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## From Scarcity to Innovation: Redefining Construction Resources: Lessons from Qatar's Aggregate Experience

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### ABSTRACT

The Gulf region is undergoing rapid urban expansion, leading to unprecedented demand for aggregates in road construction and building infrastructure. Qatar, as a prominent case study, has faced severe limitations in local limestone resources, necessitating large-scale imports of gabbro and creating significant economic and logistical pressures. In response, site trials at Rawdat Rashid explored the integration of recycled and secondary materials, notably Construction and Demolition Waste (C&DW) and Incinerator Bottom Ash (IBA). Results indicated that up to 20% IBA and 50% C&DW could replace natural aggregates in concrete and blocks without compromising performance, prompting revisions to the Qatar Construction Specifications. This article highlights three key lessons from Qatar's experience: (i) IBA is not a marginal addition but a viable, functional component within construction mixes; (ii) Gulf nations paradoxically face aggregate scarcity while neglecting abundant resources such as desert sand, industrial ash, and plastic waste; and (iii) desert sand, long considered unsuitable, remains underutilized rather than inherently unusable. Together, these insights demonstrate the urgency of redefining material resources in Gulf infrastructure policy. Instead of limiting attention to import substitution, strategic utilization of local secondary materials can mitigate aggregate scarcity and open pathways toward more sustainable construction systems. The Qatari case underscores the regional necessity of converting overlooked materials into engineered resources for future resilience in road and infrastructure development.

### INTRODUCTION

On 25 March 2019, during an academic visit to Qatar, I had the opportunity to meet Dr. Mohammed Saif Al-Kuwari, who presented me with his book, which documents pioneering site trials of recycled and secondary aggregates. This work provided a timely insight into one of the Gulf's pressing infrastructure challenges: the depletion of natural aggregate resources and the heavy dependence on imported gabbro for road and concrete construction. The experience also raised critical questions regarding why abundant regional materials particularly desert sand and industrial ash remain underexploited despite their potential in construction applications.

Qatar presents a compelling case study. Its rapid infrastructural growth, accelerated by preparations for the FIFA World Cup 2022 and wider urban expansion, has amplified pressure on limited local limestone deposits, which are often geologically weak, highly variable in strength, and contaminated by sulphates or chlorides. Consequently, Qatar has resorted to large-scale aggregate imports, with reported volumes exceeding 20 million tonnes annually. This reliance has imposed economic burdens, logistical constraints at ports, and environmental costs associated with long-distance transport.

In response, experimental trials at Rawdat Rashid landfill demonstrated that Construction and Demolition Waste (C&DW) and Incinerator Bottom Ash (IBA) could serve as partial aggregate replacements in structural concrete

and non-load bearing blocks. The results, supported by updates to the Qatar Construction Specifications (QCS), confirm that IBA at 20% substitution and C&DW at 50% substitution can deliver satisfactory performance. These findings suggest a broader regional imperative: Gulf states must move beyond conventional quarrying and imports, reimagining neglected resources such as desert sand and ash as integral to sustainable infrastructure strategies

### LITERATURE REVIEW

#### Aggregates and Bitumen in Road and Infrastructure Systems

Aggregates and bitumen together constitute the foundation of modern road construction. In asphalt mixtures, aggregates account for 90–95% of the total weight, while bitumen serves as the binding agent, providing cohesion and durability under traffic and climatic stresses. In concrete, aggregates comprise nearly 70% of the volume, playing a decisive role in structural capacity, shrinkage resistance, and overall service life. Consequently, the availability and quality of aggregates determine not only the cost of infrastructure projects but also their long-term performance and environmental footprint. While bitumen is globally available through petroleum refining, aggregates are heavy, bulky, and costly to transport, making local supply a critical factor in construction economics. Quarrying and processing also raise concerns of environmental degradation, dust

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emissions, and landscape alteration. Regions with limited high-quality aggregate resources, such as the Arabian Gulf, face a dual challenge: growing demand due to rapid urbanization, and restricted supply due to the weak geological quality of local limestone.

### The Qatari Context: Dependence on Imported Limestone and Gabbro

Qatar illustrates these challenges in sharp relief. Its geology is dominated by geologically young, weak limestone, often highly porous, variable in strength, and contaminated with sulphates and chlorides, making it unsuitable for high-strength concrete or asphalt applications. As a result, Qatar has relied heavily on imported gabbro, sourced primarily from overseas quarries, to meet the massive demands of its infrastructure boom. By 2012, aggregate imports into Qatar exceeded 20 million tonnes annually. This dependence placed strain on port facilities, raised transportation and handling costs, and created vulnerabilities in construction schedules tied to international shipping. The economic and logistical pressures underscored a paradox: while vast expanses of desert sand surround Qatar, its infrastructure was being built with imported rock transported thousands of kilometres.

### Site Trials of Recycled and Secondary Aggregates in Qatar

To address these challenges, Qatar initiated pioneering site trials at the Rawdat Rashid landfill site, the country's largest construction and demolition waste disposal facility. The trials, led by Dr. Mohammed Saif Al-Kuwari and collaborators, explored the feasibility of integrating recycled and secondary materials into concrete and block production. Four main experimental pathways were investigated:

1. Excavation Waste (EW): Used to replace up to 50% of coarse aggregates in structural C40 concrete. Results indicated that EW, after crushing and screening, provided compressive strength comparable to that of imported gabbro when used in controlled proportions.

2. Construction and Demolition Waste (CDW): Incorporated into concrete blocks at 50% substitution levels. CDW consisted of crushed concrete, masonry, and related debris, processed to reduce contaminants. Performance tests on non-load bearing hollow blocks showed compressive strengths exceeding QCS 2010 minimum requirements (7.0 MPa).

3. Incinerator Bottom Ash (IBA): Added as a 20% replacement for coarse aggregate in non-load bearing blocks. Despite concerns of expansive reactions, properly weathered and processed IBA demonstrated safe performance, meeting strength specifications and offering a promising pathway for reusing waste from municipal solid waste incineration.

4. Crushed Rock Fines (CRF): Investigated as a partial substitute for washed river sand, given Qatar's limited reserves of suitable fine aggregate. Laboratory

trials showed that up to 60% of washed sand could be replaced with CRF (limestone or gabbro fines) without compromising performance. In fact, 60% limestone CRF replacement reduced cement demand by 10% while improving compressive strength and water absorption.

Together, these trials demonstrated that recycled and secondary aggregates could be viable alternatives in both structural and non-structural applications, directly reducing Qatar's reliance on imported gabbro.

### Performance Outcomes and Policy Implications

After one year of monitoring, results from the site trials revealed that the recycled and secondary aggregates performed equivalently, or in some cases better, than conventional gabbro-based controls. This evidence led to revisions in the Qatar Construction Specifications (QCS 2010), allowing greater substitution of natural aggregates with recycled materials. The trials were recognized with the 2013 Qatar Contractors Forum award for "Most Innovative Project," underscoring their significance in shifting industry perceptions. Moreover, the trials highlighted the importance of policy support in enabling material transitions. Qatar's National Vision 2030 explicitly commits to balancing economic growth with environmental sustainability, providing a strong framework for integrating recycling and circular economy principles into infrastructure delivery.

### International Experiences in Recycling and Resource Substitution

Qatar's efforts align with broader international trends. In the European Union, recycling rates of C&DW exceed 70% in leading countries, with RCA and IBA widely incorporated into sub-base layers, embankments, and even structural concrete (Pavlù *et al.*, 2019). Australia has demonstrated successful use of recycled plastic waste blended with demolition materials in road bases (Arulrajah *et al.*, 2017). In India, rapid urbanization and aggregate scarcity have spurred the development of C&DW recycling plants, though uptake remains uneven due to limited regulatory enforcement (Ghosh *et al.*, 2016). These experiences demonstrate that aggregate scarcity can be mitigated by integrating recycled and secondary materials, provided supportive policies and standards are in place.

Beyond Europe and Australia, international literature on the valorisation of industrial residues and marginal sands provides further precedent for Gulf-oriented innovation. Incinerator bottom ash (IBA) has been repeatedly shown to perform adequately in cementitious systems when properly aged, metal-removed, and graded; for instance, Lam, Poon, and Chan (2010) reported enhanced behaviour of IBA in cement-based materials following targeted pre-treatment, while earlier work by Pera *et al.* (1997) evidenced the safe incorporation of IBA in concrete with controlled expansion and satisfactory strength development. Parallel to IBA, several studies have investigated the engineering of "marginal" sand sources typically characterised by

unfavourable grading and particle morphology through particle packing optimisation, fines management, and chemical/pozzolanic activation.

These approaches aim to transform underutilised, locally abundant sands into functional constituents in concrete or bound layers, often in combination with supplementary binders or secondary aggregates. Collectively, these findings suggest that the combination of secondary aggregates (e.g., CDW, EW, CRF) with pre-treated industrial ashes and engineered sands can deliver performance compatible with infrastructure demands, provided that specifications and mix designs are adapted to reflect material-specific behaviour rather than legacy assumptions about natural aggregates.

### Research Gap: Untapped Potential of Desert Sand and Industrial Ash in the Gulf

Despite these advances, the Gulf region lags behind in systematically exploiting its unique resources. Recycling initiatives in Qatar and Oman have been limited to pilot-scale projects, with little progress toward scaling or codifying practices. Most notably, two abundant resources remain neglected:

- **Desert Sand:** Often dismissed due to its rounded particle shape, fine grading, and low angularity, desert sand has been largely excluded from construction mixes. Yet research indicates that with proper grading modifications, chemical activation, or blending, desert sand can serve as a viable aggregate component. Its abundance across the Gulf makes it a strategic, underutilized asset.
- **Industrial Ash:** Including fly ash from power plants, cement bypass dust, and IBA from waste incineration. Produced in large volumes across the region, these materials represent both an environmental liability and a potential construction resource. While Qatar's trials provided promising insights into IBA utilization, a comprehensive framework for industrial ash valorization remains absent.

The neglect of these resources reflects a significant research and policy gap. Bridging this gap requires tailored approaches for Gulf climatic and cultural contexts, building upon Qatar's pioneering efforts to create a holistic strategy for sustainable material use. This aligns with international findings that marginal sands and industrial ashes can be engineered into functional mixes (Lam *et al.*, 2010; Pera *et al.*, 1997), yet a coherent Gulf-specific framework remains absent.

## MATERIALS AND METHODS

### Case Study Approach

This study adopts a case study methodology, focusing on Qatar's large-scale trials of recycled and secondary aggregates conducted at the Rawdat Rashid landfill. The case study method is particularly suitable for infrastructure research in Gulf contexts, where field-based evidence remains limited and site-specific conditions strongly influence material performance. The approach combines review of published experimental results, analysis of

updated Qatar Construction Specifications (QCS), and integration of broader literature on recycled materials in arid climates.

### Rawdat Rashid Site Context

Rawdat Rashid, located west of Doha, is Qatar's largest construction and demolition waste (C&DW) disposal site. For decades, the site received heterogeneous mixtures of excavation spoil, demolition debris, and waste concrete. In preparation for systematic trials, materials were crudely separated into Excavation Waste (EW) and Construction and Demolition Waste (CDW) streams. These were subsequently processed crushed, screened, and sorted into coarse aggregate fractions of 5–10 mm and 10–20 mm suitable for concrete production.

Additionally, Incinerator Bottom Ash (IBA) was sourced from a municipal Energy-from-Waste facility in Mesaieed, while Crushed Rock Fines (CRF) were obtained from imported gabbro and limestone crushing operations. Together, these four material streams represented the core of the site trials.

### Material Characterization

- **Excavation Waste (EW):** Predominantly weak limestone fragments, with occasional inclusions of asphalt, concrete, and blocks. Processing removed oversized particles and contaminants. EW was characterized by moderate strength variability and high fines content, but sufficient angularity for use in coarse aggregate substitution.
- **Construction and Demolition Waste (CDW):** Primarily crushed concrete and masonry debris, grey in colour, and more heterogeneous than EW. CDW was screened to reduce lightweight contaminants such as wood, plastic, and gypsum.
- **Incinerator Bottom Ash (IBA):** Produced at 850°C in a controlled incineration process, quenched in water, weathered for one month, and then screened to remove metals and unburnt materials. Supplied in single-size fraction (5–10 mm).
- **Crushed Rock Fines (CRF):** By-products from quarry crushing of gabbro and limestone. Characterized by higher fines content (<75 µm), angular particle shape, and rougher surface texture compared to natural river sand. Physical and chemical properties of each stream were determined through standard tests for grading, water absorption, sulphate content, chloride content, and Los Angeles abrasion resistance.

### Mix Designs and Substitution Ratios

The site trials investigated the following substitution ratios:

- **C40 Structural Concrete:**
  - Control: 100% imported gabbro coarse aggregate + 100% washed sand.
  - Variant A: 50% EW replacing gabbro.
  - Variant B: 60% CRF replacing washed sand.
- **Concrete Blocks (Non-load Bearing, 7 MPa minimum strength):**

- Control: 100% imported gabbro + 100% washed sand.

- Variant C: 50% CDW replacing gabbro.
- Variant D: 20% IBA replacing gabbro.

Blinding concrete of C20 strength class was also produced with 80% EW and 20% CDW, demonstrating that high substitution levels were feasible for non-structural layers.

### Production and Testing Protocols

Concrete batching was conducted at ReadyMix Qatar's Mesaiaed plant under hot desert conditions, where daytime temperatures often exceeded 39°C. To mitigate thermal effects, chilled water and ice were incorporated into the mixing process to maintain fresh concrete temperatures below 32°C.

Key production and testing steps included:

- Central mixing in controlled batches with automated weighing of aggregates.
- Slump tests at both plant and site to monitor workability, with observed reductions of ~23% between plant (220 mm average) and site (170 mm average).
- Compressive strength tests at 3, 7, and 28 days (BS EN 12390-3).
- Block compressive strength tests at 28 days (BS EN 771-3).
- Durability assessments, including water absorption and density.

### Standards and Specifications

All mixes were benchmarked against the Qatar Construction Specifications (QCS 2010). Key requirements included:

- Concrete (C40): Compressive strength  $\geq 40$  MPa at 28 days.
- Concrete Blocks: Minimum average compressive strength  $\geq 7.0$  MPa.
- Aggregate Quality: Limits on sulphates, chlorides, and deleterious fines.

Where necessary, test results were also compared to international standards such as BS EN and ASTM, ensuring broader comparability of outcomes.

### Analytical Framework

The methodology integrates both quantitative and qualitative analysis:

1. Quantitative: Strength, workability, and durability performance relative to controls.
2. Qualitative: Policy and industry implications of using secondary materials, especially in terms of logistical feasibility, market acceptance, and alignment with Qatar's Vision 2030 sustainability objectives.

This dual framework ensures that the findings are not limited to technical feasibility but also address broader systemic considerations of resource utilization and infrastructure planning.

## RESULTS AND DISCUSSION

Performance of Recycled and Secondary Aggregates in

Qatar

### 1. Structural Concrete (C40)

#### Control Mix

The control C40 concrete mix, produced with 100% imported gabbro coarse aggregate and natural washed sand, consistently achieved compressive strengths above 40 MPa at 28 days, thereby fulfilling the QCS 2010 requirement for C40 structural concrete. Slump values recorded at the batching plant averaged 220 mm, while site tests (after transport and placement under hot ambient conditions exceeding 39°C) dropped to around 170 mm, reflecting a slump loss of ~23%. This reduction was attributed to evaporation and higher absorption of fine particles, a critical operational parameter for Gulf environments where temperature control is difficult. Chilled water and ice were used during batching to keep fresh concrete temperatures below 32°C, ensuring compliance with QCS thermal control provisions.

#### 50% EW Substitution

When 50% of imported gabbro was replaced with Excavation Waste (EW) sourced from Rawdat Rashid, the 28-day compressive strengths ranged from 39–42 MPa, essentially equivalent to the control. Although water absorption values showed a slight increase, they remained within QCS permissible limits. Petrographic examination confirmed the angularity of EW particles contributed positively to interlock and strength retention, despite their higher porosity compared to gabbro. This indicates that, with appropriate crushing and screening, EW can substitute up to 50% of coarse aggregate in structural concrete without compromising performance.

#### 60% CRF Substitution

Replacing 60% of washed natural sand with Crushed Rock Fines (CRF) both limestone and gabbro fines yielded concrete with compressive strengths slightly higher than the control mix at 28 days. More importantly, cement consumption was reduced by ~10%, as CRF's angular and rougher texture enhanced paste-aggregate bonding, reducing bleeding and segregation. Water absorption values were also improved relative to the control, reflecting better packing density. These results are particularly significant in Qatar, where natural washed sand reserves are extremely limited and often contaminated with sulphates beyond QCS thresholds. By contrast, CRF provided a controlled, high-quality substitute that improved both performance and sustainability. It was further observed that workability decreased significantly in CRF-rich mixes unless the dosage of superplasticizer was carefully adjusted. In mixes with 50% EW, some coarse particles tended to fragment during central mixing, which slightly increased the fines content but did not negatively affect compressive strength. Importantly, chemical analysis confirmed that CRF mixes contained lower sulphate contents compared to natural washed sand, which frequently exceeded QCS sulphate limits,

thereby improving durability performance. Slump loss during transport was slightly more pronounced in EW and CRF mixes compared to the control; however, this was effectively managed through the use of chilled water, ice, and adjusted superplasticizer dosages, ensuring adequate workability under Gulf climatic conditions.

### Concrete Blocks (Non-load Bearing)

#### Control Mix

Concrete masonry blocks manufactured with 100% imported gabbro aggregates consistently exceeded the QCS 2010 minimum requirement of 7.0 MPa, averaging around 11.0 MPa at 28 days. Beyond compressive strength, the control blocks demonstrated uniform density and water absorption within QCS limits, serving as a robust benchmark for comparison. The gabbro's high specific gravity ( $\sim 2.8 \text{ g/cm}^3$ ), low absorption ( $< 1\%$ ), and clean grading underpinned this performance. This control case validates that the testing programme and curing conditions were well designed, ensuring comparability with substitution mixes.

#### 50% CDW Substitution

When 50% of coarse aggregate was replaced with Construction and Demolition Waste (CDW) sourced from Rawdat Rashid, the blocks achieved average compressive strengths of 9.9 MPa, well above the QCS threshold. While slightly lower than the gabbro control, the performance was comfortably within specification and considered structurally reliable for non-load bearing masonry. Importantly, CDW was a heterogeneous stream consisting of crushed concrete, blocks, and masonry rubble. Therefore, extensive pre-sorting and contamination control were essential: lightweight impurities such as wood, plastics, gypsum, and plaster were removed; oversized particles were crushed; and fines were screened out. Physical testing revealed CDW aggregates had a lower bulk density ( $\sim 2.3 \text{ g/cm}^3$ ) and higher absorption (3–5%) compared to gabbro, which explained the marginal strength reduction. Nevertheless, the angularity of CDW particles contributed positively to mechanical interlock. The outcome confirms that CDW, when properly processed, is not a “last resort material” but a practical and safe substitute in block production, particularly valuable given Qatar's massive CDW stockpiles (estimated 80–100 million tonnes).

One limitation noted was that compressive strength variability was slightly higher than in the control blocks, reflecting the heterogeneous nature of CDW aggregates. This underscores the importance of selective demolition and improved sorting practices to ensure more consistent material properties.

#### 20% IBA Substitution

Blocks incorporating 20% Incinerator Bottom Ash (IBA) achieved average compressive strengths of 9.0 MPa at 28 days, again exceeding the QCS threshold of 7.0 MPa. Though marginally lower than the CDW and control

mixes, the performance was stable and well within acceptable ranges. Crucially, IBA required special pre-treatment:

- It was weathered for one month to hydrate free lime and stabilise sulphates.
- Ferrous/non-ferrous metals and unburnt residues were removed using mechanical sorting.
- The ash was screened into a controlled 5–10 mm fraction suitable for block production.

Chemical analyses confirmed that sulphate and chloride contents, though higher than gabbro, remained below the maximum permissible limits after weathering. Physical tests showed IBA had lower density ( $2.2\text{--}2.4 \text{ g/cm}^3$ ) and higher water absorption (6–8%), yet its rough and porous surface improved bonding with the cement paste, compensating for these drawbacks. Long-term monitoring over 12 months revealed no evidence of deleterious expansion, cracking, or durability loss, dispelling concerns about instability.

Given Qatar's annual IBA generation ( $\sim 0.05 \text{ Mt/year}$ ) and stockpiles ( $\sim 1 \text{ Mt}$ ), even modest substitution ratios could divert large volumes from landfill, transforming an environmental liability into a functional secondary aggregate stream. In addition to strength performance, it was recorded that blocks containing 20% IBA exhibited a marginally lower bulk density compared to control blocks. While this reduction was minor, it could be considered advantageous for non-load-bearing masonry, as it reduces dead load without compromising compressive strength. Durability monitoring included periodic water absorption tests and visual inspections over 12 months, which revealed no evidence of micro-cracking, surface deterioration, or expansion, further confirming the long-term stability of IBA in block production.

#### Blinding Concrete (C20)

A blinding concrete mix comprising 80% EW (Excavation Waste) and 20% CDW was trialled for non-structural sub-layer applications, where the primary function is levelling and providing a working platform. Despite the very high substitution ratio, the mix comfortably achieved the C20 strength class required under QCS, with compressive strengths above 20 MPa at 28 days. Density and water absorption values remained within acceptable ranges, although higher absorption was noted due to the porous nature of EW and CDW.

From a practical perspective, this mix demonstrated several key points:

1. High substitution feasibility: Even when 80% of aggregates were secondary materials, performance was adequate for intended use.
2. Cost and environmental savings: Maximising recycled content in low-demand applications reduces reliance on imported gabbro and diverts large waste volumes from landfill.
3. Operational adjustments: Higher water demand and slump variability required closer monitoring at batching, underscoring the importance of contractor awareness

when scaling such mixes.

The success of the C20 blinding mix underscores a principle highlighted in the Qatar trials: substitution levels can be adjusted according to structural demand, with higher substitution ratios viable in non-structural layers and more conservative ratios in structural elements. It was noted that the higher absorption of EW and CDW increased water demand, requiring closer monitoring of water-to-cement ratios during batching to maintain slump consistency. Despite this operational adjustment, the use of high substitution levels in C20 mixes substantially reduced overall material costs, since EW and CDW stockpiles were readily available at Rawdat Rashid, minimizing procurement expenses.

### Comparative Analysis

Across all tested scenarios, recycled and secondary aggregates equalled or outperformed conventional mixes. EW replaced 50% of gabbro in C40 mixes without loss of strength; CRF replaced 60% of washed sand while improving strength and reducing cement consumption; CDW substituted 50% of block aggregates while exceeding QCS minimums; and IBA, often considered risky, successfully contributed 20% of block mixes. This comparative evidence proves that aggregate scarcity in Qatar is not solely a supply-chain problem but can be mitigated through intelligent reuse of local waste streams. It also demonstrates that high-performance construction can be achieved under Gulf climatic conditions, provided processing and quality control are applied rigorously. When comparing control and substitution mixes, several important trends were identified. In structural concrete, the substitution of 50% EW and 60% CRF achieved compressive strengths equivalent or superior to 100% gabbro mixes, while also reducing cement consumption and lowering sulphate content. In non-load-bearing blocks, both 50% CDW and 20% IBA exceeded the QCS 2010 minimum requirement of 7.0 MPa, despite the lower bulk density and higher absorption of recycled aggregates.

These differences in physical properties highlight that strength equivalence does not automatically imply identical behaviour, and attention must be given to long-term durability and water management in recycled-rich mixes. Nevertheless, one year of field monitoring confirmed no deterioration in performance, indicating that the risks are manageable when materials are properly processed and conditioned. From an operational standpoint, slump loss and increased water demand were observed more frequently in recycled aggregate mixes, particularly with CRF and EW, yet these challenges were effectively mitigated through superplasticizer dosage and chilled water batching. From an economic perspective, the use of on-site materials such as EW and CDW significantly reduced hauling and disposal costs, while the diversion of IBA directly reduced landfill burdens. Collectively, the comparative results prove that recycled and secondary aggregates not only match conventional aggregates in mechanical performance but also contribute measurable benefits in cost, sustainability, and resource security. This multi-dimensional equivalence technical, economic, and environmental provides compelling evidence for mainstreaming these materials in Qatar's construction sector.

- It was also noted that compressive strength variability was marginally higher in CDW mixes, reflecting the heterogeneous nature of demolition waste and underscoring the need for improved segregation and selective demolition practices.

- In the case of IBA, the slightly lower bulk density of blocks compared to the gabbro control could even be advantageous for non-load-bearing masonry, reducing dead load while maintaining adequate strength.

To place the trial outcomes in a broader material context, Table 1 compares Qatar's reliance on imported aggregates with the availability and performance of local recycled and secondary resources. The data highlight a persistent utilisation gap: while millions of tonnes of gabbro and limestone continue to be imported annually, vast volumes of local materials such as EW, CDW, IBA, CRF, and desert sand remain underexploited.

**Table 1:** Imported aggregates versus local recycled and secondary resources in Qatar: volumes, trial performance, and utilisation gap.

Material Type	Source	Estimated Annual Volume / Stockpile	Use in Rawdat Rashid Trials	Observed Performance	Utilisation Gap
Imported Gabbro	Imported via Mesaieed & Ras Laffan	~20–25 Mt/year	Control in C40 concrete & blocks	Strong mechanical performance	High dependency; supply chain risk
Imported Limestone	Imported	~5–8 Mt/year	Minor role in CRF blends	Meets QCS limits	Dependency persists
Excavation Waste (EW)	Rawdat Rashid	~5–6 Mt/year inflow	50% substitution in C40; 80% in C20	Equivalent strength; manageable absorption	Largely stockpiled; underutilised
Construction & Demolition Waste (CDW)	Rawdat Rashid	7 Mt/year inflow; 80–100 Mt stockpile	50% substitution in blocks	≥9.9 MPa (above QCS)	Still perceived as low-grade; limited uptake

Incinerator Bottom Ash (IBA)	Domestic Solid Waste Management Centre	~0.05 Mt/year; 1 Mt stockpile	20% substitution in blocks	≥9.0 MPa; stable after 12 months	Mostly landfilled
Crushed Rock Fines (CRF)	Local quarry fines	Not systematically recorded	60% substitution of sand in C40	Slightly >40 MPa; reduced cement by 10%	Treated as waste; limited acceptance
Desert Sand	Local dunes	~90 Mt reserves; 15 Mt/year use	Not trialled in concrete	Considered “unsuitable” due to grading	Abundant but ignored

This comparison reinforces the paradox identified in the Qatari case: while import dependency remains extremely high, equally massive local stocks of secondary resources remain underutilised, highlighting the need for a paradigm shift in defining construction materials.

### Policy and Specification Implications

The utilisation gaps identified in Table 1 underscore that technical feasibility alone is insufficient to shift material practices in Qatar. Bridging the gap between abundant local resources and heavy reliance on imported gabbro required targeted policy reforms. The Rawdat Rashid trials therefore translated their findings into direct recommendations for the Qatar Construction Specifications (QCS 2010), which became the critical vehicle for institutionalising recycled and secondary aggregates (RSA). The trial outcomes directly informed revisions to the Qatar Construction Specifications (QCS 2010). The core recommendations emerging from the Rawdat Rashid study can be summarised as follows:

- Allowing recycled aggregates to be used in higher strength classes (up to C40 concrete), instead of restricting them to low-grade, non-structural applications.
- Raising allowable fines content in aggregates where CRF is used, as higher fines did not correlate with reduced performance.
- Replacing the Sand Equivalent (SE) test with the Methylene Blue (MB) test, offering a more reliable indicator of harmful clay minerals in CRF.
- Reducing the minimum relative density requirement for aggregates (from 2.6 to 2.0 g/cm<sup>3</sup>), thereby preventing the exclusion of technically viable but lighter materials such as EW, CDW, and IBA.
- Setting quantitative recycling targets, including diverting 50% of Rawdat Rashid inflows (~6.25 million tonnes per year) into construction applications by 2016.
- Expanding the scope of RSA applications to unbound sub-base layers, cement bound materials (CBM), and pavement-grade concretes, given the road sector consumes the largest share of imported aggregates.
- Improving CDW quality through soft stripping, i.e., selective removal of lightweight materials (wood, plastics, gypsum, plaster) before crushing and screening, to ensure consistency and reliability.

These recommendations were not abstract suggestions but were directly grounded in field evidence, forming the

basis for policy reform in Qatar.

### Higher Strength Classes (C40)

Prior to the Rawdat Rashid trials, QCS restricted recycled aggregates to non-structural or low-strength applications, effectively marginalising their use. The demonstrated success of EW and CRF in achieving 28-day compressive strengths above 40 MPa proved that RSA could reliably meet structural requirements. This finding removed a key barrier to adoption, as contractors and consultants could now specify recycled aggregates in mainstream C40 concrete. The formal recognition of RSA for higher strength mixes created regulatory certainty and gave industry confidence to invest in recycling infrastructure.

### Fines and Testing Protocols

The trials highlighted major shortcomings in fines quality assessment. The Sand Equivalent (SE) test, traditionally used for natural sands, consistently underestimated the suitability of CRF by misclassifying benign stone fines as harmful. CRF mixes that “failed” SE testing still delivered equal or superior strength compared to controls, revealing the test’s inadequacy. The study therefore recommended the adoption of the Methylene Blue (MB) test as a more accurate measure of clay contamination. This change, along with raising the maximum fines content permissible, acknowledged the inherent differences between natural and manufactured sands and allowed CRF to compete on fair terms.

### Bulk Density Thresholds

QCS previously mandated a minimum aggregate relative density of 2.6 g/cm<sup>3</sup>, which automatically disqualified many secondary aggregates. EW, CDW, and IBA typically exhibited densities in the range of 2.2–2.4 g/cm<sup>3</sup>. Although lighter, these materials proved structurally sound when properly processed and batched. By lowering the requirement to 2.0 g/cm<sup>3</sup>, QCS ensured that aggregates were judged on performance rather than arbitrary density limits. This revision was particularly crucial for IBA, enabling its mainstream use in masonry and block production.

### Quantitative Recycling Targets

Perhaps the most ambitious policy reform was the introduction of specific recycling targets. The study

proposed diverting 50% of Rawdat Rashid inflows ( $\approx 6.25$  million tonnes per year) into construction applications by 2016. This figure was not arbitrary: it aligned with the site's annual intake capacity and demonstrated the scale at which RSA could realistically offset imports. By embedding numerical goals into policy, recycling shifted from a voluntary initiative into a mandated practice, encouraging contractors, developers, and suppliers to adapt. The targets also justified capital investment in advanced sorting, crushing, and processing equipment at Rawdat Rashid.

### Expanding RSA Applications to Road Infrastructure

The study underscored that the largest consumer of aggregates in Qatar was not the building sector but the road and infrastructure sector. Therefore, limiting RSA to blocks and building concrete would have marginal impact. The report explicitly recommended extending future trials to unbound sub-base layers, cement bound materials (CBM), and pavement-grade concretes. Successful integration in these applications would create the largest savings in import substitution and deliver the greatest environmental benefits by reducing quarrying and shipping.

### Soft Stripping for Improved CDW Quality

The trials demonstrated that variability in CDW performance often stemmed from contamination with lightweight materials such as wood, plastics, gypsum, and plaster. To mitigate this, the study recommended adopting soft stripping practices prior to demolition, where such materials are selectively removed at the source before crushing. This would improve the consistency of recycled aggregates, reduce variability in compressive strength, and lower the cost of downstream processing. By integrating soft stripping into demolition contracts, Qatar could significantly enhance CDW quality and maximise its reuse potential.

### Institutional and Regional Impact

These policy and specification reforms represented a watershed moment for Qatar. The QCS updates legitimised RSA in structural concrete, block production, and potentially road applications, establishing a clear regulatory framework that removed uncertainty for contractors. The trials were publicly recognised with the “Most Innovative Project” award at the 2013 Qatar Contractors Forum, accelerating industry acceptance. Collectively, the policy implications illustrate how experimental findings were successfully translated into regulatory action. They also demonstrate that technical performance alone is insufficient to change industry practice; without regulatory frameworks, recycling remains marginal. By embedding RSA into QCS, Qatar set a precedent for the wider Gulf region on how to align construction standards with sustainability objectives, reduce dependence on imported gabbro, and embrace circular economy principles at scale.

### Lessons Learned

The Rawdat Rashid trials yielded several important lessons:

- IBA as a Functional Component: At 20% replacement in blocks, IBA proved safe and effective, showing that industrial ashes can be engineered into construction products rather than landfilled (Lam *et al.*, 2010; Pera *et al.*, 1997).
- EW and CDW as Reliable Substitutes: Excavation and demolition waste, once processed and decontaminated, can replace up to 50% of coarse aggregate in both structural and non-structural mixes. Stockpiles at Rawdat Rashid are estimated at 80–100 million tonnes, offering a vast, untapped supply.
- CRF as a Sand Substitute: With natural washed sand reserves in Qatar estimated at  $\sim 90$  million tonnes, and annual consumption at 15 million tonnes, shortages are inevitable. CRF, proven viable at 60% substitution, is therefore essential to long-term sustainability.
- Institutional Support as a Catalyst: Without updates to QCS and government mandates, industry adoption would have remained marginal. Policy reform is crucial to mainstream recycled aggregates.
- Durability monitoring over 12 months confirmed that RSA mixes including EW, CDW, and IBA showed no evidence of expansion, cracking, or surface deterioration, reinforcing their suitability under Gulf climatic conditions.
- Operationally, the trials highlighted that EW and CRF mixes required closer monitoring of water-to-cement ratios and superplasticizer dosages due to higher absorption and greater slump loss, underscoring the importance of tailored batching controls.
- For CDW, the importance of soft stripping was emphasised: selective removal of wood, plastics, and gypsum prior to crushing significantly improved aggregate quality and reduced variability in block performance.
- Finally, the trials demonstrated that the largest sustainability impact will occur when RSA are extended beyond building concrete into road applications such as unbound sub-base, cement bound materials (CBM), and pavement concretes, sectors which consume the majority of imported aggregates in Qatar.

### The Gulf Paradox: Abundant but Untapped Resources

The Qatari case highlights a paradox common across the Gulf: billions of dollars are spent annually importing gabbro and limestone, while vast volumes of desert sand, fly ash, cement bypass dust, and IBA accumulate unused. Desert sand is often dismissed due to its rounded morphology and fine grading, yet its problem is one of perception and adaptation, not inherent unsuitability. Industrial ashes are treated as liabilities instead of resources. This contradiction reflects a systemic gap in how Gulf nations define and value “construction resources.”

- At Rawdat Rashid alone, stockpiles of excavation and demolition waste were estimated at 80–100 million tonnes,

with annual inflows of approximately 12.5 million tonnes. Similarly, Qatar produces around 0.05 million tonnes of IBA annually, with cumulative stockpiles approaching 1 million tonnes. At the same time, natural sand reserves of around 90 million tonnes are being depleted at a consumption rate of nearly 15 million tonnes per year, highlighting the unsustainable balance between imports and local underutilisation.

- This paradox is not only technical but also economic. While billions of Qatari riyals are spent annually on importing gabbro and limestone through ports such as Mesaieed and Ras Laffan, equally massive volumes of local waste materials remain unused. This creates a dual burden of high import dependency and growing waste management challenges.

- The paradox also has an environmental dimension. Industrial ashes such as IBA, fly ash, and cement bypass dust are treated as liabilities, requiring costly disposal and monitoring. Yet the Rawdat Rashid trials proved that, when properly conditioned, these materials can transition from environmental risks to valuable construction resources.

- Regionally, the Gulf paradox is widespread. In the UAE, the Al Dhafra facility has processed millions of tonnes of C&D waste but utilisation in structural applications remains limited. In Saudi Arabia, large volumes of fly ash from power stations are still landfilled. In Oman, vast desert sand deposits and construction waste streams remain underexploited despite growing aggregate demand. These shared conditions underline that the Qatari case is a microcosm of a broader Gulf-wide challenge.

### Broader Regional Implications

The broader implications of the Rawdat Rashid trials can be framed across three dimensions:

- Economic: By reducing reliance on imports, Gulf nations can lower costs, improve supply-chain resilience, and reduce exposure to international shipping disruptions.

- Environmental: Diverting C&D waste, EW, and IBA from landfills reduces greenhouse gas emissions and supports circular economy goals.

- Strategic: Harnessing local resources enhances material self-sufficiency and aligns with national visions such as Qatar National Vision 2030 and Oman Vision 2040, both of which prioritise sustainability and reduced dependency on external supply chains.

These implications can be elaborated in greater detail as follows:

- Economically, the reliance on imported gabbro has strained port capacity at Mesaieed and Ras Laffan, with millions of tonnes landed annually and transported over long distances at considerable cost. By contrast, utilising on-site resources such as EW and CDW reduces both procurement costs and logistical burdens, freeing up port capacity for other strategic imports. The substitution of local recycled aggregates therefore delivers not only cost savings but also supply chain resilience in the face of

global shipping disruptions.

- Environmentally, the benefits extend beyond landfill diversion. CRF mixes demonstrated a 10% reduction in cement consumption, directly lowering CO<sub>2</sub> emissions from clinker production. Furthermore, the diversion of IBA, CBPD, and fly ash from landfill prevents the release of harmful leachates and methane, turning waste liabilities into carbon-saving resources. Collectively, these outcomes embed circular economy principles into the construction sector while delivering measurable emissions reductions.

- Strategically, the trials revealed that policy reform is the decisive enabler of change. The QCS updates created the regulatory certainty necessary for adoption, and a similar approach could be applied at the GCC level through harmonised specifications. Aligning national efforts under regional frameworks would strengthen resource sovereignty and facilitate cross-border flows of recycled aggregates. By doing so, Gulf nations can accelerate the transition from dependency on imported gabbro to a self-reliant, circular resource economy, fully consistent with Qatar National Vision 2030, Oman Vision 2040, and broader GCC sustainability agendas.

### Synthesis

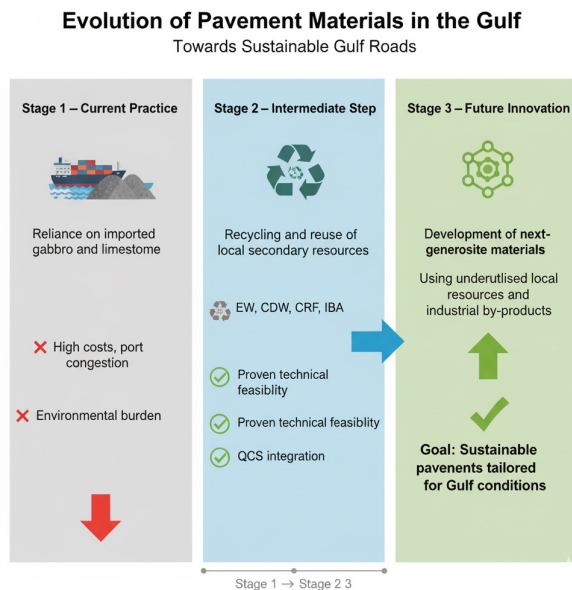
The Qatari experience demonstrates that aggregate scarcity is not simply a geological limitation but a multi-dimensional systems challenge involving technology, operations, policy, industry culture, and economic incentives. The Rawdat Rashid trials proved beyond doubt that recycled and secondary aggregates including EW, CDW, IBA, and CRF are technically and operationally viable under Gulf climatic conditions. Compressive strengths, durability monitoring, and field performance confirmed their functionality, while operational trials highlighted the adjustments required in batching, water demand, and quality control.

Yet the lessons extend well beyond technical feasibility. The decisive factor in mainstreaming these materials was the revision of the Qatar Construction Specifications (QCS 2010), which legitimised their use up to C40 concrete, incorporated CRF-specific testing protocols, adjusted density requirements, and set quantitative recycling targets. These reforms converted experimental findings into enforceable policy, signalling to contractors and consultants that RSA were not experimental curiosities but regulated materials with institutional legitimacy. The synthesis of these findings reveals that the critical challenge is not whether alternatives can work they clearly can but how they can be scaled into national supply chains. Achieving the target of diverting 6.25 million tonnes of Rawdat Rashid inflows annually requires not only technical proof but also investment in recycling infrastructure, reliable demolition and segregation practices, and strong government mandates. This shift from pilot trials to systemic adoption marks the difference between localised innovation and national transformation.

Furthermore, the Qatari case provides a replicable model

for the wider Gulf region. Similar conditions exist in the UAE, Saudi Arabia, and Oman, where imported gabbro dominates supply chains despite abundant underutilised resources such as desert sand, fly ash, cement bypass dust, and vast CDW stockpiles. By adapting the QCS model at a GCC level through harmonised specifications, Gulf nations could reduce collective import dependency, strengthen resource sovereignty, and accelerate progress toward circular economy goals embedded in national visions such as QNV 2030 and Oman Vision 2040. Finally, the synthesis points toward future directions. To maximise sustainability impact, RSA must be expanded beyond building concrete and masonry into road applications, particularly unbound sub-base, cement bound materials (CBM), and pavement concretes the sectors that consume the majority of imported aggregates. The trials at Rawdat Rashid therefore represent not an endpoint but a foundation: a clear demonstration that Gulf nations can redefine what counts as “construction resources” and transition from dependence on imports to a model of local resource valorisation and circular economy resilience. This transition from current reliance on imports, through recycling of local resources, to future innovation in sustainable materials is illustrated in Figure 1.

## CONCLUSION



**Figure 1:** From recycling to innovation: Conceptual pathways for sustainable construction in the Gulf.

The Rawdat Rashid trials in Qatar confirmed that recycled and secondary aggregates (RSA) including excavation waste (EW), construction and demolition waste (CDW), crushed rock fines (CRF), and incinerator bottom ash (IBA) are technically and operationally viable under Gulf climatic conditions. Structural concrete with 50% EW, sand replacement with 60% CRF, and block mixes with 50% CDW or 20% IBA all achieved or exceeded Qatar Construction Specification (QCS) thresholds. Durability

monitoring over 12 months showed no expansion, cracking, or surface deterioration, proving that local waste streams can perform on par with, or even outperform, imported gabbro and limestone when properly processed. The central lesson is that the barrier is not feasibility but mainstreaming. The trials exposed policy, cultural, and logistical challenges that sustain dependence on imports, despite clear technical evidence. They also highlighted the Gulf paradox: massive imports of aggregates coexist with underutilised local reserves of sand, industrial ash, and construction waste. This paradox calls for a redefinition of “construction resources” to include engineered materials derived from abundant but neglected streams. Moving forward, the study recommends expanding RSA use into road infrastructure, particularly unbound sub-base, cement bound materials, and pavement concretes, which consume the largest share of aggregates. Policy reforms should harmonise GCC standards, enforce recycling targets, and provide regulatory certainty to contractors. Operational improvements are needed in CDW segregation, IBA pre-treatment, and batching protocols for EW and CRF. Strategically, integrating RSA into national visions such as Qatar National Vision 2030 and Oman Vision 2040 will advance circular economy goals and strengthen resource sovereignty.

In summary, the Qatari case demonstrates that aggregate scarcity is not a matter of geology but of systems design. By redefining construction resources and embedding RSA into mainstream practice, Gulf nations can transform waste liabilities into strategic assets and lay the foundation for next-generation sustainable materials.

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