Recycling Demolition Debris into Sustainable Construction Materials: A Comprehensive Review Study

Belal Almassri, Bassam Tayeh, Ahmed Tamimi and Fahed Qawasmi

***Abstract*— This article aims at converting rubble from demolished buildings into sustainable construction materials, addressing the growing need to manage debris from disasters, wars, and aging infrastructure. Such waste poses health and environmental hazards, and current reliance on landfills is both costly and unsustainable. The research investigates the feasibility of recycling materials like concrete and bricks, focusing on safety, cost-efficiency, and environmental impact. The paper objectives include reducing reliance on natural resources, promoting circular economy practices, and lowering construction costs. Recent studies findings indicate that replacing traditional materials with recycled debris is not only possible but also a promising solution for sustainable and resilient construction.**

INTRODUCTION

Reusing the demolished buildings' wastes and debris, and encouraging the reproduction of building materials such as concrete, steel and brick, is one of the important topics that has received great attention from researchers around the world. There is a need to reduce the environmental problems resulting from these building wastes and debris, which account for 30-40% of solid waste [1]. An appropriate management is required of massive amounts of demolitions wastes composed of debris and rubbles; Construction and Demolition C&D waste has been receiving great attention for contaminant removal as an effective adsorbent. Due to higher surface area, composition, availability and low-cost C&D wastes-based adsorbents demonstrated a high affinity for the removal of metals and inorganic substances [2].

The recycling of demolition debris into sustainable construction materials has evolved significantly over the past decade, reflecting growing environmental concerns and advancements in technology. The foundational work by [3] highlighted the critical barriers to achieving higher recycling rates for building materials, which currently hover around 40%. Zhang emphasized the importance of technological feasibility in recycling, particularly for concrete, which boasts a recycling rate of 50 to 57 percent. The ability to reuse materials efficiently not only mitigates landfill waste but also contributes to energy savings over a building's lifespan. [4] further expanded on the potential of recycled materials by examining the shear behavior of crushed concrete and bricks. Their findings revealed that these recycled materials exhibit similar properties to natural granular materials, suggesting that they can be effectively utilized in engineering applications. However, they also cautioned that despite the benefits of recycling, there are inherent challenges that must be addressed to increase the acceptance and use of these materials within the construction industry.

I. RESEARCH BACKGROUND

A. Construction and Demolition Waste:

In the context of the increasing generation of construction and demolition waste (C&DW) in Europe, Del Río Merino et al [5] underscored the urgent need for improved recycling practices. Their study presented comprehensive C&DW management plans to optimize the recovery and reuse of materials, thereby enhancing sustainability in construction. The authors pointed out that while the potential for recycling is significant, practical strategies for implementation are still lacking in many regions, highlighting a critical gap between theory and practice. Building on these discussions, Rakhshan et al. [6] conducted a systematic review to identify factors influencing the reuse of building components. Their methodology presented the importance of a clear research framework in advancing the understanding of deconstruction and demolition practices. By systematically analyzing existing literature, they highlighted gaps in knowledge that future research could address, thereby contributing to the broader discourse on sustainable construction. Reis et al. [7] provided a comprehensive overview of the current applications of recycled aggregates from C&DW. They detailed various uses, such as in pavement construction and ready-mix concrete, and emphasized that recycled aggregates can match the quality of natural materials. The research identified key areas for future studies, including the establishment of standardized testing and the exploration of political strategies to enhance the acceptance of recycled materials in the construction sector. According to [8], about 75% of construction and demolition (C&D) wastes originate from concrete (shown in figure 1), with the concrete industry having the greatest unsustainable impact due to landfill disposal.

Belal Almassri, Ahmed Tamimi and Fahed Qawasmi are with the Civil Engineering Department, College of Engineering, Palestine Polytechnic University (corresponding author: e-mail: mbelal@ppu.edu).

Bassam Tayeh is with the Civil Engineering Department, College of Engineering, Islamic University of Gaza.

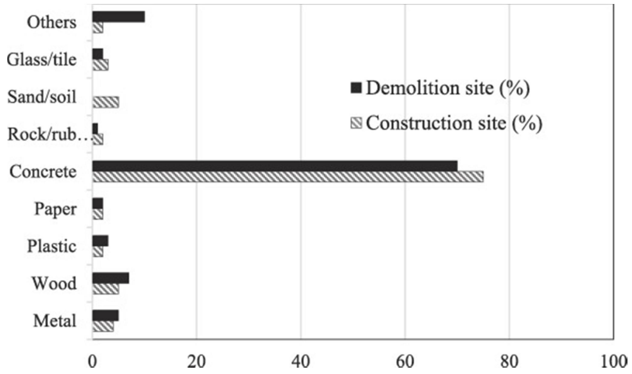

Figure 1. A typical composition of construction and demolition wastes *[8]*

In order to promote sustainable development, numerous researchers and construction agencies have worked to reduce the construction industry's environmental impact, energy consumption, and CO2 intensity. Therefore, recycling and reusing construction waste is among the most resourceful and promising paths to sustainable development. [9], [10], [11]. The amount of aggregate used for construction remains the largest contributor to construction and demolition (C&D) waste generation [12]. As a result, recycling and reusing aggregates can benefit sustainability. It is possible, for example, to crush the concrete pavement that has been demolished during highway construction, and to reuse the recovered aggregate materials for construction of same pavement (either concrete or asphalt) or to recycle them into new pavements [13], [14].

Recycled Concrete Aggregate RCA in structural applications, has been proven to be a common practice. It showed effective behavior in some mix designs and replacement percentages. However, their use in pavement construction has not been fully practised due to the uncertainties in the characterization, method of recovery, properties, and sustainability gain over a long period [15], [16], [17], [18]. Major obstacles that siege the use of RCA in concrete construction are the lack of codes and standards for qualifying an RCA source and the unclear impact of RCA on concrete performance [19]. Medium and large-scale structural reinforced concrete elements (beams, columns, etc), which includes RCA in their mixture design need to be extensively tested, to investigate the modes of failure and the durability of these applications.

B. Gaza War 2023-now:

As a result of the ongoing war in Gaza and the use of explosive weapons in the Gaza Strip, enormous quantities of debris pose significant risks to human health and the environment. According to the United Nations, the quantity of debris from the continuous conflict is more than that of all the debris from previous conflicts in the Gaza Strip since 2008. The 2008 conflict left nearly 600,000 tons of rubble, while it is estimated that 2 million tons of debris resulted in Gaza as a consequences of 2014 conflict which lasted for 51 days. In May 2021, over than 370,000 tons of demolition waste composed of rubbles and debris was generated during 11 days of conflict in Gaza. In March 2024, the UN estimated that the war had left 23 million tons of rubble and unexploded weapons in Gaza caused by the continuous conflict (shown in figure 2), and it would take about 15 years to remove the rubble [20]. At the meantime, a new way of thinking and an extensive scientific research project is required to deal with such exceptional situation, like in Palestine in a coordinated and coherent manner.

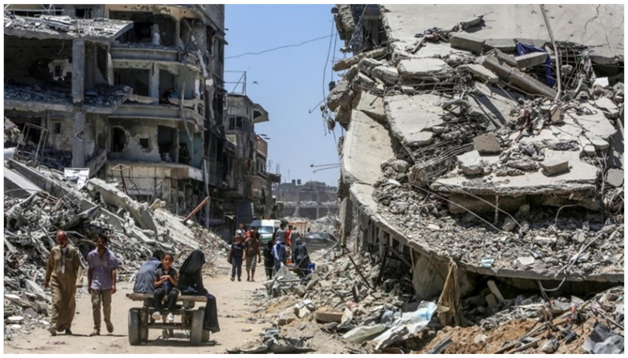

Figure 2. Rubbles from the ongoing conflict Gaza, 2024

II. CURRENT APPLICATIONS OF RECYCLED AGGREGATES RCA

A. Background:

The development of sustainable infrastructure has become a strategic priority for governments and stakeholders in the construction sector. The reuse of construction and demolition (C&D) waste stands as a fundamental pillar in achieving this goal, due to its direct impact on reducing pressure on natural resources and lowering carbon emissions [21], [22]. Among the most promising recyclable materials in this sector is Recycled Concrete Aggregate (RCA), which is obtained from demolished or dismantled concrete structures.

Recent studies have demonstrated that RCA can serve as an effective alternative to Natural Aggregate (NA) in various applications, particularly in the construction of road base and subbase layers [23]. This practice offers not only environmental benefits but also economic advantages by reducing the costs associated with the extraction and transportation of raw materials [24].

The growing demand for infrastructure, driven by rapid population growth and urban expansion, has intensified the need for sustainable materials. At the same time, the construction industry remains one of the largest producers of solid waste, further emphasizing the necessity of efficient waste management strategies [25]. It is estimated that concrete waste accounts for nearly 70% of total construction and demolition debris, making it a highly valuable resource for reuse.

Field experiences and recent applications have shown that using RCA in road and infrastructure projects is not only an environmentally responsible choice, but also contributes to the production of flexible and durable pavement layers capable of withstanding various operational conditions [26]. This reinforces the reliability of RCA and supports its broader adoption in future infrastructure development.

In addition, the use of recycled aggregates (RA) in the production of concrete and mortar significantly reduces the need for extracting natural gravel and sand from quarries. This, in turn, mitigates environmental impacts on ecosystems and decreases the depletion of natural resources as well as greenhouse gas emissions [27], [28]. Environmental policies, such as the European Union Directive 2018/851, play a vital role in increasing the demand for recycled aggregates and supporting the transition toward a circular economy [29]. The adoption of similar regulations in other countries is essential to promoting sustainability in the construction industry, particularly in concrete production.

B. Experimental Studies:

The durability and mechanical behavior of Recycled Concrete Aggregate (RCA) were evaluated using the ASTM C88 sodium sulfate test, which simulates environmental weathering through cycles of immersion and drying. The test results indicated that RCA exhibits a higher weight loss than natural aggregates due to the presence of adhered mortar and micro-cracks; however, with proper processing and grading, its performance remains acceptable for use in road base applications [15], [30]. Moreover, studies have shown that the resilient modulus of RCA and other recycled aggregates tends to decrease with increasing freeze-thaw (F-T) cycles, highlighting the importance of understanding these environmental effects when designing long-lasting flexible pavements [25].

To address these concerns, this study examined the stiffness and durability of RCA-based pavement materials under F-T exposure through laboratory testing and numerical simulations. Mechanical properties such as resilient modulus and permanent deformation were measured for base and subbase layers containing RCA. These parameters were then incorporated into 3D numerical models using FLAC3D to simulate pavement behavior under heavy moving loads and environmental cycles. The results contribute to the growing body of knowledge on sustainable pavement design and provide practical insights for engineers aiming to balance environmental impact with long-term performance [16].

Several studies have reported that the mechanical performance of concrete can be influenced by the partial or full replacement of natural aggregates with recycled concrete aggregate (RCA). In a related experimental investigation, concrete specimens were prepared with a fixed water-to-cement ratio of 0.56, and coarse natural aggregates were replaced with RCA at varying rates of 0%, 20%, 30%, and 60%. The mechanical properties namely compressive, tensile, and flexural strength were evaluated at two curing intervals: 7 and 28 days.

Lu et al. [31] revealed a general decline in all three strength parameters with increasing RCA content. However, the reductions observed at lower replacement levels (20% and 30%) were not statistically significant, indicating that RCA can be used in moderate proportions without compromising structural integrity. The most significant reduction in compressive strength was noted at the 60% replacement level, where strength decreased by approximately 50% compared to the control mix.

The reduction in mechanical performance was mainly attributed to the higher water absorption of RCA, weak bonding at the interface between the adhered old mortar and the new cement paste, and poor interfacial transition zones (ITZ). Furthermore, particle degradation during mixing led to increased fines, which negatively affected the consistency and strength of the mix. These findings are consistent with previous studies that have highlighted similar trends [25], [30].

Several studies have indicated that increasing the replacement level of natural aggregate (NA) with recycled concrete aggregate (RCA) leads to a reduction in both workability and slump of concrete mixes [23]. This is primarily due to the higher water absorption and irregular texture of RCA compared to natural aggregates.

In terms of mechanical properties, various experimental results suggest: A combination of 30% coarse recycled concrete aggregated CRCA and 20% fine recycled concrete aggregates FRCA can yield compressive strength comparable to conventional concrete (CC), indicating that moderate RCA usage is feasible in structural applications [27]. Using 60% CRCA and 30% FRCA with a water-to-cement (W/C) ratio of 0.48 has been shown to maintain acceptable mechanical performance, especially when the mix design is optimized to compensate for RCA's physical limitations [28], However, complete replacement (100%) of both CRCA and FRCA has been associated with a significant reduction in compressive strength, ranging from 36% to 42% compared to CC [32].

Other studies observed that a 30% CRCA and 20% FRCA mix resulted in only a modest 10% reduction in compressive strength [25], further supporting the viability of partial replacement.

A replacement of 50% of CRCA resulted in a 5% to 15% decrease in tensile strength. Replacing 50% of FRCA can lead to a drop in tensile strength of up to 35% due to the fine particles' porosity and weak bonding with the cement matrix [33].

Table 1, highlights that the mechanical performance of RCA-based concrete is not solely dependent on replacement levels, but also strongly influenced by mix optimization. Therefore, negative outcomes in some studies may reflect poor mix designs rather than an inherent limitation of RCA itself.

Table 1: Comparison of High RCA Replacement

Research	RCA Replacement	W/C Ratio	Key Result
Silva et al. [25]	60% RCA	0.56	50% drop in compressive strength
Thomas et al. [28]	60% CRCA + 30% FRCA	0.48	Maintained acceptable mechanical properties
Pedro et al. [32]	30% CRCA + 20% FRCA	Not specified	Comparable compressive strength to conventional concrete

C. Conclusion:

The comparative analysis of various studies demonstrates that the mechanical performance of recycled aggregate concrete (RAC) is highly dependent on both the replacement ratio and the mix design parameters, particularly the water-to-cement (W/C) ratio. While high RCA replacement levels (e.g., 60%) without proper adjustment in mix design tend to result in significant losses in compressive strength—up to 50%—other studies confirm that optimized mixes (such as 60% CRCA + 30% FRCA with W/C = 0.48) can maintain acceptable performance. Additionally, partial replacements such as 30% CRCA + 20% FRCA have been shown to yield compressive strength values comparable to conventional concrete. These findings underline the importance of strategic material blending and mix proportioning when incorporating RCA, rather than setting strict upper limits on replacement percentages. Thus, the comparison supports the feasibility of using RCA in structural applications, provided that performance-based design and proper quality control measures are implemented.

III. GLASS AS A REPLACEMENT OF TRADITIONAL SAND IN CONCRETE MIX DESIGN

Glass is among the most vital and widely utilized materials worldwide. Once its intended use is complete, waste glass can be sorted, cleaned, and re-melted to produce new glass items. However, factors such as contamination, variation in types and colors, and the absence of proper sorting facilities hinder this recycling process. As a result, waste glass often accumulates in stockpiles or ends up in landfills [34], [35]. Glass waste (GW) poses a significant environmental challenge due to its non-biodegradable nature and its contribution to the saturation of landfill sites across the globe [36], [37], [38]. This issue is particularly critical in densely populated urban areas, where the availability of new landfill space is limited.

However, research findings on the use of waste glass in concrete remain inconsistent. Results vary significantly depending on the type, particle size, and replacement percentage of glass used [39], [40]. Additionally, limited studies have explored the simultaneous incorporation of glass sand and glass powder, and even fewer have systematically identified the optimal replacement levels under combined conditions. The use of recycled glass as a partial replacement for fine aggregate in self-compacting concrete (SCC) presents a sustainable alternative to natural sand, addressing both environmental concerns and material scarcity. Finely crushed glass particles (≤4.75 mm) can improve the workability of SCC due to their smooth, non-porous surfaces, which enhance flowability without significantly increasing water demand. Studies have shown that replacing natural sand with 10–20% recycled glass sand (RGS) can either maintain or slightly enhance compressive and tensile strength due to improved particle packing and potential pozzolanic activity. However, when the replacement exceeds 30%, a decline in mechanical performance may occur, attributed to weak interfacial bonding and increased risk of alkali-silica reaction (ASR). This risk can be mitigated through the use of supplementary cementitious materials (SCMs) such as fly ash and silica fume. Additionally, recycled glass contributes to better chloride ion resistance and reduced environmental impact by lowering CO_2 emissions and landfill waste. The optimal replacement level for structural performance and durability appears to be within the 10–20% range, while higher levels require precise mix design and ASR control measures [41], [42].

The feasibility of using recycled glass sand (RGS) as a partial replacement for natural sand in concrete was evaluated by testing substitution levels of 10%, 20%, 30%, 40%, and 50% by weight. The study revealed that incorporating 10–20% RGS enhanced compressive strength (by 5–10%), reduced water absorption, and improved chloride ion resistance, primarily due to the pozzolanic reactivity and non-porous nature of finely ground glass. However, mechanical performance began to decline at replacement levels above 30%, with strength reductions of up to 15% observed at 50% RGS. This decline was attributed to microcracking from alkali-silica reaction (ASR) and weaker bonding in the interfacial transition zone (ITZ), especially when coarse glass particles (>300 µm) were utilized. The study concluded that RGS replacement should be limited to 20% in structural concrete unless used in combination with supplementary cementitious materials (SCMs) such as fly ash or metakaolin. These findings are consistent with the work of Sharifi [42] who also reported optimal performance at or below 20% RGS, but differ from the results of Islam et al. [41] who noted satisfactory outcomes at 30% replacement, likely due to the use of finer glass particles [43].

Table 2: Comparison of RGS Use in Conventional vs. Self-Compacting Concrete

	Tamanna et al. [43]	Sharifi et al. [42]
Objective	To evaluate the properties of conventional concrete using recycled glass	To assess the performance of self-compacting concrete (SCC) incorporating

	sand (RGS) as a partial replacement for natural sand.	RGS as a fine aggregate substitute.
Replacement Range Tested	10% – 50% of natural sand	10% – 30% of natural sand
Best Performance Observed	At 10–20% replacement: increased compressive strength, reduced water absorption, improved chloride resistance.	At 20% replacement: enhanced workability with no significant loss in compressive strength.
Issues at Higher Replacement Ratios	Decline in strength at >30% due to ASR-induced microcracking and weaker Interfacial Transition Zone (ITZ).	At >30%: reduced compressive strength and increased Alkali-Silica Reaction (ASR) risk.
Performance-Influencing Factors	Glass particle size (>300 µm increases ASR risk); absence of supplementary cementitious materials (SCMs).	Particle grading, flowability, and stability of SCC without additional water.
Final Recommendation	Limit RGS to ≤20% in conventional concrete; combine with SCMs to control ASR.	Limit RGS to ≤20% in SCC to maintain mechanical performance and rheology.

IV. REUSING DEMOLITION DEBRIS IN CONCRETE PAVING BLOCKS

Over the past 15 years, research from around the globe has consistently shown that demolition rubble (especially crushed concrete) can be recycled into new concrete blocks and paving units with successful results. Early feasibility studies [44] showed that moderate replacement of natural aggregate with recycled concrete aggregate yields comparable block strength. Subsequent experiments [45], [46] demonstrated at scale that 15–50% recycled aggregate content in paving blocks can satisfy all relevant standards. More recent advances even pushed the envelope to 100% recycled aggregate usage – for instance, Zengfing et al. [47] and Dafedar et al. [48] both produced blocks entirely from RCA that met compressive strength requirements. Key challenges such as slight strength loss or higher water absorption have been overcome by optimized mix design (e.g., adding supplementary cementitious materials like fly ash/slag as in [49] or improved compaction techniques (as with Farooq et al. [50] using high-pressure casting). Across studies, a general trend is that coarse recycled concrete aggregate can replace natural gravel fairly well, with typically only a 10–20% reduction in strength up to about 50% replacement, whereas recycled fine aggregate tends to be more problematic if used in high amounts. Many researchers therefore limit or exclude the fine recycled fraction or compensate with more cement or admixtures when fine RCA is used.

In terms of durability, recycled-aggregate blocks often have slightly higher absorption and shrinkage, but most studies report these remain within acceptable ranges (usually <6–7% absorption, similar to normal concrete blocks). Freeze-thaw resistance and abrasion resistance of recycled aggregate blocks have also been shown to meet standards in multiple cases. An important takeaway is that quality control of the recycled aggregate (cleaning, grading, and avoiding contaminants) is crucial – when properly processed, even 100% RCA concrete can achieve ~90% of the strength of normal concrete and meet structural usage criteria.

From a practical perspective, these studies collectively support the implementation of recycled debris in new construction: concrete paver blocks for roads, interlocking tiles for walkways, and concrete masonry units for walls can all incorporate recycled concrete rubble without performance penalty, as long as mix designs are intelligently adjusted. Some have even reported cost savings or at least comparable costs, and significant environmental benefits (like reduced landfill usage, conservation of natural sand/gravel, and lower CO_2 emissions). Several researchers have called for updated standards and guidelines to explicitly allow high-percentage use of recycled aggregates in precast products – a change that would accelerate industry adoption. Paving blocks made with recycled concrete aggregates can achieve required compressive strengths (often 40–60 MPa) and durability for heavy traffic, as evidenced by numerous case studies. Fully closing the loop (100% aggregate recycling) is attainable in certain products (especially with modern production techniques), though partial replacement (20–60%) is more commonly optimal.

V. NEXT STEPS AND OPTIMAL HANDLING OF DEBRIS

The successful utilization of debris and recycled materials in construction is generally an overall process consisting of several stages from waste production to end use. To effectively reuse a debris material, it is necessary to understand how its chemistry and mineral composition can affect any potential negative properties and how the negative properties can affect the physical and mechanical properties of the end product.

The next steps methodology should adopt several extensive experimental tests and finite element numerical modelling approach, which studies the mechanical and physical properties of the special recycled material, and the properties of the applications of the structural elements:

- Experimental tests should be undertaken on recycled concrete aggregates RCA, to compare the physical properties of those recycled materials to the traditional ones. (i.e. Specific Gravity, water absorption, Bulk Density, and Los Angeles Abrasion test)

- Experimental tests should be conducted on the workability, slump and their relationship to recycled materials replacement ratios.
- Experimental tests should illustrate the relationship between replacement ratios and the ultimate strength of the recycled materials.
- Tests on concrete strength which uses the glass as a replacement of the sand in the concrete mix design.
- Finite Element based approaches are required to predict the mechanical properties of structural elements and the applications of recycled materials.
- Perform Life Cycle Cost Analysis LCCA, to evaluate the economic viability of using recycled materials by comparing initial and ongoing costs to those of conventional materials.

Table 3: Optimal Handling and research required for each debris category

Debris Category	**Optimal Handling**	**Research Required**
Recyclable		
Concrete	Sorted from debris and downsized to max. 50cmx50cmx50cm for recycling.	Separation, Crushing, testing and Evaluation studies are required.
Masonry Blocks & Roofing Tiles	Cleaned and left at site for reuse or removed for recycling.	Reuse, Reproduction of Eco-Friendly blocks, strength tests are required.
Timber Materials	Sorted from debris and either left at site for reuse or removed for recycling/recovery	Recycling studies, treatment and applications are required.
Metals	Ideally handed over to owners and if not, then prepared at site for local reuse (i.e. reinforcement bars straightened for reuse)	Research on tensile strength of steel bars, ductility and friction of reused bars are required.
Glass	Sorted, Crushed and either reused or removed to landfills.	Research is required on replacement of sand in concrete mix design.
Plastics	Sorted where possible and removed for recycling or left within debris.	Recycling and environmental studies are required.
Asphalt	Sorted where possible and removed for recycling or left within debris if smaller quantities.	Mechanical Properties studies, recycling into hot mix asphalt.
Debris Category	**Optimal Handling**	**Research Required**
Non-Recyclable		
General internal and external building contents including fixtures and fittings, furniture, personal belongings etc.	To be returned to owner (if present) enabled to recover personal items with remaining left in debris for removal.	Safe Disposal studies are required.
Excavation soil	To be removed from Site	Soil Contamination tests
Other non-combustible materials.	To be removed from Site	Safe Disposal studies are required.
Debris Category	**Optimal Handling**	**Research Required**
Hazardous Materials		
Oil and chemical waste, as well as hazardous waste including asbestos and contaminated soil.	Sorted from debris (where safe to do so) with correct packaging, labelling and disposal.	Safe Disposal studies are required.

VI. . CONCLUSION AND RECOMMENDATIONS

This comprehensive review confirms that recycling construction and demolition debris offers a technically feasible and environmentally sustainable pathway toward resilient infrastructure. The performance of Recycled Concrete Aggregates (RCA) and other reused materials—when combined with optimized mix designs and proper quality control—has proven comparable to conventional construction materials in many structural and non-structural applications. The integration of waste glass as a partial replacement for natural sand further extends the scope of sustainable material reuse.

However, the urgency of applying these findings is significantly heightened in the context of the 2023–2024

Gaza conflict. According to United Nations estimates, more than 23 million tons of debris and rubble—exceeding the cumulative total from all previous wars in Gaza since 2008—now pose a critical environmental, humanitarian, and logistical challenge. Without proper handling, this unprecedented volume of waste threatens public health, overwhelms landfill systems, and delays recovery efforts.

In this regard, the war debris in Gaza must not be treated solely as hazardous waste, but rather as a strategic resource for reconstruction. Through scientifically-backed recycling methods, Gaza's rubble can be transformed into building blocks for schools, homes, and roads—ushering in a model of circular recovery that combines economic necessity with environmental stewardship.

To enable this transformation, the following actions are strongly recommended:

1. Initiate a national and international recovery plan to coordinate the safe collection, sorting, and reuse of Gaza's rubble in a manner aligned with health and safety regulations.
2. Develop technical guidelines and legal frameworks that regulate the use of RCA, recycled glass, and other debris-based components in construction.
3. Implement pilot-scale demonstration projects using recycled aggregates for paving blocks, road bases, and low-rise structures to validate long-term performance.
4. Strengthen laboratory testing programs to assess durability, mechanical properties, and optimal mix proportions for local recycled materials under Gaza's specific conditions.
5. Incorporate Life Cycle Assessment (LCA) and Cost Analysis (LCCA) to ensure economic viability alongside environmental benefits.
6. Promote academic and vocational training for engineers, technicians, and contractors to build local expertise in debris recycling.
7. Encourage donor agencies and NGOs to invest in mobile crushing, sorting, and testing units suitable for conflict zones and disaster areas.

By embracing debris as a building resource—especially in crisis zones like Gaza—this study provides a roadmap not just for waste reduction, but for post-conflict resilience and sustainable rebuilding.

VII. REFERENCES

[1] R. Jin, H. Yuan, and Q. Chen, 'Science mapping approach to assisting the review of construction and demolition waste management research published between 2009 and 2018', *Resources, Conservation and Recycling*, vol. 140, pp. 175–188, 2019.

[2] S. Pallewatta, M. Weerasooriyagedara, S. Bordoloi, A. K. Sarmah, and M. Vithanage, 'Reprocessed construction and demolition waste as an adsorbent: An appraisal', *Science of the Total Environment*, vol. 882, p. 163340, 2023.

[3] F. Zhang, 'Framework for building design recyclability', 2008.

[4] I. Chidiroglou, F. O'Flaherty, and A. K. Goodwin, 'Shear behaviour of crushed concrete and bricks', *Proceedings of the Institution of Civil Engineers-Construction Materials*, vol. 162, no. 3, pp. 121–126, 2009.

[5] M. del Río Merino, P. Izquierdo Gracia, and I. S. Weis Azevedo, 'Sustainable construction: construction and demolition waste reconsidered', *Waste management & research*, vol. 28, no. 2, pp. 118–129, 2010.

[6] K. Rakhshan, J.-C. Morel, H. Alaka, and R. Charef, 'Components reuse in the building sector–A systematic review', *Waste Management & Research*, vol. 38, no. 4, pp. 347–370, 2020.

[7] G. S. dos Reis, M. Quattrone, W. M. Ambrós, B. Grigore Cazacliu, and C. Hoffmann Sampaio, 'Current applications of recycled aggregates from construction and demolition: A review', *Materials*, vol. 14, no. 7, p. 1700, 2021.

[8] M. Arabani and A. Azarhoosh, 'The effect of recycled concrete aggregate and steel slag on the dynamic properties of asphalt mixtures', *Construction and Building Materials*, vol. 35, pp. 1–7, 2012.

[9] R. Jin, B. Li, T. Zhou, D. Wanatowski, and P. Piroozfar, 'An empirical study of perceptions towards construction and demolition waste recycling and reuse in China', *Resources, Conservation and Recycling*, vol. 126, pp. 86–98, 2017.

[10] Y. Menaria and R. Sankhla, 'Use of waste plastic in flexible pavements-green roads', *Open Journal of Civil Engineering*, vol. 5, no. 03, p. 299, 2015.

[11] X. Shi, A. Mukhopadhyay, D. Zollinger, and Z. Grasley, 'Economic input-output life cycle assessment of concrete pavement containing recycled concrete aggregate', *Journal of cleaner production*, vol. 225, pp. 414–425, 2019.

[12] V. W. Tam, M. Soomro, and A. C. J. Evangelista, 'A review of recycled aggregate in concrete applications (2000–2017)', *Construction and Building materials*, vol. 172, pp. 272–292, 2018.

[13] A. Albayati, Y. Wang, Y. Wang, and J. Haynes, 'A sustainable pavement concrete using warm mix asphalt and hydrated lime treated recycled concrete aggregates', *Sustainable Materials and Technologies*, vol. 18, p. e00081, 2018.

[14] Z. Zhang, K. Wang, H. Liu, and Z. Deng, 'Key performance properties of asphalt mixtures with recycled concrete aggregate from low strength concrete', *Construction and Building Materials*, vol. 126, pp. 711–719, 2016.

[15] X. Xu *et al.*, 'Potential use of recycled concrete aggregate (RCA) for sustainable asphalt pavements of the future: A state-of-the-art review', *Journal of Cleaner Production*, vol. 344, p. 130893, 2022.

[16] M. Akbas, O. Subasi, and R. Iyisan, ‘The effect of RCA pavements on the liquefaction-induced settlement’, *Scientific Reports*, vol. 13, no. 1, p. 6944, 2023.

[17] S. Ali and A. Ejaz, ‘Effect of Recycled Concrete Aggregates (RCA) for Rutting Susceptibility in Flexible Pavement’, *Construction Technologies and Architecture*, vol. 13, pp. 41–48, 2024.

[18] E. Covilla-Varela, E. Turbay, R. Polo-Mendoza, G. Martínez-Arguelles, and J. Cantero-Durango, ‘Recycled Concrete Aggregates (RCA)-based asphalt mixtures: A performance-related evaluation with sustainability-criteria verification’, *Construction and Building Materials*, vol. 403, p. 133203, 2023.

[19] E. O. Fanijo, J. T. Kolawole, A. J. Babafemi, and J. Liu, ‘A comprehensive review on the use of recycled concrete aggregate for pavement construction: Properties, performance, and sustainability’, *Cleaner Materials*, vol. 9, p. 100199, 2023.

[20] C. I. Yavuz and S. B. Unal, ‘War and environmental health in Gaza’, *East Mediterr Health J*, vol. 31, no. 2, pp. 151–153, 2025.

[21] V. W. Tam, L. Tam, and S. Zeng, ‘Cost effectiveness and tradeoff on the use of rainwater tank: An empirical study in Australian residential decision-making’, *Resources, conservation and recycling*, vol. 54, no. 3, pp. 178–186, 2010.

[22] C. S. Poon, S. Kou, and L. Lam, ‘Use of recycled aggregates in molded concrete bricks and blocks’, *Construction and building materials*, vol. 16, no. 5, pp. 281–289, 2002.

[23] S. Kou and C. S. Poon, ‘Enhancing the durability properties of concrete prepared with coarse recycled aggregate’, *Construction and building materials*, vol. 35, pp. 69–76, 2012.

[24] T. Ding, J. Xiao, and V. W. Tam, ‘A closed-loop life cycle assessment of recycled aggregate concrete utilization in China’, *Waste management*, vol. 56, pp. 367–375, 2016.

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

[26] Federal Highway Administration (US), *Highway statistics 2004*. Federal Highway Administration, 2006.

[27] L. Evangelista and J. De Brito, ‘Durability performance of concrete made with fine recycled concrete aggregates’, *Cement and Concrete Composites*, vol. 32, no. 1, pp. 9–14, 2010.

[28] C. Thomas, J. Setién, and J. Polanco, ‘Structural recycled aggregate concrete made with precast wastes’, *Construction and Building Materials*, vol. 114, pp. 536–546, 2016.

[29] P. Ludlow, ‘The European Commission’, in *The New European Community*, Routledge, 2018, pp. 85–132.

[30] M. C. Rao, S. Bhattacharyya, and S. Barai, ‘Recycled aggregate concrete: A sustainable built environment’, presented at the Review of Literature. International Conference on Sustainable Built Environment (ICSBE) Kandy, Citeseer, 2010, pp. 13–14.

[31] L. Lu, ‘Optimal replacement ratio of recycled concrete aggregate balancing mechanical performance with sustainability: A review’, *Buildings*, vol. 14, no. 7, p. 2204, 2024.

[32] D. d Pedro, J. De Brito, and L. Evangelista, ‘Structural concrete with simultaneous incorporation of fine and coarse recycled concrete aggregates: Mechanical, durability and long-term properties’, *Construction and Building Materials*, vol. 154, pp. 294–309, 2017.

[33] P. K. Singh and P. Rajhans, ‘Experimental investigation and SVR model to predict the mechanical properties of RAC by enhancing the characteristic of RCA using surface treatment method along with modified mixing approach’, *Construction and Building Materials*, vol. 393, p. 132032, 2023.

[34] M. Amin, A. M. Zeyad, B. A. Tayeh, and I. Saad Agwa, ‘Effect of ferrosilicon and silica fume on mechanical, durability, and microstructure characteristics of ultra high-performance concrete’, *Construction and Building Materials*, vol. 320, p. 126233, Feb. 2022, doi: 10.1016/j.conbuildmat.2021.126233.

[35] W. Dong, W. Li, and Z. Tao, ‘A comprehensive review on performance of cementitious and geopolymeric concretes with recycled waste glass as powder, sand or cullet’, *Resources, Conservation and Recycling*, vol. 172, p. 105664, Sep. 2021, doi: 10.1016/j.resconrec.2021.105664.

[36] V. Mymrin, K. Alekseev, M. A. Avanci, P. H. B. Rolim, C. L. Pedroso, and D. E. Pedroso, ‘Environmentally clean ceramics manufacture with the application of hazardous car production sludge and galvanic process glass waste’, *The International Journal of Advanced Manufacturing Technology*, vol. 119, no. 5, pp. 3607–3616, Mar. 2022, doi: 10.1007/s00170-021-08341-3.

[37] O. Adekomaya and T. Majozi, ‘Mitigating environmental impact of waste glass materials: review of the existing reclamation options and future outlook’, *Environmental Science and Pollution Research*, vol. 28, no. 9, pp. 10488–10502, Mar. 2021, doi: 10.1007/s11356-020-12263-0.

[38] A. Adesina, ‘Performance and sustainability overview of alkali-activated self-compacting concrete’, *Waste Disposal & Sustainable Energy*, vol. 2, no. 3, pp. 165–175, 2020.

[39] N. A. Soliman and A. Tagnit-Hamou, ‘Using glass sand as an alternative for quartz sand in UHPC’, *Construction and Building Materials*, vol. 145, pp. 243–252, Aug. 2017, doi: 10.1016/j.conbuildmat.2017.03.187.

[40] J. Zhao and S. Li, ‘Performance study and environmental evaluation of alkali-activated materials based on waste photovoltaic glass’, *Journal of Cleaner Production*, vol. 379, p. 134576, Dec. 2022, doi: 10.1016/j.jclepro.2022.134576.

[41] G. M. S. Islam, M. H. Rahman, and N. Kazi, ‘Waste glass powder as partial replacement of cement for sustainable concrete practice’, *International Journal of Sustainable Built Environment*, vol. 6, no. 1, pp. 37–44, Jun. 2017, doi: 10.1016/j.ijsbe.2016.10.005.

[42] Y. Sharifi, M. Houshiar, and B. Aghebati, ‘Recycled glass replacement as fine aggregate in self-compacting concrete’, *Frontiers of Structural and Civil Engineering*, vol. 7, no. 4, pp. 419–428, Dec. 2013, doi: 10.1007/s11709-013-0224-8.

[43] N. Tamanna, R. Tuladhar, and N. Sivakugan, ‘Performance of recycled waste glass sand as partial replacement of sand in concrete’, *Construction and Building Materials*, vol. 239, p. 117804, Apr. 2020, doi: 10.1016/j.conbuildmat.2019.117804.

[44] P. Matar and R. El Dalati, ‘Using recycled concrete aggregates in precast concrete hollow blocks’, *Materialwissenschaft und Werkstofftechnik*, vol. 43, no. 5, pp. 388–391, 2012.

[45] C. Rodríguez, I. Miñano, M. Á. Aguilar, J. M. Ortega, C. Parra, and I. Sánchez, ‘Properties of concrete paving blocks and hollow tiles with recycled aggregate from construction and demolition wastes’, *Materials*, vol. 10, no. 12, p. 1374, 2017.

[46] M. Contreras-Llanes, M. J. Gázquez, and M. Romero, ‘Eco-Friendly Pavements Manufactured from Mixed Recycled Aggregates Obtained from Construction and Demolition Waste: An Industrial-Scale Validation’, *Materials*, vol. 16, no. 24, p. 7544, 2023.

[47] Z. Zengfeng, L. Courard, S. Groslambert, T. Jehin, A. Léonard, and X. Jianzhuang, ‘Use of recycled concrete aggregates from precast block for the production of new building blocks: An industrial scale study’, *Resources, Conservation and Recycling*, vol. 157, p. 104786, 2020.

[48] M. M. M. Dafedar, K. B. Rao, B. Pai, and G. B. Bekkeri, ‘Evaluation of the engineering properties and sustainability of solid masonry blocks produced with recycled concrete aggregates’, *Innovative Infrastructure Solutions*, vol. 9, no. 11, pp. 1–19, 2024.

[49] A. Abdulmatin, W. Tangchirapat, and C. Jaturapitakkul, ‘Environmentally friendly interlocking concrete paving block containing new cementing material and recycled concrete aggregate’, *European Journal of Environmental and Civil Engineering*, vol. 23, no. 12, pp. 1467–1484, 2019.

[50] M. U. Farooq, R. Hameed, M. Tahir, M. G. Sohail, and S. Shahzad, ‘Mechanical and durability performance of 100% recycled aggregate concrete pavers made by compression casting’, *Journal of Building Engineering*, vol. 73, p. 106729, 2023.