the C&D pipeline.
- **Workflow Compliance:** Examine the extent to which users follow prescribed sorting logic, particularly when operating under time pressure.

REFERENCES

- [1] Y. Zhuang et al., “Nudge wasteout: Understanding the impacts of green nudges on on-site construction waste management based on metaverse serious game,” *Environ. Impact Assess. Rev.*, vol. 118, 2026.
- [2] I. Papamichael et al., “Construction and demolition waste framework of circular economy: A mini review,” *Waste Management & Research*, 2023.
- [3] T.-J. Irabor et al., “Gaming for change: Exploring systems thinking and sustainable practices through complexity-inspired game mechanics,” *Humanit. Soc. Sci. Commun.*, vol. 12, no. 1, 2025.