

Circular Construction: Recycling Plastic Waste into Washroom Infrastructure for Schools in Ghana

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ABSTRACT

Access to adequate sanitation is a fundamental component of community resilience and public health, yet many schools in low-resource settings lack proper facilities. The Waste-to-Infrastructure project, led by Engineers Without Borders Netherlands, addresses this challenge by transforming locally collected plastic waste into durable construction bricks used for building school washrooms in Kumasi, Ghana. This approach contributes simultaneously to solving two pressing issues: the accumulation of plastic waste in the environment and the scarcity of safe, hygienic sanitation infrastructure. The project adopts a circular economic perspective, recovering plastic waste from the environment while reducing reliance on carbon-intensive construction materials. The present work emphasizes plastic sand bricks, with continued studies examining additional material integrations to expand research directions and potential large-scale applications. The resulting structures are designed for ease of assembly, low maintenance, and adaptability to local needs, ensuring both environmental and social sustainability. Beyond infrastructure provision, the project strengthens education and inclusion, as improved sanitation directly supports higher school attendance, particularly for female students. By combining material innovation, sustainable construction practices, and community engagement, the Waste-to-Infrastructure project demonstrates how engineering solutions can reinforce resilience against environmental and social hazards, while contributing to global sustainability goals.

Keywords: plastic waste, circular construction, school washroom, plastic bricks

INTRODUCTION

The Waste-to-Infrastructure initiative in Kumasi, Ghana, led by Engineers Without Borders Netherlands (EWB-NL) in collaboration with TrashSmart Ghana, addresses two interconnected challenges: plastic waste accumulation and inadequate school sanitation infrastructure. Within this broader initiative, the present paper documents a humanitarian engineering workflow for translating recycled plastic brick development into a buildable school washroom concept design and an implementation pathway suitable for local construction practice.

This paper reports on project development activities, co-design decisions, and implementation readiness while experimental investigations as well as structural verifications are in progress. The paper consolidates insights from years of volunteer work, student-led design studies, and project documentation, including brick geometry development, a washroom handbook preparation, and stakeholder-informed construction planning in Ghana. The work is framed as an applied case study in circular construction and community-oriented infrastructure development.

Previous student research has supported the technical development of the concept by investigating recycled-plastic brick geometry and expected structural behaviour using finite-

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element simulations under representative load conditions for single-storey washroom walls (Patrignani, 2025). The design of a production system to convert plastic waste into construction bricks was also examined in relation to the social, physical, and economic context of Kumasi, Ghana (van der Ouw, 2025). Moreover, student and volunteer efforts have developed a standard washroom concept design, shown in Figure 1, and a construction handbook to support on-site implementation and handover to local builders (Weij, Pasveer, & Tebrunsveld, 2026). In parallel, ongoing work in collaboration with the Humanitarian Engineering group at the University of Twente includes coordinated student projects that are currently advancing the processing route, laboratory-based material characterization, and wall-scale structural integrity verification of the recycled-plastic brick system.

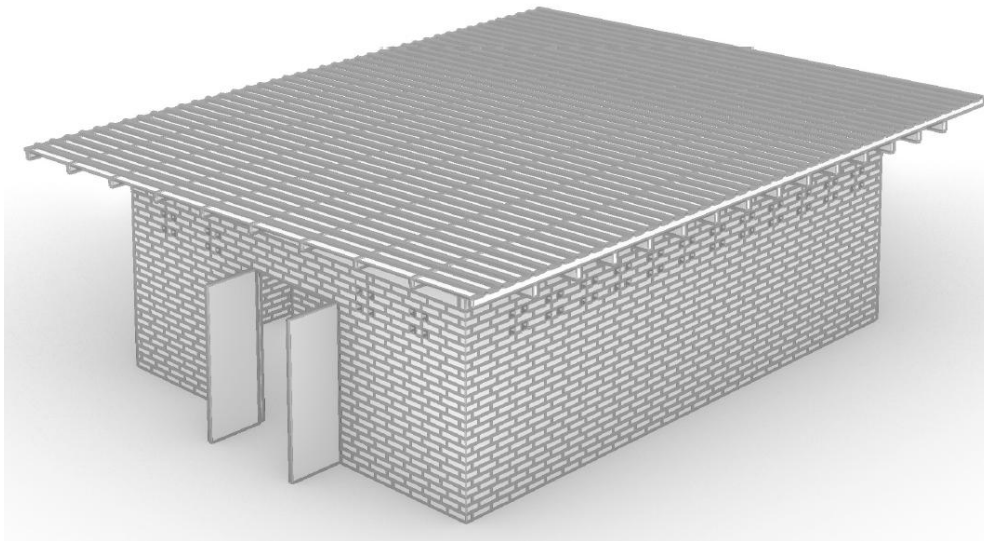


Figure 1. Washroom 3D design made by plastic bricks in Kumasi, Ghana

PROBLEM STATEMENT

Many schools in Ghana lack adequate washroom facilities (Figure 2), which negatively affects hygiene, dignity, and school attendance, particularly for girls. At the same time, plastic waste management remains a persistent environmental and urban challenge. Conventional construction approaches for school sanitation may be constrained by cost, supply chains, and limited local access to suitable materials and standardized solutions.

The project therefore seeks a context-appropriate construction system that is affordable, buildable with local resources, and compatible with local continuation after external volunteers leave. For the brick-based washroom concept, the challenge is not only material development but also the integration of brick geometry, construction detailing, stakeholder requirements, and practical implementation sequencing into a coherent and deployable solution.

PROJECT GOALS

The Waste-to-Infrastructure project goals can be summarized as follows:

- Develop a sustainable business model.
- Enhance the capacity of the local partner to collect plastic waste through value-chain optimization using appropriate software.
- Support scale-up plans through container-based mobile recycling technology.
- Provide architectural and structural designs for the pilot project.
- Develop methods and equipment to improve construction efficiency.
- Build local capacity and skills to ensure long-term business sustainability.



Figure 2. Example of existing washroom facilities in Kumasi, Ghana [site visit, 2023]

At the same time, the project is linked to the following Sustainable Development Goals:

- Goal 1 – No Poverty: Creating employment opportunities, particularly for women involved in the collection and cleaning of plastic waste, can improve household income.
- Goal 2 – Good Health and Well-being: Accumulated plastic waste can encourage the breeding of disease vectors such as mosquitoes, which transmit malaria, one of the major causes of mortality in the region. In addition, the absence of proper sanitation facilities in schools can increase the occurrence of water- and hygiene-related diseases.
- Goal 3 – Quality Education: The lack of proper sanitation facilities can lead to absenteeism among students and teachers, and reduce enrolment, particularly for girls. Providing adequate water, sanitation and hygiene facilities can support improved educational participation and outcomes.
- Goal 4 – Decent Work and Economic Growth: Improved sanitation, better access to education, and enhanced well-being support productivity and contribute to local economic development.
- Goal 5 – Industry, Innovation and Infrastructure: The project supports local fabrication of equipment, training of artisans, and construction of essential infrastructure.
- Goal 6 – Sustainable Cities and Communities: Improved waste management contributes to circular and more sustainable community practices.
- Goal 7 – Climate Action: Cement production is a major source of greenhouse gas emissions. Substituting cement-intensive materials with recycled plastic-based construction products can contribute to decarbonization in the construction sector.
- Goal 8 – Life Below Water: Recycling plastic waste can reduce plastic leakage to waterways and ultimately the ocean.

METHODOLOGY

This paper is structured around three complementary workstreams: (a) plastic waste collection and processing development led by local partners with support from the wider team, (b) design and refinement of the recycled-plastic brick concept and geometry, and (c) architectural and structural detailing of the washroom together with construction planning for the pilot implementation.

Waste collection

Plastic waste collection in Kumasi is carried out through the local partner, TrashSmart, and its established collection capacity and supporting community-based networks, see Figure 3. The project prioritizes strengthening this collection chain through improved organization, tracking, and value-chain optimization supported by appropriate software, followed by manual sorting and cleaning prior to processing into recycled-plastic bricks.



Figure 3. Plastic waste collection in Kumasi, Ghana [site visit, 2023]

Waste processing

Waste processing is described as a staged workflow that converts collected plastic into a controlled feedstock for brick production, see Figure 4. After sorting and cleaning to remove contaminants, the plastic is prepared through mechanical size reduction to achieve a consistent input material for the selected brick-manufacturing process. The downstream forming approach and associated production parameters are being refined through ongoing design development and laboratory testing, with the aim of defining practical quality-control checks and acceptance criteria prior to on-site implementation.



Figure 4. Plastic waste processing in Kumasi, Ghana [site visit, 2023]

Brick design

The brick concept currently adopted as the starting point for washroom layout development is an interlocking rectangular unit with nominal dimensions of 300 × 100 × 100 mm (L × W × H) incorporating three top studs, complemented by 2-by-1 and 1-by-1 modular variants to accommodate corners, terminations, and local layout adjustments. This baseline direction is guided not only by modularity and constructability, but also by practical constraints identified in the project's design documentation, including mould complexity, manufacturability-driven width limitations, and the intention to minimize on-site cutting due to buildability considerations and potential microplastic generation.

Moreover, prior student research provides supporting evidence for the feasibility of recycled-plastic bricks in low-rise washroom applications, having evaluated multiple interlocking geometries through finite-element simulations under representative low-load conditions for single-storey wall segments. Based on the stated assumptions, the investigated concepts remained in the elastic range under service-level demands and a pyramid-type geometry emerged as a promising candidate in view of both structural response and manufacturing constraints (Patrignani, 2025).

Although the present paper does not reproduce those simulations, the reported outcomes support the pilot-stage strategy adopted herein: a robust geometry and interlock mechanism can enhance assembly stability and offer increased tolerance to uncertainty in material behaviour, production variability, and dimensional tolerances, which is particularly relevant while laboratory testing for material characterization and performance verification is still ongoing.

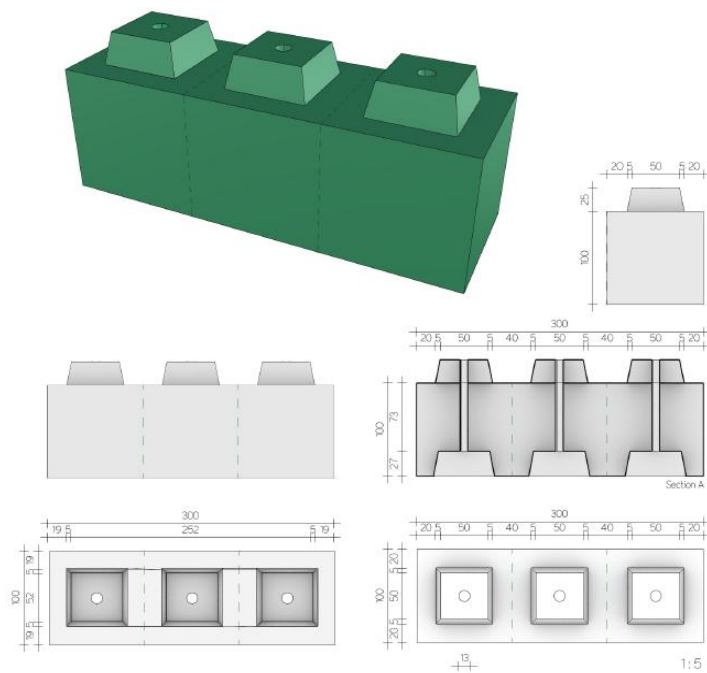


Figure 5. Brick concept design (Patrignani, 2025, Weij, Pasveer, & Tebrunsvelt, 2026)

Washroom design

For the washroom design, the work has been translated into a practical, handover-oriented package (Weij, Pasveer, & Tebrunsvelt, 2026) that prioritizes constructability, durability, and continuity of implementation by local builders. The baseline concept is developed as a standardized low-rise unit for school settings, with clear architectural layout logic and detailing intended to be executed using locally available skills, tools, and materials, while remaining compatible with the modular wall strategy based on recycled-plastic bricks. The floor plan of the standard washroom design is presented in Figure 6, while the floor plan of the extended

washroom design is presented in Figure 7, which incorporates separate facilities for teachers, people with disabilities, and changing rooms.

The construction handbook consolidates the build sequence, identifies critical interfaces (foundation-to-wall, wall-to-roof, openings, and service provisions), and provides adequate guidance to support on-site execution and transfer of responsibility after volunteering phases conclude. Feedback obtained through communication with local workers and partners, in Ghana, has been treated as a primary design driver: detailing and sequencing are kept deliberately simple, reliance on specialized equipment is minimized, and practical considerations such as tolerances, workmanship variability, material availability, and maintenance needs are explicitly acknowledged in the construction approach.

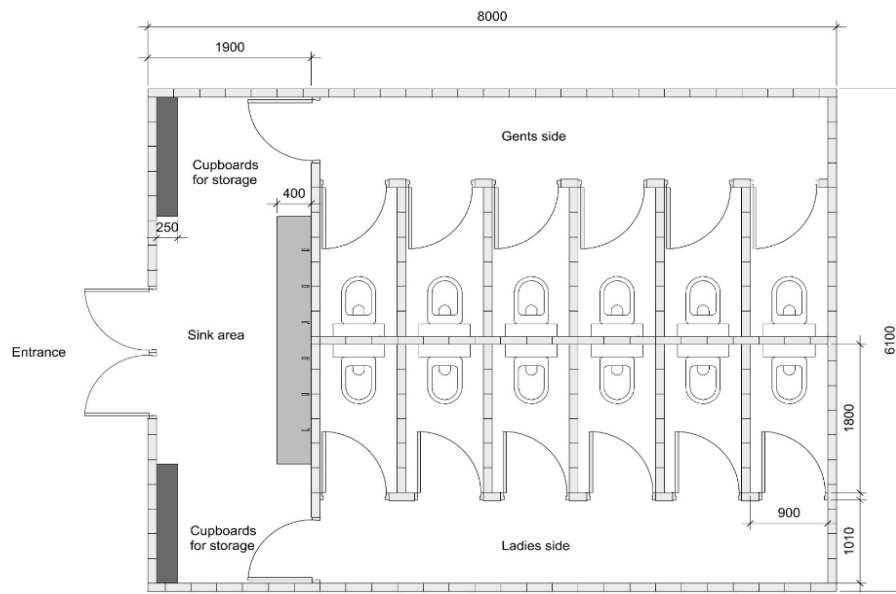


Figure 6. Standard washroom design – Floor plan (Weij, Pasveer, & Tebrunsvelt, 2026)

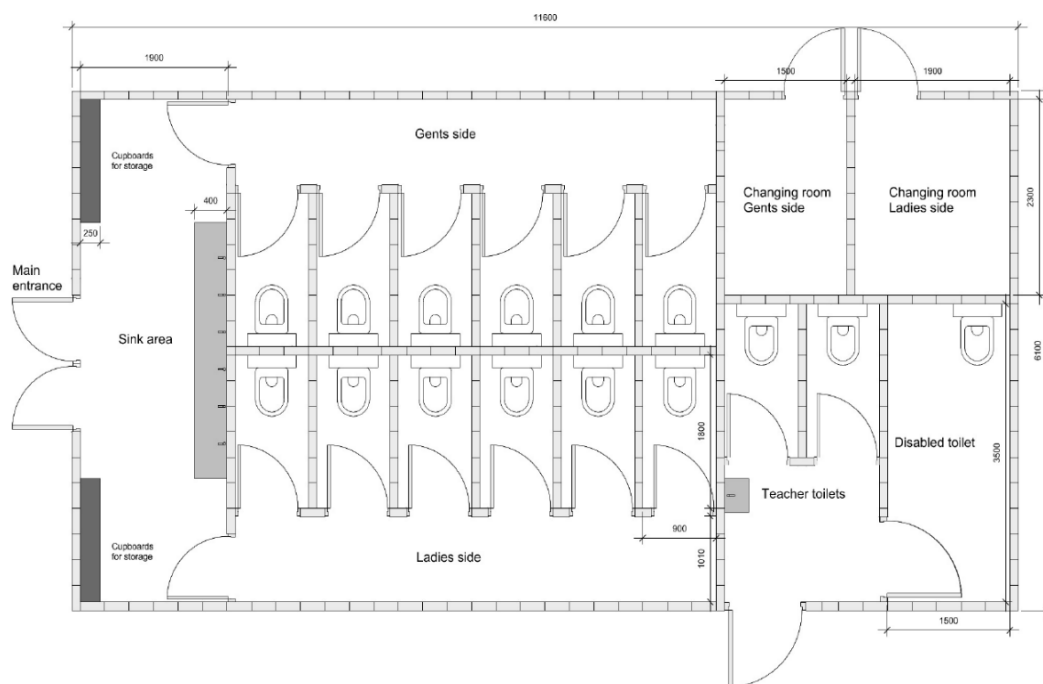


Figure 7. Extended washroom design – Floor plan (Weij, Pasveer, & Tebrunsvelt, 2026)

From a structural standpoint, the concept adopts a conservative stability strategy by enhancing outer-wall stability through vertical steel reinforcement bars, anchored to the foundation reinforcement mat using binding wire ties, as illustrated in Figure 8. Following excavation and placement of the ring-beam footprint, the unexcavated soil is compacted to a depth of approximately 50 mm, after which a water-resistant membrane is installed over the compacted surface, with particular attention to sealing around branch pipes to prevent moisture ingress from the underlying soil. A 50 mm layer of lean concrete is then cast on top of the membrane and allowed to harden, forming a practical working base for subsequent wall construction.

Wall assembly proceeds by laying the first brick course in accordance with the floor plan, using units at the prescribed locations so that they align and slide over the vertical rebars. The same placement logic is repeated for subsequent brick layers, considering that wooden door frames are positioned in the designated openings to support the masonry above door openings and to facilitate later door installation.

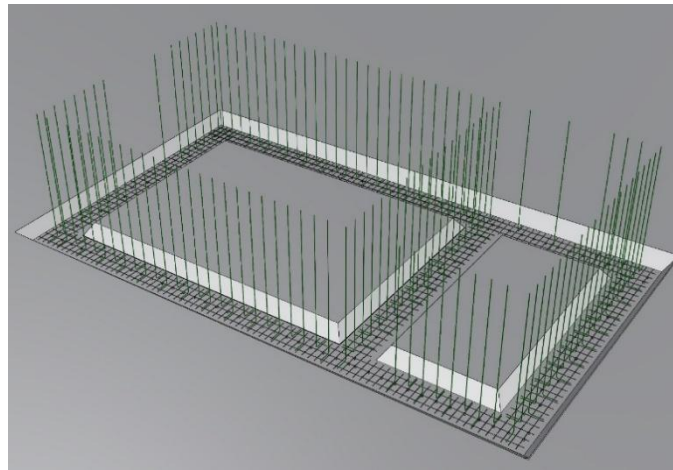


Figure 8. Extended washroom design – Excavation and rebars placement (Weij et al., 2026)

At the top of the walls, a ring-beam system is installed to improve continuity and global integrity and to provide a robust connection with the roof. Timber beams are lifted into position and lowered so that the rebars pass through pre-drilled holes, and the procedure is repeated for all four beams, as shown in Figure 9. The beams are then connected to each other using wood brackets and screws, employing straight brackets for the exterior beam connections and L-shaped brackets for the interior corners, to ensure a stable closed frame.

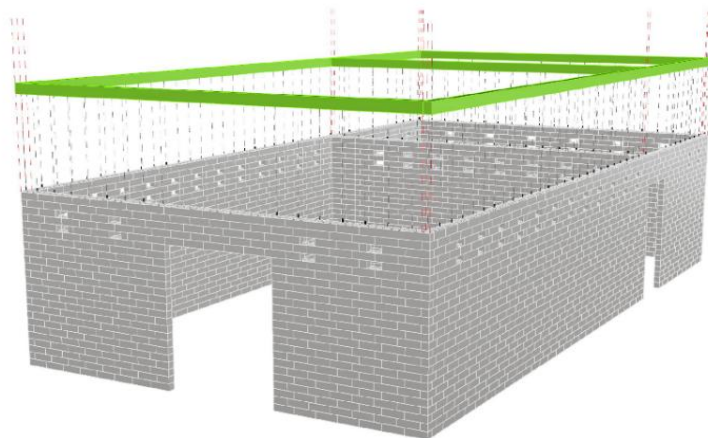


Figure 9. Extended Washroom Design - Ring beam placement (Weij et al., 2026)

Roof construction follows a modular sequence in which purlins and the specified vertical blocks are placed according to the floor plan and to provide an approximately 2% upward slope along the designated roof direction to promote drainage. Where daylight provision remains insufficient, an additional low-cost “light in a bottle” daylighting solution is indicated, consisting of a transparent plastic bottle filled with water and a small amount of bleach installed through the roof to refract and distribute sunlight within the interior.

The washroom layout is also designed to facilitate an efficient connection to the sewage system. Upon completion of the main building components, the plumbing is finalized by identifying the vertical branch pipes protruding through the walls and foundation and aligning toilet and sink locations with the floor plan, ensuring watertight joints to maintain hygiene and durability.

ONGOING RESEARCH

In the current project phase, the project has progressed beyond conceptual design and documentation, while key verification tasks are still underway. To address the need for technical substantiation and implementation feasibility, the ongoing engineering and economic workstreams are summarized below, highlighting the parallel development of material characterization, structural verification, and cost-estimation tools that will inform the pilot phase.

Engineering framework

Ongoing engineering work is currently strengthening the technical basis of the solution through coordinated student-led research at the University of Twente. One workstream focuses on the plastic-sand processing route, while achieving a homogeneous mixture is treated as a critical requirement because local sand pockets may act as weak zones in brick and wall performance.

A second workstream is developing a wall-scale finite element model of the interlocking brick assembly to evaluate wall integrity under code-defined load cases and to derive minimum required material properties needed for safe application. The modelling process includes numerous simulations and parametric evaluation of wall patterns and interlock configurations. These modelling activities are complemented by an ongoing laboratory experimental campaign on bricks with different plastic types, like PP and HDPE, and varying sand content, with the objective of quantifying material property ranges and providing validated input parameters for the structural verification models.

Economic framework

A preliminary cost-estimation framework has been established to support pilot planning and future scale-up decisions. The current calculation structure decomposes unit brick cost into (i) labour inputs (time required per brick and labour rate), (ii) material inputs (plastic mass per brick and sand mass per brick, together with unit costs), (iii) tooling and equipment depreciation (mould replacement interval and mould cost as well as extruder investment and service life allocated over production days and daily throughput), and (iv) energy consumption (electricity price, extruder power demand, and operating time per unit).

In this paper, these parameters are presented as the initial basis of the economic evaluation. However, final cost values are not reported at this stage, as they depend on ongoing research outcomes (verified mix compositions, production details and energy demand) and will be finalized using local quotations and measured production rates during the pilot implementation phase.

CONCLUSIONS

This paper presents an implementation-oriented humanitarian engineering case study in which recycled-plastic brick development is integrated with school washroom design for pilot deployment in Ghana. At the current project stage, the principal outcomes are not final structural test results but a coherent set of technical and operational deliverables that support field implementation, including a candidate brick concept, standardized washroom layouts, and a detailed construction handbook enabling handover to local builders. The compiled evidence indicates that progress in circular construction initiatives depends on coordinated advancement across material development, geometry and interlock design, construction detailing, and stakeholder engagement, with implementation readiness requiring that these streams mature in parallel rather than sequentially.

The available studies and project documentation indicate that recycled-plastic-brick washrooms are a promising approach for low-rise school sanitation infrastructure, provided that the structural and durability performance of the selected brick system is verified and that construction practices are validated on site. Accordingly, the ongoing laboratory experimental campaign (covering different plastic types and varying sand content) and the development of wall-scale numerical verification models constitute the key next steps toward defining acceptable material-property ranges and confirming structural integrity under representative load cases. In parallel, the established cost-estimation framework supports future decision-making by identifying the dominant cost drivers (materials, labour, energy, and equipment/tooling depreciation) that will govern scalability. The forthcoming pilot construction in Ghana will provide the critical practical evidence needed to refine design assumptions and to assess constructability, durability, and replication potential for broader application.

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