International Journal of Innovative Research in Science and Engineering
Volume 11, Issue 10, 2025
www.ijirse.com
ISSN: 2454-9665

"Transforming Waste into Strength: Sustainable Applications of Recycled Aggregates in Concrete Production a Comprehensive review"

Mahadeva M.[1*], V. Vishal[2]
[1]*Assistant Professor,* [2]*Undergraduate Students, Department of Civil Engineering,*
RNS Institute of Technology, Channasandra, *Bengaluru, India*
**Corresponding Author: mahadevm10@gmail.com*

Abstract

The increasing generation of construction and demolition (C&D) waste has raised significant environmental and economic concerns worldwide, emphasizing the need for sustainable recycling practices in the construction industry. Recent research highlights the potential of recycled concrete aggregates (RCA) derived from C&D waste as a partial or complete replacement for natural aggregates in concrete production. Studies reveal that RCA generally exhibit higher porosity and water absorption due to adhered mortar, influencing workability, density, and mechanical performance of concrete. Nonetheless, when properly processed and graded, RCA can achieve compressive strengths and durability levels comparable to conventional mixes, particularly in non-structural and medium-strength applications. Investigations into durability performance indicate that recycled aggregate concrete (RAC) may experience increased carbonation depth, chloride ingress, and freeze–thaw sensitivity, though optimized mix designs, admixtures, and surface treatments can mitigate these effects. Beyond structural concrete, RCA has been successfully incorporated into melded bricks and blocks, offering viable pathways for large-scale utilization. Fine recycled aggregates (FRCA) also present opportunities but require careful mix proportioning to address strength and durability concerns.

Keywords: *Construction and Demolition Waste, Recycled Concrete Aggregate (RCA), Sustainable Concrete, Durability, Circular Economy, Mechanical Properties, Fine Recycled Aggregates (FRCA), Environmental Impact, Green Construction, Resource Efficiency.*

10.5281/zenodo.17786089

1. Introduction

The construction industry is among the largest global consumers of raw materials, accounting for nearly 40–50% of total resource use. This intensive consumption results in extensive environmental impacts, particularly through quarrying of natural aggregates, energy-intensive cement production, and massive generation of construction and demolition (C&D) waste. Urbanization and infrastructure expansion in both developed and developing nations have amplified these challenges, with C&D waste contributing to one-third of total solid waste streams in many countries. Improper disposal of this waste not only consumes valuable landfill space but also contributes to environmental degradation, leachate contamination, and increased carbon emissions. In response, there is a growing emphasis on circular economy principles that promote recycling and re-utilization of C&D waste to minimize the ecological footprint of the built environment.

One of the most promising avenues in this regard is the incorporation of recycled concrete aggregate (RCA) into new concrete mixes. RCA is obtained by crushing waste concrete from demolished structures, road pavements, or construction rejects, and processing it into aggregate fractions suitable for reuse. Compared to natural aggregates, RCA is characterized by higher porosity, adhered mortar content, and variability in quality, which influence the mechanical and durability properties of the resulting recycled aggregate concrete (RAC). Despite these challenges, extensive studies suggest that with appropriate processing, mix design adjustments, and quality control, RCA can successfully replace natural aggregates in a wide range of structural and non-structural applications.

2. Literature Review

Poonet al. (2002) [1]Use of Recycled Aggregates in moulded Concrete Bricks and BlocksPoon et al. investigated the utilization of recycled aggregates in moulded concrete bricks and blocks, demonstrating that these materials can achieve adequate strength and durability when mix proportions are optimized. Their findings confirmed the feasibility of using RCA in non-structural masonry applications, providing a sustainable alternative that reduces landfill waste and conserves natural resources.Silvaet al. (2014) [2]Properties and Composition of Recycled Aggregates was conducted a comprehensive meta-analysis of over 230 studies examining the physical, chemical, and mechanical properties of RCA. They concluded that RCA typically

10.5281/zenodo.17786089

exhibits lower density, higher water absorption, and reduced strength due to adhered mortar, but also noted that advanced processing methods such as mechanical pre-soaking and thermal treatment can significantly improve quality, allowing RCA to perform comparably to natural aggregates in many concrete applications.Thomaset al. (2016) [3]Properties of High-Strength Concrete Containing Recycled Aggregateswere evaluated the influence of RCA incorporation in high-strength concrete mixes. Their results indicated that while strength and workability slightly decline with higher RCA content, these effects can be mitigated through optimized mix design and the use of supplementary cementitious materials. The study reinforces that structural-grade RAC is achievable when mix parameters are carefully controlled.Xiaoet al. (2012) [4]Overview of Recycled Aggregate Concrete Research in China was reviewed fifteen years of Chinese research on RAC, summarizing developments in mechanical performance, durability, and microstructural characterization. The review highlighted that although RAC generally exhibits reduced compressive strength and increased shrinkage, ongoing innovations in material processing and mix proportioning have improved its feasibility for both structural and non-structural applications.Tamet al. (2018) [5]A Review of Recycled Aggregate in Concrete Applications (2000–2017)synthesized global studies on RCA usage, focusing on performance, environmental benefits, and standardization needs. The review emphasized that while significant progress has been made, inconsistent RCA quality, limited fine aggregate utilization, and a lack of life-cycle assessment (LCA) studies continue to hinder full-scale adoption. The authors advocate for performance-based guidelines and better recycling infrastructure.Nagatakiet al. (2004) [6]Recycling Process–Induced Damage Sensitivity of RCA analysed microstructural damage and mechanical sensitivity in RCA induced during crushing and processing. The study revealed that excessive crushing can increase microcrack density and mortar detachment, leading to inferior mechanical properties. Controlled processing and surface treatments were proposed to enhance RCA quality and performance consistency.Etxeberriaet al. (2007) [7]Influence of RCA Content and Production Process on ConcretePropertiesexperimentally examined concretes with varying RCA replacement levels and processing conditions. The results showed that strength and stiffness decrease with increasing RCA content but remain within acceptable limits up to 50% replacement when water content and admixture use are optimized. The study provided valuable data for establishing replacement ratio guidelines.Liuet al. (2014) [8]Experimental Study on the Failure Mechanism of Recycled Concrete investigated the failure behaviour of RAC under compressive and tensile

10.5281/zenodo.17786089

loads, focusing on crack initiation and propagation patterns. Their study concluded that adhered mortar and pre-existing microcracks in recycled aggregates increase brittleness and reduce stiffness. The findings contribute to understanding the microstructural basis for RAC's mechanical performance and failure modes.Tabshet al. (2009) [9]Influence of Recycled Concrete Aggregates on Strength Propertiesexplored the strength performance of concretes with varying RCA content, reporting a general reduction of 10–25% in compressive strength compared to natural aggregate concrete. They highlighted that strength loss can be minimized through optimized grading, mix proportioning, and curing conditions, supporting the controlled structural use of RCA.Marzouket al. (2014) [10]Environmental and Economic Impact Assessment of C&D Wasteemployed system dynamics modelling to compare the environmental and economic outcomes of waste disposal versus recycling scenarios. The study concluded that recycling C&D waste reduces landfill use, greenhouse gas emissions, and long-term costs, demonstrating the dual environmental and financial benefits of sustainable waste management.Rochaet al. (2009) [11]Reuse of Building Components in Brazil—Socioeconomic andLegalPerspectives examined the reuse of building components within Brazil's construction sector, identifying key social, economic, and regulatory factors affecting adoption. The analysis emphasized that legal frameworks and public awareness are critical in promoting component reuse, aligning with circular economy objectives.Oliveiraet al. (2017) [12]Economic Analysis of Processing Technologies in CDW RecyclingPlatformsassessed the economic viability of different processing technologies in construction and demolition waste recycling. Their findings indicated that higher-capacity plants with advanced sorting and crushing systems improve material quality and profitability, though initial investment remains a barrier in developing markets.Diagneet al. (2015) [13]Effect of Recycled Clay Brick Content on RCA Performanceinvestigated the influence of incorporating recycled clay bricks into RCA blends, focusing on mechanical and durability properties. They observed that higher brick content decreases strength and durability but may still yield acceptable performance for road sub-base and low-strength concrete applications when properly blended.Barbudaet al. (2012) [14]Barbuda et al. performed statistical evaluations of recycled aggregates obtained from different demolition sources for sub-base applications. Their results demonstrated that despite variability in composition, consistent quality can be achieved through controlled blending and stabilization, supporting the practical reuse of mixed recycled aggregates in road construction.Hossainet al. (2016) [15]Life-Cycle Assessment of Recycled versus Virgin

10.5281/zenodo.17786089

Aggregate Productionconducted an LCA comparing environmental impacts of RCA and natural aggregates. The study revealed that recycled aggregates significantly reduce energy consumption and greenhouse gas emissions—by up to 70%—highlighting their environmental advantages when produced under efficient processing conditions.Kimet al. (2013) [16]Mechanical and Durability Properties Using Contaminated RecycledAggregatesevaluated concrete produced with RCA contaminated by chlorides and sulphates from marine or industrial environments. They found that washing and selective treatment effectively reduce contamination impacts, enabling safe reuse of such RCA in non-structural and low-exposure applications.Slatteryet al. (2014) [17]Economic Viability Model for C&D Waste Recycling—The CaseofIrelanddeveloped a model to assess the financial feasibility of C&D waste recycling systems. Their analysis showed that profitability depends on processing scale, logistics, and government incentives, illustrating how economic modelling can guide sustainable waste management strategies.Dentata et al. (2005) [18]Cost and Duration Analysis for Deconstruction and Demolitioncompared the cost and time requirements of building econstruction versus traditional demolition in Massachusetts. The study concluded that although deconstruction is more labour-intensive and initially costlier, it offers long-term savings through material recovery, landfill reduction, and environmental benefits.

3. Research Gap

Despite considerable research on recycled aggregate concrete (RAC), several critical gaps continue to hinder its large-scale use in sustainable construction. The quality of recycled concrete aggregate (RCA) remains inconsistent due to variations in source materials and processing methods, and there is still no standardized framework for evaluating or classifying its properties. The relationship between RCA's microstructure, particularly the interfacial transition zone, and its long-term mechanical performance is not yet fully understood. Durability concerns such as increased porosity, susceptibility to carbonation, and reduced resistance to chloride penetration and freeze–thaw cycles also remain unresolved, especially under harsh environmental conditions. The use of fine recycled aggregates has received limited attention, with challenges related to water absorption, workability, and strength optimization still posing barriers. Furthermore, although supplementary cementitious materials can enhance RAC performance, the combined effects of different additives, curing regimes, and aggregate

10.5281/zenodo.17786089

treatments require more systematic investigation. Comprehensive life-cycle and cost–benefit analyses are also scarce, leaving uncertainties about the true environmental and economic advantages of RCA. Finally, weak regulatory support, limited design-code inclusion, and insufficient field data continue to restrict the widespread structural application of RAC, highlighting the need for further research and standardized implementation strategies.

4. Methodology

4.1 Research Design

The research adopts a **mixed-method approach** combining an extensive **systematic literature review**, **experimental investigation**, and **analytical evaluation** to address the key gaps related to the performance, standardization, and sustainability of Recycled Concrete Aggregate (RCA) in concrete production. The methodology is structured to (1) evaluate existing data to establish critical parameters influencing RCA performance, (2) experimentally assess the influence of RCA characteristics and supplementary cementitious materials (SCMs) on concrete properties, and (3) develop a framework for optimizing mix design and assessing life-cycle sustainability.

4.2 Systematic Literature Review

The review will focus on the following parameters:

- Physical and mechanical properties of RCA (density, water absorption, crushing value, and strength).
- Durability performance of RAC under various environmental conditions (carbonation, chloride ingress, freeze–thaw).
- Microstructural behavior, including interfacial transition zone characteristics and porosity.
- Effects of SCMs (fly ash, silica fume, GGBS) on RAC performance.
- Economic and environmental implications, including life-cycle cost and carbon footprint.

A PRISMA-based framework (Preferred Reporting Items for Systematic Reviews and Meta-Analyses) will be applied to ensure a transparent and reproducible review process. Collected data will be synthesized using descriptive and statistical analysis to identify trends, inconsistencies, and research gaps, which will guide the experimental design.

4.3 Materials and Aggregate Characterization

The second phase focuses on experimental validation of the findings from the literature review. RCA will be sourced from local construction and demolition waste recycling facilities, ensuring

10.5281/zenodo.17786089

a representative range of aggregate qualities. Natural aggregates (NA) will serve as control materials. RCA will be processed through crushing, screening, and removal of impurities such as wood, gypsum, and plastics.

A comprehensive characterization of the aggregates will be conducted according to ASTM and EN standards, including:

- Physical properties: particle size distribution, specific gravity, bulk density, and water absorption.
- Mechanical properties: aggregate crushing value, impact value, and Los Angeles abrasion resistance.
- Chemical composition: X-ray fluorescence (XRF) to determine oxide content and possible contaminants.
- Microstructural analysis: Scanning Electron Microscopy (SEM) to study the adhered mortar and interfacial transition zone (ITZ) characteristics.

Fine recycled aggregates (fRCA) will also be evaluated to explore their potential use in concrete, particularly focusing on their water demand, surface texture, and packing density.

4.4 Mix Design and Concrete Preparation

Concrete mixes will be prepared by partially replacing natural coarse aggregates (NCA) with RCA at different levels0%, 25%, 50%, 75%, and 100%. For selected mixes, fine recycled aggregates will replace natural sand at 0%, 20%, and 40% replacement levels.

The mix design will follow ACI 211.1 standards, ensuring a constant water-to-cement ratio and target strength of 30–40 MPa. To address the high absorption rate of RCA, pre-soaking and moisture correction methods will be implemented. Supplementary cementitious materials (fly ash, silica fume, and GGBS) will be added at replacement levels of 10–30% to improve workability, microstructure, and durability. A control mix using 100% natural aggregates and ordinary Portland cement will serve as the baseline for comparison.

4.5 Testing Procedures

4.5.1 Fresh Properties

Fresh concrete will be tested for:

- Workability using the slump test (ASTM C143).
- Density and air content (ASTM C138).
- Setting time and segregation resistance, particularly for mixes with fRCA.

4.5.2 Mechanical Properties

10.5281/zenodo.17786089

After 7, 28, and 90 days of curing, concrete samples will be tested for:

- Compressive strength (ASTM C39).
- Split tensile strength (ASTM C496).
- Flexural strength (ASTM C78).
- Elastic modulus (ASTM C469).

4.5.3 Durability Performance

Durability tests will include:

- Water absorption and sorptivity (ASTM C1585).
- Rapid chloride permeability (ASTM C1202).
- Carbonation depth after accelerated exposure.
- Freeze–thawresistance(ASTMC666).These tests will evaluate the influence of RCA replacement ratio, SCM content, and pre-treatment methods on the long-term performance of RAC.

4.6 Microstructural and ITZ Analysis

To understand the relationship between RCA quality and concrete performance, microstructural examination will be carried out using SEM and X-ray diffraction (XRD). The porosity and crack propagation patterns will be analysed to assess the quality of the ITZ and determine the influence of SCMs on densification. Image analysis software will quantify microcrack density and pore structure.

4.7 Lifecycle and Sustainability Assessment

A life-cycle assessment (LCA) will be conducted following ISO 14040/44 standards to compare the environmental impacts of RAC and conventional concrete. Parameters such as energy consumption, greenhouse gas emissions, and waste diversion rates will be evaluated using specialized software (e.g., SimaPro or GaBi). Additionally, a life-cycle cost analysis (LCCA) will quantify the economic benefits of RCA use, incorporating collection, processing, and transportation costs.

4.8 Data Analysis and Validation

Experimental results will be analyzed using statistical methods, including ANOVA and regression analysis, to identify significant factors affecting RAC performance. Correlation models will be developed to relate RCA properties (density, absorption, mortar content) with

10.5281/zenodo.17786089

mechanical and durability outcomes. The results will be validated through comparison with existing literature and standards to propose optimized guidelines for RCA use in structural and non-structural applications.

4.9 Expected Outcomes

The methodology aims to establish:

1. A comprehensive performance database for RCA-based concrete under varying replacement ratios and processing conditions.
2. Improved understanding of the microstructural mechanisms influencing durability.
3. Optimized mix design strategies integrating SCMs and RCA.
4. A decision-making framework incorporating mechanical, durability, and sustainability performance to promote RCA adoption in the construction industry.

5.0 Importance of sustainable RCA utilization

The sustainable use of RCA aligns with global efforts to transition toward greener construction practices. Incorporating RCA in concrete production directly reduces the extraction of natural aggregates, conserves landfill space, and decreases greenhouse gas emissions associated with material transportation. Life-cycle assessment (LCA) studies consistently demonstrate that RAC offers environmental benefits when used in place of virgin aggregates, particularly when local waste sources are utilized. Furthermore, RCA can play a vital role in achieving sustainable development goals (SDGs), including responsible consumption and production, sustainable cities, and climate action.

Beyond environmental benefits, economic advantages also emerge. Utilizing C&D waste reduces disposal costs for contractors, creates new markets for recycled products, and supports circular economy business models. For rapidly urbanizing countries such as India, China, and Brazil, where infrastructure expansion is coupled with massive demolition activities, RAC provides a practical solution to address both waste management and resource scarcity challenges.

1.Quality Variability: RCA quality depends on source material, processing techniques, and contamination levels. Standardized classification and certification methods are needed to ensure consistency.

2. Durability Data: Long-term durability studies, particularly under aggressive environments (marine, freeze–thaw, sulphate exposure), are limited and often inconclusive.

10.5281/zenodo.17786089

3. Fine RCA Utilization: Most applications still exclude fRCA due to concerns over water demand and strength reduction. Research into optimized mix designs and chemical admixtures can expand its potential.

4. Structural Applications: While non-structural applications such as blocks and pavements are well established, structural use of RAC in load-bearing elements remains restricted in codes and standards.

5. Life-Cycle Performance: Comprehensive LCAs and performance-based design approaches are needed to quantify the holistic benefits of RAC and guide its integration into green building certifications.

6. Implementation

1. Collection of Waste Materials
    - Collect Construction and Demolition (C&D) waste (e.g., demolished concrete, bricks).
    - Transport to recycling facility.
2. Segregation & Sorting
    - Separate usable concrete waste from other debris (wood, plastic, steel, etc.).
    - Manual and mechanical sorting methods.
3. Crushing & Processing
    - Crush concrete waste into desired sizes using jaw crushers and impact crushers.
    - Remove contaminants (dust, plaster, clay).
4. Screening & Grading
    - Screen aggregates to obtain specific size fractions (fine and coarse).
    - Conduct sieve analysis for proper grading.
5. Testing of Recycled Aggregates
    - Check physical and mechanical properties (specific gravity, water absorption, crushing value).
    - Ensure compliance with IS codes / ASTM standards.
6. Concrete Mix Design
    - Replace natural aggregates with recycled aggregates (partial/full replacement).
    - Prepare different mix ratios (M20, M25, etc.).

10.5281/zenodo.17786089

7. Casting & Curing
    - Cast concrete cubes, beams, cylinders.
    - Cure specimens for 7, 14, 28 days.
8. Strength & Durability Tests
    - Compressive strength test.
    - Flexural strength test.
    - Water permeability and durability checks.
9. Comparative Analysis
    - Compare results of recycled aggregate concrete (RAC) with conventional concrete.
    - Evaluate feasibility, cost-effectiveness, and sustainability.
10. Implementation in Construction
    - Use RAC in non-structural and structural applications.
    - Promote circular economy in construction industry.

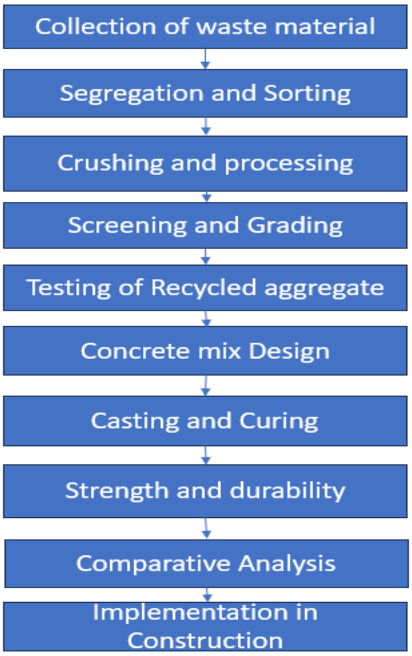

Fig 1: Flowchart of sustainable concrete production

Summary

The construction industry consumes vast amounts of natural resources and generates significant construction and demolition (C&D) waste, creating environmental and economic concerns. Recycling this waste into usable aggregates offers a sustainable alternative to conventional concrete production. The process involves collection, segregation, crushing, screening, and testing of demolished concrete to produce recycled aggregates that can replace natural aggregates partially or fully. These aggregates are then used in concrete mix designs, cast, cured, and tested for strength and durability.

Studies have shown that recycled aggregate concrete (RAC) can achieve comparable performance to conventional concrete when designed properly, making it suitable for both structural and non-structural applications. Beyond technical performance, the use of RAC reduces dependency on natural resources, lowers waste disposal issues, and promotes a circular economy. Hence, recycled aggregates present a feasible, cost-effective, and eco-friendly solution for sustainable construction practices.

Conclusion

The use of recycled aggregates in concrete production demonstrates a sustainable and environmentally responsible solution to the growing challenges of construction and demolition waste management. By collecting, processing, and testing waste materials, high-quality recycled aggregates can be produced that partially or fully replace natural aggregates without significantly compromising the strength and durability of concrete. This practice not only conserves natural resources such as sand and gravel but also reduces landfill waste and minimizes the environmental impact of construction activities.

Furthermore, experimental results and comparative analyses show that recycled aggregate concrete (RAC) can achieve satisfactory performance for both structural and non-structural applications, especially when proper mix design and quality control are ensured. Beyond technical feasibility, the adoption of RAC supports a circular economy in the construction industry, promotes cost-effectiveness, and contributes to sustainable development goals. Therefore, integrating recycled aggregates into mainstream construction practices is a practical step toward achieving greener, more resource-efficient infrastructure.

Reference

1. C.S. Poon, S.C. Kou and L. Lam (2002), “Use of recycled aggregates in moulded concrete bricks and blocks”, *Constr. Build. Mater*. 16(5) 281–289.

10.5281/zenodo.17786089

2. R.V. Silva, J. and Brito, R.K. (2014), “Properties and composition of recycled aggregates from construction and demolition waste suitable for concrete production”, *Constr. Build. Mater*. 65 201–217.
3. B.S. Thomas, and R.C. Gupta, (2016), “Properties of high-strength concrete containing recycled aggregates”, *J. Cleaner Prod*. 113 86–92.
4. J.Z. Xiao, and, X.H. Huang, (2012), “An overview of study on recycled aggregate concrete in China (1996–2011)”, *Constr. Build. Mater*. 31 364–383.
5. V.W.Y. Tam, M. Soomro, A.C.J. Evangelista, “A review of recycled aggregate in concrete applications (2000–2017)”, *Constr. Build. Mater.* 172 (2018) 272–292.
6. S. Nagataki, (2004), “Assessment of recycling-process-induced damage sensitivity of recycled concrete aggregates”, *Cem. Concr. Res.* 341445–1452.
7. M. Etxeberria, E. Vázquez, A. Mari,and M. Barra, (2007), “Influence of amount of recycled coarse aggregates and production process on properties of recycled aggregate concrete”, *Cem. Concr. Res.* 37 735–742.
8. Liu, Q., Xiao, J., & Sun, Z. (2011). “Experimental study on the failure mechanism of recycled concrete. *Cement & Concrete Research”*, **41**(10), 1050–1057.
9. S.W. Tabsh, and A.S. Abdelfatah,(2009), “Influence of recycled concrete aggregates on strength properties of concrete”, *Constr. Build. Mater.* 23 1163–1167.
10. M. Marzouk, and S. Azab, (2014), “Environmental and economic impact assessment of construction and demolition waste disposal using system dynamics, Resource”. *conserved. Recycle*. 82) 41–49.
11. C.G. da Rocha and M.A. Sattler(2009), “A discussion on the reuse of building components in Brazil: an analysis of major social, economical and legal factors, Resource”, *conserved. Recycle.* 54(2) 104–112.
12. R. Oliveira Neto, and P. Gastineau, R. (2017), “An economic analysis of the processing technologies in CDW recycling platforms”, *Waste Manage.* 60 277–289.
13. M. Diagne (2015), “The effects of recycled clay-brick content on the engineering properties, weathering durability, and resilient modulus of recycled concrete aggregate”, *Transp. Geotech.* 3 1–9.
14. A. Barbudo, F. Agrela, J. Ayuso, J.R. Jiménez and C.S. Poon,(2012),“Statistical analysis of recycled aggregates derived from different sources for sub-base applications”*, Constr. Build. Mater.* 28(1) 129–138.

10.5281/zenodo.17786089

15. M.U. Hossain,and C.S. Poon, (2016),"Comparative environmental evaluation of aggregate production from recycled waste materials and virgin sources by LCA, Resource". *conserved. Recycle.* 109 164–175.

16. Kim, K., Shin, M., and Cha, S. (2014). Combined effects of recycled aggregate and fly ash towards concrete sustainability. *Construction and Building Materials*, 52, 66-74.

17. X. Duran, H. Lenihan, B. and O'Regan(2006),"A model for assessing the economic viability of construction and demolition waste recyclingthe case of Ireland, Resource. Conserve",*Recycle. 46(3)* 302–320.

18. N. Dantata (2005), "An analysis of cost and duration for deconstruction and demolition of residential buildings in Massachusetts, Resource", *Conserve. Recycle.* 44 1–15.

10.5281/zenodo.17786089