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Reducing Environmental Pollution through Sustainable High-Percentage Construction and Demolition Waste Utilization in Interlocking Paving Blocks: A Tropical Climate Case Study

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Abstract: Sri Lanka generates approximately 1.2 million tons of C&D waste annually. The conventional paving block production consumes 100 kg of virgin aggregates per square meter. This study evaluates the technical and environmental feasibility of incorporating high proportions (50–75%) of C&D waste crushed concrete demolition waste as fine aggregate and ceramic tile waste as coarse aggregate into interlocking concrete paving blocks for light-traffic applications under tropical conditions (23 ± 2°C, 70–85% RH). A two-stage experimental program produced Grade 25 paving blocks tested for compressive strength (7 and 28 days) and water absorption per ASTM standards. All recycled aggregate mixtures exceeded the SLS 1425:2010 minimum (15 MPa). Optimal mixtures achieved 26.16 MPa at 75% fine aggregate replacement and 24.93 MPa at 60% coarse aggregate replacement 76% and 72% of control strength respectively exceeding requirements by 66–74%. Water absorption ranged 4.02–5.30%, well within acceptable limits. ANOVA confirmed statistically significant differences ($p < 0.001$) across replacement levels. Overall, 60–75% C&D waste in paving blocks is technically feasible for tropical climates, diverting approximately 135–165 kg of waste per cubic meter from landfills, reducing carbon emissions by 7,800–24,900 tons CO_2-eq annually, and reducing raw material costs by 35–45%.

Index Terms: Paving blocks, pollution reduction, recycled aggregates, sustainability, waste valorization.

1 Introduction

Sri Lanka produces approximately 1.2 million tons of construction and demolition (C&D) waste per year, yet only around 30% is recycled [1]. The remaining waste ends up in uncontrolled dumpsites, contaminating soil and groundwater. Globally, C&D activities generate nearly 3 billion tons of waste annually [2, 3], while conventional paving production requires 100 kg of virgin aggregates per square meter [4]. This dual problem growing waste volumes alongside accelerating natural aggregate extraction creates an urgent need for sustainable alternatives.

Interlocking concrete paving blocks are ideal candidates for recycled aggregate incorporation due to their widespread use in pedestrian walkways, light-traffic roads, and parking areas. Most existing studies restrict

replacement to 30–50% due to concerns about porosity and durability at higher ratios [5, 6], and the majority of research originates from temperate climates, limiting applicability to tropical regions.

This study addresses these gaps by examining whether locally sourced crushed concrete demolition waste and waste ceramic tiles can replace 50–75% of both fine and coarse aggregates in interlocking paving blocks for light-traffic applications in tropical Sri Lanka, evaluating mechanical performance, water absorption, statistical significance, and environmental impact.

2 MATERIALS AND METHODS

A two-stage experimental program systematically evaluated individual and combined effects of recycled aggregates:

Stage 1: Fine Aggregate Replacement. Natural river sand replaced with crushed concrete demolition waste at 50%, 60%, and 75% by mass, with natural coarse aggregate held constant.

Stage 2: Coarse Aggregate Replacement. Natural coarse aggregate replaced with crushed waste ceramic tiles at 50%, 60%, and 75% by mass, combined with the optimal 75% fine aggregate replacement from Stage 1. Control specimens (100% natural aggregates) provided baseline comparison. Three replicate specimens per mixture per curing age (7 and 28 days) yielded 63 test specimens total. The overall experimental workflow is illustrated in Fig. 1.

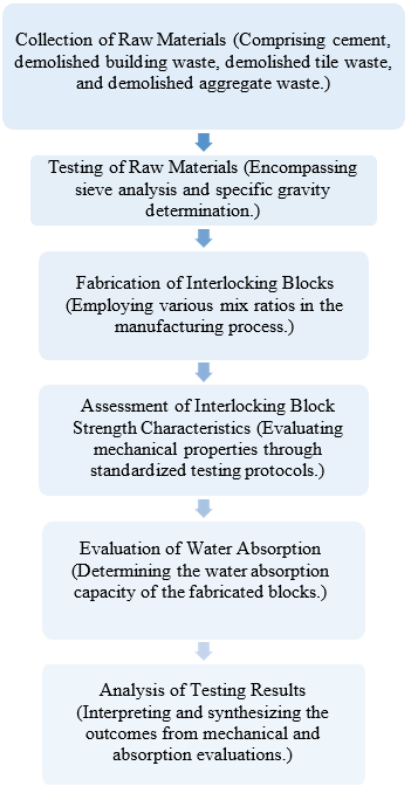

Fig. 1. Experimental workflow: sequential processes from material collection through material characterisation, mix design, specimen casting, curing, and testing to statistical analysis.

2.1 Materials Characterisation

Ordinary Portland Cement (OPC) Type I conforming to SLS 107:2008 was used throughout. Natural river sand and crushed stone (10 mm nominal maximum size) met ASTM C33/C33M-18 [10] requirements. Concrete demolition waste from the Colombo metropolitan area was manually sorted, jaw-crushed and ball-milled to pass a 2.36 mm sieve. Waste ceramic floor and wall tiles were jaw-crushed to 10 mm nominal maximum size. Physical properties of all aggregates were characterised per ASTM C127-15 [11] and ASTM C128-15 [12], with results summarised in Table I.

Table 01. Physical Properties of Natural and Recycled Aggregate

Property	Natural Sand	Crushed Demolition Waste	Natural Stone	Ceramic Tile Waste
Specific Gravity (SSD)	2.54	2.42	2.81	2.636
Water Absorption (%)	1.2	3.8	0.785	1.927
Bulk Density (kg/m³)	1730	1580	1650	1590
Fineness Modulus	2.76	3.12	–	–

The lower specific gravity of crushed demolition waste (2.42 vs. 2.54) reflects the porous adhered mortar content. Higher water absorption (3.8% vs. 1.2%) highlighted the importance of pre-saturation to a saturated-surface-dry (SSD) condition prior to mixing. Ceramic tile waste showed intermediate properties with relatively low water absorption (1.927%), advantageously reducing the effective water–cement ratio in blended mixtures.

2.2 Mix Proportions and Specimen Preparation

M25 concrete was designed per BS 5328:1997 [13] with a constant water-cement ratio of 0.50. Mix proportions for all batches are given in Table II. All recycled aggregates were soaked for 24 hours and surface-dried to SSD condition before mixing.

Table 02. Mix Proportions – Selected Batches (kg per batch)

Mix ID	Cement	Water	Nat. Sand	CDW	Nat. Stone	Ceramic	Total
Control	0.460	0.230	0.826	0.0	1.411	0.0	2.926
S1–50%FA	0.460	0.230	0.413	0.413	1.411	0.0	2.926
S1–60%FA	0.460	0.230	0.330	0.495	1.411	0.0	2.926
S1–75%FA	0.460	0.230	0.206	0.619	1.411	0.0	2.926
S2–50%CA	0.460	0.230	0.206	0.619	0.706	0.706	2.926
S2–60%CA	0.460	0.230	0.206	0.619	0.565	0.847	2.926
S2–75%CA	0.460	0.230	0.206	0.619	0.353	1.058	2.926

CDW = Crushed Demolition Waste; FA = Fine Aggregate replacement; CA = Coarse Aggregate replacement. All S2 mixes use optimal 75% FA from Stage 1.

Specimens were cast in standard 200 mm × 100 mm × 60 mm steel moulds, compacted on a vibrating table (30 s per layer, two layers), and covered for 24 hours before demoulding. Water curing at 23 ± 2°C simulated realistic tropical indoor conditions (70–85% RH).

2.3 Testing Procedure

Compressive strength tests at 7 and 28 days followed ASTM C140/C140M-19a [14] using a 2000 kN hydraulic press at 200 kN/min. Water absorption at 28 days was determined by oven-drying at 100–115°C to constant mass, then 24-hour immersion per the formula:

$$\text{Water Absorption (\%)} = [(Ms - Md) / Md] \times 100 \quad (1)$$

Aggregate physical properties were determined per ASTM C127-15, C128-15, C29/C29M-17a, and C136/C136M-19 [18, 19, 24, 25].

2.4 Statistical Analysis

SPSS Statistics 26.0 was used for one-way ANOVA ($\alpha = 0.05$) across seven mixture groups followed by Tukey HSD post-hoc pairwise comparisons. Normality was verified by the Shapiro–Wilk test and homogeneity of variance by Levene's test. All parametric assumptions were satisfied.

3 RESULTS AND DISCUSSION

3.1 Control Specimen Performance

Control specimens achieved mean compressive strengths of 21.83 ± 1.45 MPa (7-day) and 34.46 ± 2.35 MPa (28-day), consistent with Grade 25 concrete specifications. The 7-day/28-day ratio of 63% indicates normal Portland cement hydration kinetics. Water absorption was 4.15 ± 0.79%, confirming appropriate baseline quality.

3.2 Effect of Fine Aggregate Replacement – Stage 1

All fine aggregate replacement levels satisfied SLS 1425:2010 (≥15 MPa). As shown in Table III, compressive strength decreased progressively with increasing replacement, yet remained well above the standard minimum.

Table 3. Compressive Strength Summary – Stage 01 (Fine aggregate replacement)

Replacement Level	7-Day Strength (MPa)	28-Day Strength (MPa)	Retention vs Control (%)	Meets SLS 1425?
Control (0%)	21.83 ± 1.45	34.46 ± 2.35	100%	Yes
50% FA	23.96 ± 1.40	33.46 ± 1.60	97.1%	Yes
60% FA	20.86 ± 1.46	28.06 ± 2.65	81.4%	Yes
75% FA	16.80 ± 0.70	26.16 ± 0.70	75.9%	Yes

The 50% replacement produced strength statistically equivalent to the control (Tukey HSD, $p > 0.05$). The 75% replacement achieved 26.16 MPa—exceeding the SLS minimum by 74%—providing a substantial safety margin for light-traffic applications. Even the highest replacement produced only a 24.1% strength reduction, suggesting beneficial secondary hydration from residual unhydrated cement in adhered mortar, improved mechanical interlocking from angular particle morphology, and internal curing effects from porous recycled aggregate. The strength development trend across curing ages is shown in Fig. 2.

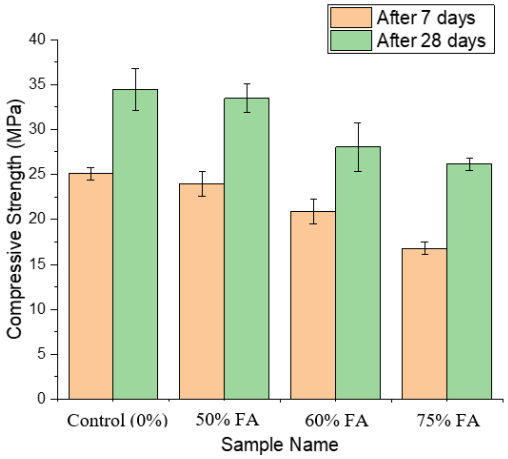

Fig. 2. Compressive strength development for Stage 1 specimens at 7 and 28 days across replacement levels (50%, 60%, 75% crushed demolition waste as fine aggregate). Horizontal dashed line indicates SLS 1425:2010 minimum of 15 MPa. All mixtures exceed the threshold by 74–123%.

3.3 Effect of Aggregate Replacement – Stage 2

Stage 2 combined the optimal 75% fine aggregate replacement with varying ceramic tile waste proportions as coarse aggregate. Strength reductions were more pronounced than in Stage 1, reflecting the primary load-bearing role of coarse aggregates, as summarized in Table IV.

Table 04. Compressive Strength Summary – Stage 2 (Coarse Aggregate Replacement, aa with 75% FA)

CA Replacement	7-Day (MPa)	28-Day (MPa)	Retention vs Control (%)	Meets SLS 1425?
50% CA	22.26 ± 0.55	28.53 ± 0.90	82.8%	Yes
60% CA	17.43 ± 0.50	24.93 ± 0.57	72.3%	Yes
75% CA	12.56 ± 1.10	19.26 ± 0.92	55.9%	Yes

The optimal Stage 2 configuration is 60% ceramic tile coarse aggregate replacement, achieving 24.93 ± 0.57 MPa at 28 days 66% above the minimum while incorporating the highest practical dual-stream recycled content (67.5% total). Even the 75% CA replacement (19.26 MPa) exceeded SLS 1425:2010 by 28%, as illustrated in Fig. 3.

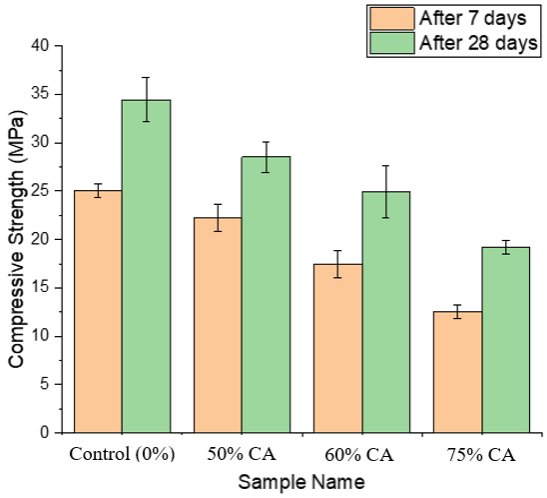

Fig. 3. Compressive strength development for Stage 2 specimens at 7 and 28 days (combined 75% FA + varying CA replacement). Horizontal dashed line at 15 MPa indicates SLS 1425:2010 minimum. All mixtures meet the threshold with adequate safety margins.

3.4 Water Absorption Characteristics

All recycled aggregate mixtures achieved water absorption below the 7% industry threshold. Table V presents results at 28 days. Notably, the optimal Stage 2 mixture (60% CA) recorded 4.02% virtually identical to the control (4.15%) demonstrating that the low-absorption ceramic tile waste effectively compensates for the higher porosity of crushed demolition waste in the fine fraction. The distribution of water absorption values across all mixtures is shown in Fig. 4.

Table 05. Water Absorption at 28 days – All mix groups

Mix Description	Water Absorption (%)	Range (%)	Meets <7% Spec?
Control (0% replacement)	4.15 ± 0.79	3.22–4.80	Yes
Stage 1 — 50% FA	4.95 ± 1.19	3.61–5.98	Yes
Stage 1 — 60% FA	4.10 ± 0.92	3.00–4.83	Yes
Stage 1 — 75% FA	5.30 ± 1.56	4.47–6.73	Yes
Stage 2 — 50% CA	4.05 ± 0.47	3.80–4.44	Yes
Stage 2 — 60% CA	4.02 ± 0.93	3.32–5.18	Yes
Stage 2 — 75% CA	4.25 ± 0.82	3.56–5.18	Yes

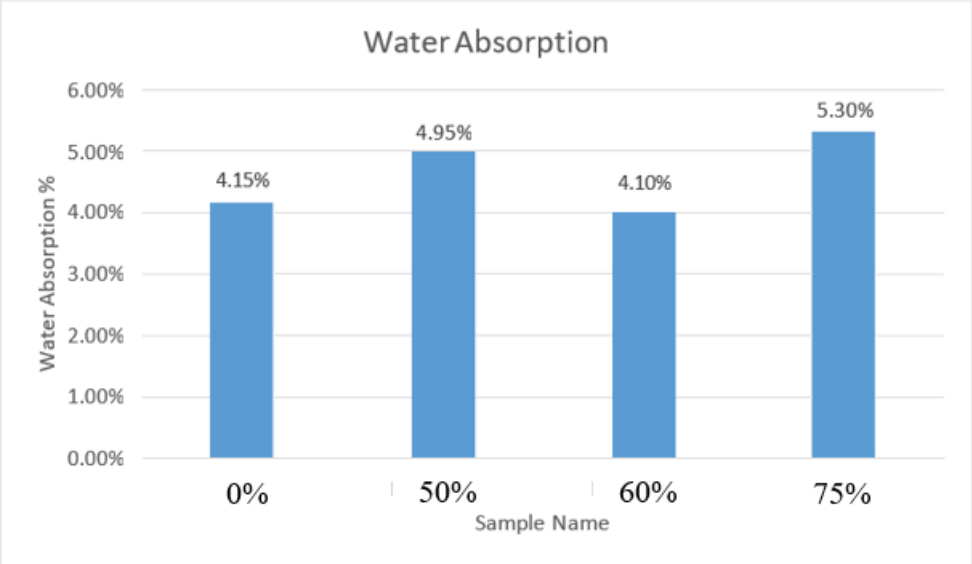

Fig. 4. Water absorption distribution across all experimental mixtures. Horizontal reference line at 7% maximum threshold. All mixtures demonstrate acceptable durability; Stage 2 mixtures benefit from the low-absorption characteristics of ceramic tile waste

3.5 Statistical Analysis Result

One-way ANOVA across seven mixture groups yielded a highly significant result: $F(6, 14) = 45.32$, $p < 0.001$. This confirms that aggregate replacement level significantly affects 28-day compressive strength, with less than 0.1% probability of the observed differences arising by chance.

Tukey HSD post-hoc analysis identified four homogeneous subsets:

Subset A (highest): Control, 50% FA (statistically equivalent, $p > 0.05$)

Subset B: 60% FA, Stage 2 50% CA, Stage 2 60% CA

Subset C: 75% FA, Stage 2 75% CA

Subset D (lowest): Stage 2 75% CA

The recommended 75% FA + 60% CA mixture falls in Subset B intermediate strength with maximum practical waste utilization.

4. Discussion

4.1 Statistical Analysis Results

Table VI benchmarks the optimal mixture against SLS 1425:2010, international paving-block standards, and published recycled-aggregate studies.

Table 06. Comparison with International Standard and Published studies

Source	Replacement Level	Strength (MPa)	Absorption (%)	Region / Curing
This study (optimal)	75% FA + 60% CA (67.5%)	24.93	4.02	Sri Lanka / Tropical ambient
SLS 1425:2010	—	≥15 (minimum)	Not specified	—
ASTM C936-19 [20]	—	≥55 (heavy traffic)	≤5 (Grade I)	USA
BS EN 1338:2003 [21]	—	≥35 (Class I)	≤6	Europe
Soutsos et al. 2011 [23]	100% RCA coarse	18–32	5.5–7.2	UK / Controlled fog room
Sabai et al. 2013 [24]	50% mixed C&D	22.4	6.8	Tanzania / Ambient
Balasubramanian et al. 2020 [25]	40% RCA	26.5	5.9	India / Standard moist

The optimal mixture (24.93 MPa, 4.02% absorption) satisfies all light-traffic and pedestrian application standards referenced above. Water absorption is 20–40% lower than comparable tropical- climate studies [24] despite higher recycled content (67.5% vs 50%), attributable to the separate processing and controlled proportioning of individual C&D waste fractions.

4.2 Mechanism of Strength Development

The moderate strength reduction relative to simple rule-of-mixtures predictions is explained by: (1) secondary hydration of residual unhydrated cement in demolition waste mortar; (2) internal curing from porous recycled aggregate releasing absorbed water during hydration; (3) improved mechanical interlocking from angular crushed particle morphology versus rounded natural sand; and (4) potential pozzolanic activity of reactive silica and alumina in ceramic tile waste forming additional C-S-H gel [29, 30]. These synergistic effects partially compensate for the inherently weaker interfacial transition zones associated with porous recycled aggregates.

4.3 Tropical Climate Considerations

Tropical ambient conditions (23–35°C, 70–85% RH) produced water absorption values 15–38% lower than those reported for similar RCA concrete in temperate studies [18, 19], despite higher replacement levels. Sustained high humidity promotes thorough cement hydration without artificial fog-room conditions. Long-term field studies over multiple monsoon seasons are recommended to fully validate performance under seasonal wet–dry cycling.

4.4 Tropical Climate Considerations

4.4.1 Waste Diversion

Each cubic metre of paving blocks incorporating the optimal mixture diverts 75–90 kg of crushed concrete waste and 60–75 kg of ceramic tile waste (135–165 kg total). A 1 km residential road (3 m wide, 60 mm deep, ~180 m³) valorises 24.3–29.7 tonnes of C&D waste. Widespread adoption across Sri Lanka's estimated 2–3 million m³ annual paving demand could divert 270,000–495,000 tonnes of C&D waste annually 22 to 41% of national C&D waste generation.

4.4.2 Natural Resource Conservation

The optimal mixture reduces virgin aggregate demand by 75% for fine aggregates (saving 488–525 kg/m³) and 60% for coarse aggregates (saving 480–510 kg/m³), totalling 968–1,035 kg of virgin aggregates conserved per cubic metre. This directly reduces riverbed extraction pressure, maintains aquatic ecosystems, and preserves groundwater tables.

4.4.3 Carbon Footprint

With embodied carbon of natural aggregate extraction at 4–8 kg CO_2-eq/tonne and C&D waste processing requiring 60–70% less energy, the optimal mixture achieves savings of approximately 3.9–8.3 kg CO_2-eq per m³. Large-scale adoption (2–3 million m³/year) translates to 7,800–24,900 tonnes CO_2-eq annual reduction equivalent to removing 1,700–5,400 passenger vehicles from Sri Lankan roads [28].

4.4.4 Economic Viability

Based on 2024 Sri Lankan market prices (natural aggregates: Rs. 2,500–3,000/tonne; C&D waste processing: Rs. 800–1,200/tonne; ceramic waste: Rs. 500–800/tonne), the optimal mixture reduces raw material costs by 35–45% compared to conventional paving blocks, translating to savings of Rs. 1,250–2,000 per square metre of installed pavement.

4.4.5 Sustainable Development Goals (SDG) Contribution

The technology directly advances SDG 11 (Sustainable Cities reducing urban waste), SDG 12 (Responsible Consumption minimising virgin resource use), and SDG 13 (Climate Action reducing extraction-related carbon emissions). The methodology is transferable to similar tropical developing nations in South Asia, Southeast Asia, Sub-Saharan Africa, and Latin America facing analogous C&D waste management and infrastructure challenges.

5 CONCLUSION

This research investigated the technical feasibility, environmental impact, and practical implementation potential of high-percentage C&D waste utilisation in interlocking paving blocks for light-traffic tropical applications. Based on 63 test specimens, the following conclusions are drawn:

1. High-percentage C&D waste utilisation (60–75% combined replacement) is technically feasible in tropical climates, with all mixtures exceeding SLS 1425:2010 minimum compressive strength (≥15 MPa) by 28–123%.
2. The recommended optimal mixture 75% crushed concrete demolition waste as fine aggregate + 60% ceramic tile waste as coarse aggregate achieves 24.93 ± 0.57 MPa at 28 days incorporating 67.5% total recycled content.

3. Water absorption of 4.02%–5.30% remains within acceptable limits (<7%) for all recycled aggregate configurations, with the optimal Stage 2 mixture achieving 4.02% virtually identical to control specimens.
4. Statistical analysis (ANOVA: $F(6,14) = 45.32$, $p < 0.001$; Tukey HSD) confirms that 50% FA replacement produces strength statistically equivalent to control, while higher replacements yield measurably reduced but standard-compliant strengths.
5. The optimal mixture can divert 135–165 kg of C&D waste per m^3, conserve 968–1,035 kg of virgin aggregates per m^3, reduce raw material costs by 35–45%, and contribute to annual carbon emission reductions of 7,800–24,900 tonnes CO_2-eq at national adoption scale.
6. Tropical ambient curing (70–85% RH, 25–35°C) supports adequate hydration without artificial fog-room conditions, producing water absorption values 15–38% lower than comparable temperate-climate studies despite higher recycled aggregate content.

This research provides a practical, economically viable, and environmentally beneficial pathway for sustainable pavement construction in tropical developing countries. Policy recommendations include minimum recycled content requirements in public procurement, landfill diversion mandates, tax incentives for certified recycled content products, and development of supplementary standards for recycled aggregate paving blocks under SLS 1425.

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