https://doi.org/10.65646/3cp3es20dpa6a082

Circular Economy Potential of Construction and Agricultural Waste Streams in Sri Lanka: A PRISMA-Based Systematic Review of Recycled Aggregate Concrete and Coconut-Shell Biochar

A.K.P. Arandara
Department of Civil Engineering
Open University of Sri Lanka
Nawala, Sri Lanka
akara@ou.ac.lk

***Abstract*: The transition from a linear to a circular economy is essential for addressing resource depletion, construction and demolition (C&D) waste generation, and agricultural biomass disposal in the construction industry. Sri Lanka faces growing challenges associated with rapid infrastructure development and the underutilization of waste resources, particularly recycled concrete waste and coconut shell residues. Although recycled aggregate concrete (RAC) and agricultural waste-derived biochar have been widely investigated as sustainable construction materials, their integrated application within a circular economy framework remains limited.**

The review specifically focuses on two selected waste-resource pathways: the recovery of C&D concrete waste as recycled aggregate for concrete production and the valorisation of coconut-shell waste as biochar for incorporation into recycled aggregate concrete. This study presents a PRISMA-based systematic literature review evaluating the circular economy potential of construction and agricultural waste through the utilization of recycled aggregate concrete and coconut shell biochar (CSB). Peer-reviewed journal articles and conference papers published between 2011 and 2026 were identified from major scientific databases and synthesized using thematic analysis following PRISMA screening and eligibility assessment.

The review indicates that recycled aggregates reduce dependence on virgin construction materials while supporting effective C&D waste management. Coconut shell biochar enhances the mechanical properties, durability, microstructural performance, and alkali–silica reaction resistance of recycled aggregate concrete. The review also highlights Sri Lanka's Construction and Concrete Waste Recycling Centre as a significant step towards circular construction.

Based on the synthesized evidence, this study proposes a Construction–Agriculture Circular Resource Loop Framework that integrates construction and agricultural waste into a unified circular economy model for sustainable infrastructure development in Sri Lanka. The framework provides practical guidance for policymakers, researchers, and industry to advance resource circularity through integrated waste valorisation strategies.

Keywords: Circular Economy; Construction and Demolition Waste; Recycled Aggregate Concrete; Coconut Shell Biochar; Sustainable Concrete; Waste Valorisation; PRISMA; Sri Lanka.

I. INTRODUCTION

The construction industry is among the largest consumers of natural resources and one of the principal generators of construction and demolition (C&D) waste worldwide. Rapid urbanisation, infrastructure expansion and building renewal have substantially increased the demand for virgin construction materials while generating enormous quantities of waste that are frequently disposed of in landfills. These practices accelerate natural resource depletion, increase greenhouse gas emissions and impose considerable environmental and economic burdens, highlighting the necessity for more sustainable approaches to resource utilisation (Silva, de Brito and Dhir, 2014; Ghisellini, Cialani and Ulgiati, 2016; Benachio, Freitas and Tavares, 2020).

The circular economy (CE) has emerged as a sustainable alternative to the conventional linear economic model by promoting resource efficiency through reducing, reusing, recycling and recovering materials throughout their life cycle. Within the construction sector, circular economy principles encourage the recovery of C&D waste as secondary construction materials, reducing dependence on virgin aggregates while minimizing landfill disposal and environmental impacts (Ellen MacArthur Foundation, 2013; Adams et al., 2017; Papamichael, Vougioukas and Loizidou, 2023).

Agricultural waste represents another significant resource stream capable of contributing to circular economy implementation. In recent years, biochar produced from agricultural biomass has received increasing attention owing to its potential to improve the mechanical and durability performance of cementitious materials while simultaneously sequestering carbon and converting agricultural residues into value-added construction products (Gupta, Kua and Pang, 2018; Restuccia and Ferro, 2020; Tan et al., 2021). Among the various biomass

sources, coconut shell waste possesses considerable potential for tropical countries because of its abundance, renewability and suitability for biochar production.

Sri Lanka provides a unique opportunity to integrate construction and agricultural waste streams within a circular economy framework. The generation and management of construction and demolition (C&D) waste has become an important resource-management concern in Sri Lanka. Recent government data indicate that nearly 300 tonnes of C&D waste are collected daily from the Western Province alone (Government of Sri Lanka, 2026). The scale of this recoverable material stream has prompted increasing attention to recycling and secondary-material production as alternatives to uncontrolled disposal and consumption of virgin construction resources. Although both waste streams have significant recycling potential, their utilisation remain limited. A significant recent development is the establishment of the Construction and Concrete Waste Recycling Centre at the Ekala Industrial Zone under the Clean Sri Lanka Programme in May 2026. The facility has a reported processing capacity of 200 metric tonnes of C&D waste per hour and was established with machinery and land valued at approximately LKR 350 million. The Clean Sri Lanka Secretariat allocated LKR 200 million to the project (Government of Sri Lanka, 2026). This transition from largely unmanaged disposal towards dedicated recycling infrastructure provides an important institutional basis for recovering recycled concrete aggregate and other secondary construction materials in Sri Lanka.

Sri Lanka also possesses a substantial agricultural biomass resource associated with its coconut industry. According to official statistics, approximately 2.79 billion coconuts were produced in Sri Lanka in 2024, from a cultivated extent of approximately 484,677 ha (Department of Census and Statistics, 2025). Coconut Development Authority statistics similarly report total coconut production of approximately 2.79 billion nuts in 2024, of which about 1.38 billion nuts were utilized by industry (Coconut Development Authority, 2025). This scale of coconut production indicates a substantial potential biomass stream, including coconut shells, that may be considered for value-added applications such as biochar production rather than being treated solely as a residual material.

Taken together, the reported C&D waste quantities, emerging national recycling capacity, and scale of coconut production demonstrate the practical relevance of examining these two resource streams within a circular-economy framework. C&D concrete waste represents a potential source of recycled aggregate, while coconut-shell residues represent a locally available biomass feedstock with potential for conversion into biochar. Their integration therefore offers a context-specific pathway for simultaneously advancing construction-waste recovery, agricultural-residue valorisation, and reduced dependence on virgin construction materials in Sri Lanka.

Substantial research has independently investigated recycled aggregate concrete (RAC), agricultural waste-derived biochar and sustainable construction materials. Recycled aggregate concrete has demonstrated promising structural performance when appropriately processed and designed (Tam, Tam and Zeng, 2018; Xiao, 2018), whereas coconut shell biochar has shown the capacity to enhance microstructural characteristics, mechanical properties, durability and alkali–silica reaction resistance in recycled aggregate concrete (Arandara et al., 2024; Arandara et al., 2025). However, existing studies rarely integrate these two waste streams within a unified circular economy perspective, particularly in the context of Sri Lanka. Furthermore, no comprehensive synthesis has examined how construction waste recycling and agricultural biomass utilisation can jointly contribute to a national circular economy strategy for sustainable infrastructure development.

Accordingly, this study applies the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) methodology to systematically review literature published between 2011 and 2026 relating to sustainable concrete, recycled aggregate concrete, agricultural waste-based biochar, and the mechanical and durability performance of concrete. The review synthesizes international evidence together with emerging Sri Lankan initiatives to identify research trends, knowledge gaps and opportunities for integrating construction and agricultural waste streams. Finally, a conceptual Construction–Agriculture Circular Resource Loop Framework is proposed to support circular economy implementation and sustainable infrastructure development in Sri Lanka.

Although construction and agricultural sectors generate diverse waste streams, this review does not attempt to comprehensively assess all such wastes in Sri Lanka. Instead, it focuses on two selected and potentially complementary resource pathways: (i) C&D concrete waste recovered as recycled concrete aggregate for recycled aggregate concrete (RAC), and (ii) coconut-shell waste converted into coconut-shell biochar (CSB) for use in concrete, particularly RAC. These pathways were selected to examine the potential integration of construction and agricultural waste valorisation within a common circular-economy framework.

Aim

To evaluate the circular economy potential of construction and agricultural waste streams in Sri Lanka through a PRISMA-based systematic review of recycled aggregate concrete and coconut shell biochar applications.

Objectives

a) To systematically review literature published between 2011 and 2026 on recycled aggregate concrete and agricultural waste-based biochar for sustainable concrete applications.
b) To synthesize evidence regarding the mechanical, durability and sustainability performance of recycled aggregate concrete and biochar-modified concrete.
c) To evaluate opportunities for integrating the selected construction and agricultural waste pathways within Sri Lanka's circular economy.
d) To propose a conceptual Construction–Agriculture Circular Resource Loop Framework to support sustainable construction and resource circularity in Sri Lanka.

II. RESEARCH METHODOLOGY

This study employed the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to systematically identify, screen, evaluate, and synthesize published literature relevant to the circular economy potential of construction and agricultural waste streams in sustainable concrete applications. The PRISMA methodology provides a transparent and reproducible approach for conducting systematic literature reviews by minimizing selection bias and ensuring comprehensive identification of relevant studies (Page et al., 2021). The review focused on literature related to recycled aggregate concrete (RAC), agricultural waste-based biochar, sustainable concrete, and the mechanical and durability performance of concrete published between January 2011 and June 2026.

2.1 PRISMA Framework

The electronic database searches were conducted on 15th June 2026, with the final search updated on 18th July 2026. The searches covered literature published from January 2011 to June 2026.

This systematic review was conducted in accordance with the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA 2020) framework to systematically identify, screen, assess, and synthesize literature relevant to the circular-economy potential of selected construction and agricultural waste pathways in sustainable concrete applications. The review followed four sequential stages: identification, screening, eligibility assessment, and inclusion. Records retrieved from the selected databases were consolidated and checked prior to screening. Duplicate records and records identified as ineligible prior to screening were removed, after which titles and abstracts were screened against predefined eligibility criteria. Potentially relevant publications were subsequently subjected to full-text assessment. Studies satisfying the eligibility requirements were retained for qualitative synthesis. The complete study-selection process and reasons for exclusion are presented in Figure 1.

2.2 Literature Search Strategy

The systematic literature search was undertaken during the period from **15 June to 18 July 2026** using four scientific databases: **Scopus, Web of Science, ScienceDirect, and Google Scholar**. The search covered publications issued between January 2011 and June 2026 and focused on recycled aggregate concrete (RAC), construction and demolition (C&D) waste, agricultural waste-derived biochar, coconut-shell biochar (CSB), circular economy, and sustainable concrete.

Boolean operators (AND and OR) were used to combine related search terms. The principal search expression was:

("recycled aggregate concrete" OR "recycled concrete aggregate" OR "construction and demolition waste") AND ("biochar" OR "agricultural waste biochar" OR "coconut shell biochar") AND ("circular economy" OR "sustainable concrete" OR "sustainable construction").

The search syntax was adapted, where necessary, to the search functions and fields available within each database while retaining the same principal concepts. Searches were restricted to English-language publications within the specified review period. The database-specific search strategy, search dates, limits, and number of records retrieved are explained in below.

2.3 Inclusion and Exclusion Criteria

To ensure consistency and relevance, predefined inclusion and exclusion criteria were established prior to the screening process.

Inclusion criteria

- Peer-reviewed journal articles and international conference papers.
- Publications written in English.
- Studies published between January 2011 and June 2026.
- Studies addressing one or more of the following topics:
  - ✓ Circular economy in construction.
  - ✓ Construction and demolition waste recycling.
  - ✓ Recycled aggregate concrete.
  - ✓ Agricultural waste-derived biochar.
  - ✓ Coconut shell biochar.
  - ✓ Mechanical, durability, or sustainability performance of concrete

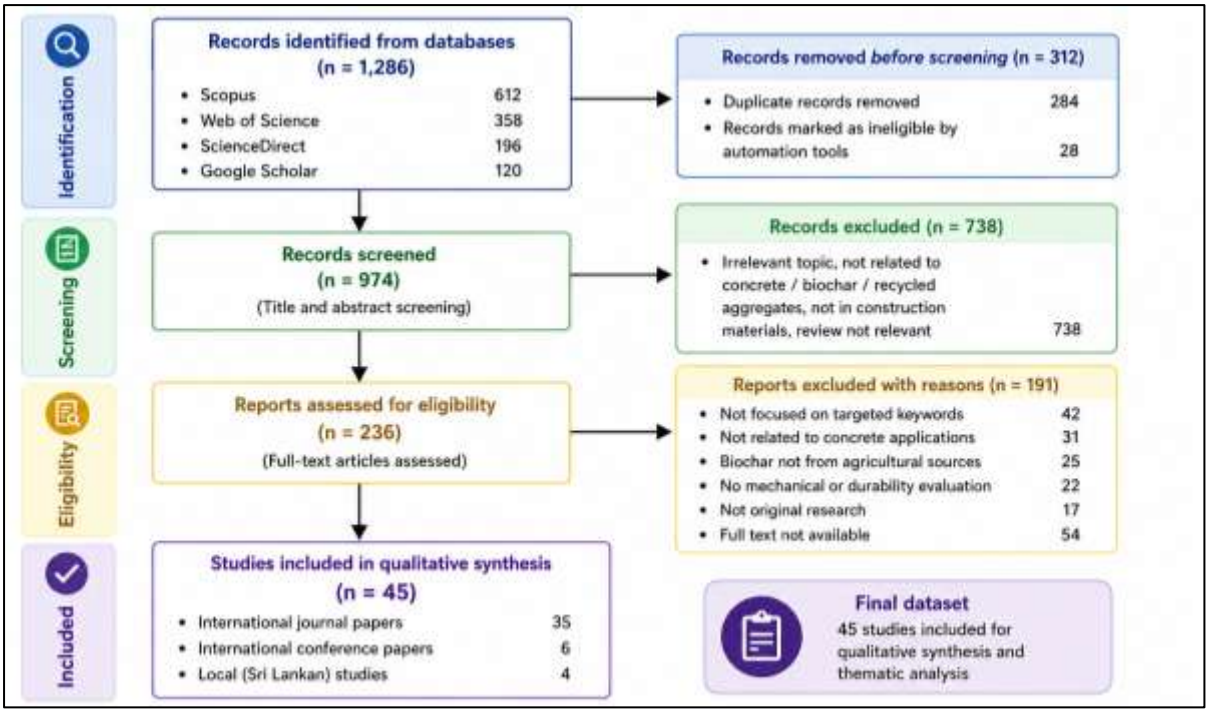


Figure 1. PRISMA 2020 flow diagram showing the identification, screening, eligibility, and inclusion of studies.

Studies providing experimental findings, systematic reviews, case studies, or policy-related discussions relevant to sustainable construction.

Exclusion criteria

- Publications published before 2011.
- Non-English publications.
- Editorials, book reviews, theses, patents, magazine articles, and unpublished reports.
- Studies unrelated to construction materials or sustainable concrete.
- Articles lacking sufficient technical information or full-text accessibility.
- Duplicate publications identified across multiple databases.

The predefined criteria were applied consistently during title and abstract screening and subsequent full-text eligibility assessment.;

2.4 Study Selection and Screening Process

The database searches identified **1,286 records**, comprising **612 from Scopus, 358 from Web of Science, 196 from ScienceDirect, and 120 from Google Scholar**. Before screening, **312 records were removed**, consisting of **284 duplicate records** and **28 records identified as ineligible prior to screening**. Consequently, **974 records** proceeded to title and abstract screening.

During title and abstract screening, **738 records** were excluded because they were irrelevant to the scope of the review, including studies not related to concrete, biochar, recycled aggregates, construction materials, or the review objectives. This resulted in **236 publications** being retained for full-text eligibility assessment.

The full texts of the 236 publications were evaluated against the predefined inclusion and exclusion criteria. At this stage, **191 publications were excluded**: 42 were not focused on the targeted keywords, 31 were not related to concrete applications, 25 considered biochar from sources outside the agricultural-waste scope, 22 did not evaluate mechanical or durability performance, 17 were not original research, and 54 had no accessible full text. Following the eligibility assessment, **45 studies** were retained for the final qualitative synthesis. The complete study-selection pathway is presented in Figure 1.

2.5 Study Quality Assessment

The methodological quality and relevance of studies retained following full-text screening were evaluated using predefined criteria appropriate to the nature of the reviewed literature. The assessment considered: **(i)** clarity of the research aim and objectives; **(ii)** adequacy of the description of materials, experimental procedures, or review methods; **(iii)** appropriateness of the research methodology; **(iv)** clarity and completeness of the reported results; **(v)** relevance to RAC, C&D waste recycling, agricultural waste-derived biochar, circular economy, or sustainable concrete; and **(vi)** adequacy of the evidence supporting the reported conclusions.

For experimental studies, particular attention was given to material characterization, mix or treatment conditions, testing procedures, and reporting of mechanical and durability outcomes. For review, case-study, and policy-oriented publications, emphasis was placed on transparency of the evidence base, relevance to the review objectives, and traceability of conclusions to the reported evidence. Studies lacking sufficient

methodological or technical information for meaningful synthesis were not retained in the final dataset.

2.6 Data Extraction and Thematic Synthesis

A structured data-extraction approach was applied to the **45 included studies**. Information extracted included author and year, study context, study type, construction or agricultural waste/material type, recycled aggregate characteristics and replacement level where reported, biochar source and incorporation level where applicable, mechanical and durability indicators, sustainability implications, and principal findings.

The extracted evidence was coded according to recurring concepts relevant to the review objectives and organized into five thematic categories: **(i) circular economy in construction; (ii) construction and demolition waste recycling; (iii) recycled aggregate concrete; (iv) agricultural waste-derived biochar; and (v) mechanical and durability performance of sustainable concrete.**

Evidence within and across these themes was compared to identify recurring findings, variations in reported performance, technological developments, research gaps, and potential relationships between construction-waste recycling and agricultural-waste valorisation. Particular attention was given to evidence concerning the engineering performance of RAC and biochar-modified concrete and their potential contribution to resource circularity. The resulting thematic synthesis provided the evidence base for developing the proposed **Construction–Agriculture Circular Resource Loop Framework** for the Sri Lankan context.

Table 1: Literature search databases and coverage

Database	Coverage
Scopus	Engineering, Materials
Web of Science	Multidisciplinary
ScienceDirect	Engineering & Environment
Google Scholar	Broad academic coverage

Table 2: Inclusion and exclusion criteria

Inclusion Criteria	Exclusion Criteria
Peer-reviewed journal articles	Non-peer-reviewed publications
International conference papers	Editorials, theses, patents
English language	Non-English publications
Published between 2011–2026	Published before 2011
Relevant to CE, RAC, biochar or sustainable concrete	Unrelated topics or inaccessible full text

III. LITERATURE REVIEW AND SYNTHEHSIS

3.1 Circular Economy in Construction

The circular economy (CE) has emerged as a transformative framework for achieving sustainable resource management by replacing the conventional linear model of material consumption with closed-loop systems based on reducing, reusing, recycling, and recovering resources. Within the construction sector, CE promotes the recovery of construction and demolition (C&D) waste, extending material life cycles while minimizing the extraction of virgin resources and reducing environmental impacts (Ellen MacArthur Foundation, 2013; Ghisellini, Cialani and Ulgiati, 2016).

Recent studies have demonstrated that the construction industry offers one of the greatest opportunities for circular economy implementation because of its substantial material consumption and waste generation. Adams et al. (2017) highlighted that circular construction requires collaboration among policymakers, designers, contractors, and material suppliers to facilitate resource recovery throughout the project life cycle. Similarly, Papamichael, Vougioukas and Loizidou (2023) emphasized that effective C&D waste management, material recycling, and policy support are fundamental enablers of circular construction practices.

Recent international initiatives have shifted the emphasis from simple waste management towards resource valorisation, whereby construction waste is regarded as a secondary raw material rather than a disposal burden. This transition supports reductions in landfill disposal, greenhouse gas emissions, and raw material consumption while promoting sustainable infrastructure development (Benachio, Freitas and Tavares, 2020; UNEP, 2024).

Key Synthesis: Circular economy principles provide a strong foundation for integrating construction and agricultural waste into sustainable construction. However, their combined application remains limited, particularly in Sri Lanka.

3.2 Construction and Demolition Waste and Recycled Aggregate Concrete

Construction and demolition waste represents one of the largest waste streams generated worldwide. Numerous studies have reported that concrete constitutes a major proportion of C&D waste, making recycled concrete aggregate (RCA) an important alternative to natural aggregates (Silva, de Brito and Dhir, 2014).

Research conducted over the past decade has demonstrated that recycled aggregates can successfully replace natural coarse aggregates in structural and non-structural concrete when appropriate processing, grading, and mix design procedures are adopted (Tam, Tam and Zeng, 2018; Xiao, 2018). Although recycled aggregates generally exhibit higher water absorption and lower density than natural aggregates due to adhered mortar, numerous studies have reported

satisfactory mechanical performance under optimized replacement ratios (Bravo, de Brito and Pontes, 2015; Li et al., 2017). Beyond its technical performance, RCA conserves natural resources by reducing the demand for virgin aggregates and diverting construction waste from landfills. These benefits make recycled aggregate concrete a key component of circular economy implementation in the construction industry. (Table 3).

Table 3: Summary of Key Findings from Selected Studies on Recycled Aggregate Concrete (RAC)

Author(s)	Research Focus	Principal Findings	Circular Economy Implications
Silva, de Brito and Dhir (2014)	Properties of recycled aggregates from C&D waste	Recycled aggregates possess higher water absorption and lower density due to adhered mortar but can produce structurally acceptable concrete with appropriate mix design.	Demonstrates the technical feasibility of converting C&D waste into valuable construction materials, reducing landfill disposal and virgin aggregate consumption.
Kou et al. (2012)	Mechanical properties of RAC	RAC produced with recycled coarse aggregates exhibited satisfactory compressive strength and structural performance under controlled replacement levels.	Supports resource conservation through replacement of natural aggregates with recycled materials.
Xiao (2018)	Structural applications of RAC	RAC can be successfully utilized in structural concrete when appropriate design procedures and quality-control measures are implemented.	Expands opportunities for high-value reuse of demolition waste within circular construction systems.
Tam, Tam and Zeng (2018)	Review of RAC applications	Proper aggregate processing, grading and pre-treatment significantly improve the engineering performance of recycled aggregate concrete.	Highlights recycling technologies as key enablers for circular-economy implementation in construction.
Bravo, de Brito and Pontes (2015)	Durability performance of RAC	Durability can be enhanced through optimized mix design and appropriate replacement ratios despite the porous nature of recycled aggregates.	Improves confidence in the long-term utilization of recycled materials for sustainable infrastructure.
Li et al. (2017)	Mechanical behaviour of RAC	Higher replacement ratios may reduce strength; however, optimized replacement levels provide satisfactory structural performance.	Encourages efficient utilization of construction waste while balancing engineering performance and sustainability.
Lim, Yoon and Moon (2018)	Influence of old mortar on RAC	Residual mortar significantly influences density, water absorption and durability characteristics of recycled aggregate concrete.	Identifies quality-improvement strategies for maximizing recycled aggregate utilization.
Poon and Chan (2019)	Sustainable concrete production using RAC	Recycled aggregates contribute to reducing carbon emissions, conserving natural resources and minimizing waste disposal.	Demonstrates the environmental and economic benefits of circular material utilization in concrete production.
Arandara et al. (2024)	Coconut-shell biochar in RAC	Coconut-shell biochar refined the microstructure of RAC and improved interfacial bonding between recycled aggregates and cement paste.	Demonstrates the synergistic integration of construction and agricultural waste streams within a circular-economy framework.
Arandara et al. (2025)	Biochar-modified RAC durability	Coconut-shell biochar enhanced mechanical performance and significantly mitigated alkali–silica reaction in recycled aggregate concrete.	Provides evidence that combining recycled aggregates with agricultural waste-derived biochar improves both durability and resource circularity.

Quantitative Synthesis of RAC Evidence: Among the studies summarized in Table 3, the reported performance of recycled aggregate concrete was strongly dependent on the proportion and quality of recycled aggregate, residual adhered mortar, aggregate processing, and mix-design conditions. The reviewed

evidence consistently indicates that increasing recycled aggregate replacement can adversely affect density, water absorption, strength, and durability when no compensating mix-design or material-treatment measures are adopted. Conversely, optimized replacement levels, aggregate pre-treatment, appropriate grading, and supplementary material modifications were reported to improve the engineering performance of RAC. Accordingly, the reviewed studies do not support a single universally optimum RCA replacement percentage; rather, the acceptable replacement level is dependent on aggregate quality, intended application, mix design, and required performance.

This is consistent with your existing RAC synthesis, which states that higher replacement ratios may reduce strength while optimized replacement levels can provide satisfactory structural performance.

Key **Synthesis:** The reviewed literature indicates that recycled aggregate concrete has developed from an alternative construction material into a technically viable circular-economy approach capable of contributing simultaneously to construction-waste management and natural-resource conservation.

3.3 Agricultural Waste-Based Biochar for Sustainable Concrete

Agricultural biomass residues are increasingly recognized as valuable feedstocks for producing biochar, a carbon-rich material obtained through the pyrolysis of organic waste under oxygen-limited conditions. Recent studies have shown that biochar enhances cementitious materials while promoting carbon sequestration and agricultural waste valorisation (Gupta, Kua and Pang, 2018; Restuccia and Ferro, 2020).

Among agricultural wastes, coconut shell has gained considerable attention because of its high lignin content, high carbon yield, and abundance in tropical countries. Coconut shell biochar (CSB) has shown significant potential as a sustainable concrete additive by refining pore structures, reducing permeability, and enhancing durability (Tan et al., 2021).

Furthermore, biochar supports circular economy implementation by converting agricultural waste into value-added construction materials, addressing waste disposal while improving the sustainability of concrete production.

Key Synthesis. Agricultural waste-derived biochar extends the circular economy beyond construction waste recycling by integrating agricultural residues into sustainable concrete production, thereby strengthening resource circularity across multiple sectors.

3.4 Mechanical and Durability Performance of RCA and Biochar-Modified Concrete

The mechanical and durability performance of recycled aggregate concrete remains a critical consideration for its widespread implementation. Earlier studies reported reductions in compressive strength and durability resulting from the porous nature of recycled aggregates and residual mortar (Silva, de Brito and Dhir, 2014; Tam, Tam and Zeng, 2018). However, more recent investigations have demonstrated that appropriate material modifications can significantly improve these limitations.

Biochar has emerged as one such modification strategy. Experimental studies have shown that biochar contributes to improved microstructural characteristics through pore refinement, enhanced hydration, and internal curing mechanisms (Gupta, Kua and Pang, 2018; Restuccia and Ferro, 2020). Recent studies by Arandara et al. (2024) demonstrated that coconut shell biochar improved the microstructure of recycled aggregate concrete, while Arandara et al. (2025) further reported enhanced resistance to alkali–silica reaction together with improvements in mechanical and durability performance (Table 4).

Collectively, these findings indicate that combining recycled aggregates with agricultural waste-derived biochar can overcome many traditional limitations associated with recycled aggregate concrete, thereby supporting high-performance sustainable concrete applications.

Overall, the quantitative performance results reported across the reviewed experimental studies were heterogeneous because of differences in recycled aggregate source and quality, replacement ratio, biochar source and dosage, pyrolysis conditions, mix proportions, curing conditions, and test methods. Therefore, the present review emphasizes reported performance ranges and directional trends where comparable data are available rather than pooling the results statistically. The evidence nevertheless shows a recurring trend whereby controlled incorporation of biochar can contribute to pore refinement and improved interfacial characteristics in RAC, with associated improvements in mechanical and durability performance. These findings should be interpreted as study-dependent rather than as evidence of a universal optimum RCA replacement or biochar dosage.

3.5 Trends, Knowledge Gaps, and Synthesis

The final qualitative synthesis comprised 45 studies, including 35 international journal papers (77.8%), six international conference papers (13.3%), and four local/Sri Lankan studies (8.9%). Thus, more than three-quarters of the reviewed evidence was represented by international journal publications, while locally focused Sri Lankan studies constituted less than one-tenth of the final evidence base. The reviewed literature covered the period from 2011 to June 2026 and demonstrated continuing research attention to circular economy, recycled aggregate concrete, agricultural waste-derived biochar, and sustainable concrete.

The comparatively limited Sri Lankan evidence base highlights the need for further local experimental, field-scale, environmental, and economic investigations into recycled aggregate concrete and agricultural waste-derived biochar. International studies provide an important technical evidence base; however, their

findings require contextual evaluation before direct application under Sri Lankan material availability, climatic conditions, construction practices, and regulatory requirements.

IV. DISCUSSION

4.1 Circular Economy Potential in Sri Lanka

The findings of this PRISMA-based systematic review indicate that Sri Lanka possesses considerable potential to implement circular economy principles within the construction sector through the simultaneous utilisation of construction and demolition (C&D) waste and agricultural biomass residues. The country experiences continuous growth in infrastructure development, generating substantial quantities of concrete waste that can be processed into recycled concrete aggregates (RCA).

Simultaneously, Sri Lanka is one of the world's major coconut-producing countries, generating significant volumes of coconut shell residues that can be converted into biochar for value-added construction applications. The reviewed literature demonstrates that recycled aggregate concrete provides a technically feasible .

Table 4: Summary of Key Findings from the Shortlisted Studies on Agricultural Waste-Based Biochar

No.	Author(s)	Biochar Source	Principal Findings	Concrete Performance Benefits
1	Gupta, Chaudhary and Sharma (2018)	Agricultural biomass biochar	Comprehensive review demonstrating that biochar enhances cement hydration, refines pore structure and improves the sustainability of cementitious materials.	Improved compressive strength, reduced permeability, enhanced durability and lower environmental footprint.
2	Gupta and Kua (2017)	Biomass-derived biochar	Biochar acts as an internal curing agent and contributes to carbon sequestration while improving cement-matrix properties.	Enhanced hydration, reduced shrinkage, improved long-term durability and sustainability.
3	Restuccia and Ferro (2020)	Agricultural-waste biochar	Biochar significantly improves the microstructure of cement composites by reducing pore connectivity and increasing matrix densification.	Increased compressive strength, improved durability and better resistance to aggressive environments.
4	Tan et al. (2021)	Agricultural biomass biochar	Biochar functions as a sustainable supplementary material capable of improving both mechanical and environmental performance of concrete.	Enhanced mechanical strength, reduced permeability and improved sustainability performance.
5	Su et al. (2022)	Agricultural biomass biochar	Review of recent developments indicating that biochar improves hydration products and pore refinement within cementitious composites.	Higher durability, lower water absorption and improved resistance to cracking and chloride penetration.
6	Thomas, Gupta and Panicker (2016)	Biomass biochar	Experimental investigation confirmed that biochar incorporation contributes to strength development and durability improvement in cement-based materials.	Improved compressive strength, reduced porosity and enhanced durability.
7	Li et al. (2019)	Agricultural biochar	Biochar particles enhanced the interfacial transition zone (ITZ) and promoted better bonding between cement paste and aggregates.	Improved flexural strength, higher compressive strength and improved crack resistance.
8	Zhang, Gao and Li (2023)	Various agricultural-waste biochars	Systematic review identified biochar dosage, particle size and pyrolysis temperature as key factors governing concrete performance.	Optimized biochar improves mechanical properties, durability and long-term service life.

9	Ramesh, Kalaivanan and Ling (2019)	Coconut-shell biochar	Coconut-shell-derived biochar demonstrated potential as a sustainable concrete additive owing to its high carbon content and porous structure.	Improved microstructure, reduced permeability and enhanced durability characteristics.
10	Arandara et al. (2024, 2025)	Coconut-shell biochar	Petrographic and experimental investigations indicated that coconut-shell biochar refines the microstructure of recycled aggregate concrete and significantly mitigates alkali–silica reaction while improving overall engineering performance.	Enhanced compressive strength, improved durability, refined pore structure, reduced alkali–silica reaction expansion and improved long-term performance of recycled aggregate concrete.

Table 5. Quantitative and Thematic Characteristics of the Reviewed Evidence

Indicator	Review finding	Interpretation
Total studies included	45	Final qualitative synthesis
International journal papers	35 (77.8%)	Dominant evidence source
International conference papers	6 (13.3%)	Supplementary international evidence
Local/Sri Lankan studies	4 (8.9%)	Limited local evidence base
Review period	2011–June 2026	Period covered by the systematic review
Construction-waste pathway	C&D concrete waste → RCA → RAC	Construction-waste circularity
Agricultural-waste pathway	Coconut-shell waste → CSB → concrete/RAC	Agricultural-waste valorisation
RCA replacement level	Study-dependent	No single optimum level established across reviewed studies
Biochar incorporation level	Study-dependent	Performance depends on dosage, source and processing conditions
Mechanical performance	Variable; improvements reported under optimized conditions	Influenced by RCA quality, replacement level and biochar characteristics
Durability/microstructure	Pore refinement and durability improvements reported in selected studies	Indicates potential performance enhancement
ASR performance	Reduced ASR expansion reported in CSB-modified RAC	Potential durability benefit

alternative to natural aggregate concrete while significantly reducing landfill disposal and the extraction of virgin aggregates (Silva, de Brito and Dhir, 2014; Tam, Tam and Zeng, 2018). Similarly, coconut shell biochar has been shown to enhance the mechanical performance, durability and alkali–silica

reaction resistance of recycled aggregate concrete through improvements in microstructural characteristics (Arandara et al., 2024; Arandara et al., 2025). Consequently, integrating these two waste streams offers an opportunity to establish a closed-loop material cycle that simultaneously addresses waste management, resource conservation and sustainable infrastructure development.

The findings suggest that construction waste recycling and agricultural biomass valorisation should no longer be considered independent sustainability initiatives. Instead, they represent complementary components of a broader circular economy strategy capable of improving resource efficiency while supporting Sri Lanka's sustainable development objectives.

4.2 Emerging National Initiatives

Sri Lanka has recently demonstrated increasing commitment towards circular economy implementation through several national initiatives promoting sustainable construction and waste resource recovery. A significant milestone is the establishment of the Construction and Concrete Waste Recycling Centre at the Ekala Industrial Zone (Ja-Ela) under the Clean Sri Lanka Programme, which represents one of the country's first large-scale facilities dedicated to processing construction and demolition waste into reusable construction materials (Government of Sri Lanka, 2026).

The facility has a processing capacity of approximately 200 tonnes of construction waste per hour, supported by modern recycling and laboratory facilities. It diverts construction waste from landfills by producing recycled aggregates, reducing dependence on virgin natural resources while promoting collaboration among government, industry, and universities in recycled construction materials research.

This initiative reflects Sri Lanka's transition towards resource recovery and circular construction. However, integrating agricultural waste, particularly coconut researchers, universities and the construction industry. The development of national standards for recycled aggregates and biochar-modified concrete, together with pilot projects, incentives and knowledge transfer programmes, would significantly accelerate industry adoption.

4.4 Proposed Construction-Agriculture Circular Resource Loop Framework

Based on the synthesis of the reviewed literature and emerging developments in Sri Lanka, this study proposes the Construction–Agriculture Circular Resource Loop Framework as a conceptual model for integrating multiple waste streams into sustainable infrastructure development (Figure 2). The proposed framework comprises two interconnected resource cycles. The first cycle converts construction and demolition (C&D) waste into recycled concrete aggregates (RCA) for new concrete production, while the second transforms coconut shell waste into biochar through pyrolysis for incorporation into recycled aggregate concrete. Together, these cycles improve mechanical performance, durability, and alkali–silica reaction resistance while promoting resource recovery.

By integrating construction and agricultural waste streams, the framework establishes a closed-loop system that reduces landfill disposal, conserves natural aggregates, lowers the environmental footprint of concrete production, and promotes agricultural waste valorisation. Its successful implementation relies on coordinated support from government, industry, research institutions, and technical standards.

The framework provides a practical circular economy pathway tailored to the Sri Lankan construction sector, enhancing material circularity, sustainable infrastructure development, and long-term resource efficiency.

shell biochar, into mainstream construction remains limited. Combining government-led recycling initiatives with locally available agricultural biomass offers a practical pathway for advancing the circular economy in the construction sector.

4.3 Challenges and Opportunities

Despite encouraging technological developments, several challenges continue to limit the widespread implementation of circular construction practices in Sri Lanka. Technical challenges include variability in recycled aggregate quality, absence of standardized biochar production procedures, limited long-term durability data and insufficient national specifications governing recycled construction materials. Economic barriers include investment costs associated with recycling infrastructure and market uncertainty regarding recycled products. In addition, limited public awareness and conservative industry perceptions continue to restrict the acceptance of recycled construction materials.

Conversely, the opportunities identified through the reviewed literature are substantial. The availability of construction waste and coconut shell residues provides an abundant domestic resource base capable of reducing dependence on imported or virgin construction materials. Advances in concrete technology have demonstrated that biochar-modified recycled aggregate concrete can achieve satisfactory engineering performance while simultaneously improving environmental sustainability. Furthermore, emerging national initiatives such as the Ekala recycling center, together with increasing government emphasis on sustainable development, provide favorable conditions for expanding circular construction practices throughout Sri Lanka.

Realizing these opportunities requires coordinated efforts among policymakers, regulatory authorities,

V. CONCLUSIONS

5.1 Key Findings

This PRISMA-based systematic review evaluated the circular economy potential of integrating construction and agricultural waste streams for sustainable concrete applications in Sri Lanka. This PRISMA-based systematic review evaluated the circular economy potential of integrating selected construction and agricultural waste pathways, with specific emphasis on recycled aggregate concrete and coconut-shell biochar applications in Sri Lanka. The synthesis of 45 studies published between 2011 and 2026 confirms that recycled aggregate concrete (RAC) and agricultural waste-derived biochar are complementary technologies that improve resource efficiency while reducing dependence on virgin aggregates and minimizing construction waste.

The findings suggest that recycled concrete aggregates provide a technically viable solution for construction and demolition (C&D) waste recycling, while coconut shell biochar improves the mechanical performance, durability, and alkali–silica reaction resistance of recycled aggregate concrete. Although research on circular construction has increased globally, integrated applications of construction and agricultural waste remain limited, particularly in developing countries. To address this gap, this study proposes the Construction–Agriculture Circular Resource Loop Framework as a practical pathway for circular economy implementation and sustainable infrastructure development in Sri Lanka.

5.2 Practical Implications

The proposed framework provides practical guidance for policymakers, researchers, and the construction industry by demonstrating how construction waste recycling and agricultural biomass valorisation can be integrated to improve resource efficiency and reduce environmental impacts. Emerging initiatives such as the Construction and Concrete Waste Recycling Centre at Ekala provide a strong foundation for expanding circular construction practices through national standards, supportive policies, and industry adoption. The framework also promotes collaboration among government, academia, and industry to accelerate innovation in sustainable construction materials.

5.3 Future Research Directions

Future research should optimize the combined use of recycled aggregates and biochar, evaluate long-term durability under tropical conditions, and quantify environmental and economic benefits through life cycle assessment (LCA) and life cycle cost analysis (LCCA). Further studies should support field-scale implementation, develop standardized production and design guidelines, and investigate digital technologies



Figure 2. Proposed Construction–Agriculture Circular Resource Loop Framework for Sri Lanka

such as Building Information Modelling (BIM), digital twins, and artificial intelligence to enhance construction waste management and resource circularity in Sri Lanka.

ACKNOWLEDGMENT

The author thanks The Open University of Sri Lanka for its continuous academic and research support. The author also acknowledges the contributions of researchers whose published studies formed the evidence base for this PRISMA-based systematic review.

REFERENCES

Adams, K.T., Osmani, M., Thorpe, T. and Thornback, J., 2017. *Circular economy in construction: Current awareness, challenges and enablers.* Proceedings of the Institution of Civil Engineers – Waste and Resource Management, 170(1), pp.15–24.

Arandara, A.K.P., Priyadarshana, T., Paranavithana, G., Mallick, R.B. and Pitawala, H.M.T.G.A., 2024. *Evaluation of coconut shell biochar on recycled aggregate concrete through petrographic studies.* Construction and Building Materials, 428, 136342.

Arandara, A.K.P., Priyadarshana, T., Paranavithana, G., Mallick, R.B. and Pitawala, H.M.T.G.A., 2025. *Investigation of coconut shell biochar as an eco-friendly additive to mitigate the alkali–silica reaction in recycled aggregate concrete.* Journal of Sustainable Construction Materials and Technologies, 10(1)

Benachio, G.L.F., Freitas, M.C.D. and Tavares, S.F., 2020. *Circular economy in the construction industry: A systematic literature review.* Journal of Cleaner Production, 260, 121046.

Bravo, M., de Brito, J. and Pontes, J., 2015. *Durability performance of concrete made with recycled aggregates from construction and demolition waste.* Construction and Building Materials, 77, pp.357–369.

Coconut Development Authority, 2025. *Sri Lanka Coconut Industry 2024 – In a Nut Shell*. Colombo: Coconut Development Authority, Sri Lanka.

Department of Census and Statistics, 2025. *Economic Statistics of Sri Lanka 2024*. Colombo: Department of Census and Statistics, Sri Lanka.

Ellen MacArthur Foundation, 2013. *Towards the Circular Economy: Economic and Business Rationale for an Accelerated Transition.* Cowes, UK: Ellen MacArthur Foundation.

Ghisellini, P., Cialani, C. and Ulgiati, S., 2016. *A review on circular economy: The expected transition to a balanced interplay of environmental and economic systems.* Journal of Cleaner Production, 114, pp.11–32.

Government of Sri Lanka, 2026. *Construction and Concrete Waste Recycling Centre Opened in Ekala under the Clean Sri Lanka Programme.* Colombo: Government of Sri Lanka.

Gupta, S., Kua, H.W. and Pang, S.D., 2018. *Biochar in cementitious materials: A review.* Construction and Building Materials, 186, pp.961–977.

Li, W., Wang, J., Xiao, J. and Li, J., 2017. *Effect of recycled aggregates on mechanical properties of concrete: A review.* Journal of Cleaner Production, 143, pp.589–609.

Page, M.J., McKenzie, J.E., Bossuyt, P.M., Boutron, I., Hoffmann, T.C., Mulrow, C.D., Shamseer, L., Tetzlaff, J.M., Akl, E.A., Brennan, S.E., Chou, R., Glanville, J., Grimshaw, J.M., Hróbjartsson, A., Lalu, M.M., Li, T., Loder, E.W., Mayo-Wilson, E., McDonald, S., McGuinness, L.A., Stewart, L.A., Thomas, J., Tricco, A.C., Welch, V.A., Whiting, P. and Moher, D., 2021. *The PRISMA 2020 statement: An updated guideline for reporting systematic reviews.* BMJ, 372, n71.

Papamichael, K., Vougioukas, E. and Loizidou, M., 2023. *Construction and demolition waste framework of circular economy: A mini review.* Waste Management & Research, 41(1), pp.1–12.

Restuccia, L. and Ferro, G.A., 2020. *Promising effects of biochar on cement-based materials.* Cement and Concrete Composites, 114, 103766.

Silva, R.V., de Brito, J. and Dhir, R.K., 2014. *Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production.* Construction and Building Materials, 65, pp.201–217.

Tam, V.W.Y., Tam, C.M. and Zeng, S.X., 2018. *Recycled aggregate in concrete: A review.* Construction and Building Materials, 172, pp.272–292.
Tan, Z., Zhang, H., Provis, J.L. and Yang, E.H., 2021. *Biochar as a sustainable supplementary material in concrete.* Cement and Concrete Research, 143, 106364.

United Nations Environment Programme (UNEP), 2024. *Global Waste Management Outlook 2024.* Nairobi: United Nations Environment Programme.

Xiao, J., 2018. *Recycled Aggregate Concrete Structures.* Singapore: Springer.