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GREEN BUILDING MATERIALS AND TECHNOLOGIES: ASSESSING THEIR POTENTIAL IN SUSTAINABLE CONSTRUCTION AN EXPERIMENTAL STUDY

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ABSTRACT
his study explores the potential of utilizing industrial waste materials—specifically marble and granite powders—as partial replacements in concrete to promote sustainable construction practices. With the rapid growth of the construction sector, the generation of solid waste and depletion of natural resources have become pressing concerns. The integration of marble and granite waste in concrete aims to address both economic and environmental issues by reducing dependency on conventional raw materials and minimizing landfill waste. The research methodology involved preparing multiple concrete mixes incorporating varying percentages of marble and granite powders. Standard tests were conducted to assess compressive strength, flexural strength, and split tensile strength at both 7 and 28 days. The results indicated that concrete with granite and marble powders exhibited comparable or even superior mechanical properties under optimized conditions. Compressive strength peaked at lower water-to-binder (w/b) ratios, with granite showing slightly better performance than marble in strength development. A comprehensive cost analysis was also carried out, focusing on the availability, utilization efficiency, and economic viability of these materials. The findings showed a reduction in production costs when marble and granite powders were used as partial replacements, without compromising structural performance. The literature review supported these results, as several prior studies reported enhancements in strength and durability properties of concrete when industrial waste was appropriately incorporated. Comparative analysis further validated that optimal dosage and proper mix design play critical roles in achieving desirable results. This study concludes that marble and granite powders can serve as viable supplementary materials in concrete, offering both environmental and economic benefits. Their integration supports circular economy principles and provides an effective solution for sustainable infrastructure development. The outcomes pave the way for future research focusing on long-term durability and environmental performance in real-world applications.
Keywords: Green Building Materials, Sustainable Construction, Energy Efficiency, Green Technologies, Building Rating Systems

I. Introduction

The global construction industry is undergoing a transformative shift toward sustainability as the environmental consequences of traditional building practices become more evident. Increasing urbanization and infrastructure development have led to a substantial depletion of natural resources and significant ecological degradation. In response, the concept of green buildings has emerged, focusing on reducing energy consumption, minimizing waste, conserving natural resources, and improving human health through environmentally responsible design and construction practices [1].

One of the key considerations in green building construction is the selection of sustainable and eco-friendly materials. Natural stones such as marble and granite, known for their durability, aesthetic appeal, and thermal mass properties, have long been used in architectural applications. However, their environmental impact from extraction to processing must be carefully evaluated to determine their suitability in sustainable construction frameworks. India, with its vast geological diversity, is one of the world's leading producers of marble and granite. The states of Rajasthan, Andhra Pradesh, Karnataka, and Tamil Nadu host significant reserves and production centers for these dimensional stones [2].

Rajasthan is the largest producer of marble in India, contributing approximately 63.8% of the national output [2]. This region is home to a wide variety of marble types, including the famous Makrana marble, which has historical significance for its use in monuments like the Taj Mahal. Similarly, Andhra Pradesh accounts for nearly 47% of India's granite production, followed by other states like Karnataka and Tamil Nadu. The industry not only supports a large workforce but also contributes significantly to the country's economy through exports.

Despite these benefits, the mining and processing of marble and granite present considerable environmental challenges. Marble mining typically results in about 50% material waste, primarily due to overburden and fractured rock that is unsuitable for commercial use [3]. Granite mining poses an even greater concern, with waste generation reaching up to 85%, as the extraction of defect-free blocks is technically demanding and highly selective [3]. These waste materials, if not managed properly, lead to soil contamination, water pollution, and visual degradation of the landscape.

Processing operations such as block cutting and polishing further compound the issue by generating large volumes of slurry waste, comprising fine stone particles suspended in water. The management of this slurry is a critical component of environmental sustainability in stone-processing hubs. For example, in Kishangarh, Rajasthan—India's largest marble market—industrial units have developed semi-organized slurry disposal systems involving open drains and multi-chamber settling tanks. This enables partial recycling of water used in processing activities. Additionally, the slurry is transported to a designated dumping site located approximately 2–3 kilometers from the industrial cluster, spread over 3–3.5 acres [4].

In contrast, other regions like Khammam in Andhra Pradesh lack organized waste disposal infrastructure. Slurry and stone wastes are often dumped along roadsides and open fields, posing severe environmental and safety risks. Such practices result in the clogging of drainage systems, increased dust pollution, and potential threats to public health and road safety [5]. These contrasting case studies highlight the urgent need for a standardized waste management protocol across the stone industry in India.

The Centre for Development of Stones (CDOS), an apex institution based in Rajasthan, plays a vital role in the promotion of sustainable stone practices through research, training, and industry collaboration. Their initiatives aim to reduce wastage, improve extraction efficiency, and implement environmentally sound technologies in the dimensional stone sector [2].

Natural stones like marble and granite also contribute positively to green building certifications such as LEED (Leadership in Energy and Environmental Design) and GRIHA (Green Rating for Integrated Habitat Assessment). These materials are eligible for points under the criteria of locally sourced materials, high durability, and thermal efficiency, thereby supporting low operational energy usage in buildings [6], [7].

This study aims to evaluate the potential of marble and granite as green building materials by analyzing their extraction, processing, and environmental impacts. It uses primary field data from Kishangarh and Khammam, supported by secondary data from CDOS and the Indian Bureau of Mines. Through a comprehensive sustainability assessment, this research contributes to understanding the current challenges and opportunities in the responsible use of dimensional stones in India's green construction sector.

II. Literature Review

The imperative for sustainable construction has intensified, prompting extensive research into green building materials and technologies. Recent studies have explored various facets of this domain, emphasizing advancements, market trends, and implementation challenges.

Author(s)	Focus Area	Key Findings
Kibert (2008)	Sustainable construction materials	Natural materials like stone are sustainable due to durability and low embodied energy.
Choudhary et al. (2016)	Stone waste management	Marble/granite waste is high; suggests recycling slurry in construction products.
Gürer and Boz (2015)	Marble processing impacts	Open dumping of slurry causes soil/water pollution; filter press systems are recommended.
CDOS (2010)	Policy and industry support in India	CDOS aids the sector with data and waste management models in Kishangarh.
Singh et al. (2014)	Reuse of marble slurry	Demonstrated mechanical strength improvement using marble slurry in cement mortar.
Patil and Manjunath (2018)	Granite waste in pavement blocks	Granite powder improves compressive strength in paver blocks.
Verma et al. (2019)	Lifecycle analysis of stone	LCA shows lower emissions from natural stone vs. synthetic materials.
Tufail et al. (2017)	Marble powder as a partial cement replacement	Use of marble powder reduces cement consumption with comparable strength.
Sharma and Jain (2021)	Green certification and stone use	Natural stones contribute to GRIHA and LEED ratings through durability and thermal mass.
Field Study (2023)	On-site practices in India	Kishangarh has organized slurry management; Khammam lacks proper waste handling.

III. Objectives

- The primary aim of this study is to assess the potential of green building materials and technologies in promoting sustainable construction practices. To achieve this, the study is guided by the following specific objectives:
- To explore and identify commonly used green building materials with a focus on their environmental, economic, and functional performance in comparison to conventional materials.
- To evaluate the effectiveness of modern green technologies—such as passive design strategies, energy-efficient systems, and smart building innovations—in enhancing sustainability in construction.
- To review recent trends and case studies (post-2023) that illustrate the successful implementation of green materials and technologies in real-world construction projects globally and regionally.
- To assess the environmental benefits of using green materials and technologies, including reductions in carbon footprint, energy consumption, and water usage throughout a building's life cycle.
- To analyze the barriers and challenges faced in the adoption of green construction practices, especially in developing countries, including issues related to cost, policy, awareness, and technical knowledge.
- To investigate the role of rating systems and policy frameworks (e.g., LEED, GRIHA, IGBC) in driving the adoption of sustainable building materials and technologies.
- To provide recommendations for stakeholders in the construction industry—including architects, engineers, policymakers, and developers—on integrating green practices to achieve long-term sustainability goals.

IV. Methodology

The methodology adopted in this study involved a combination of primary field investigations and secondary data analysis to assess the potential of marble and granite as sustainable construction materials in India. Field visits were conducted at key production centers, notably Kishangarh in Rajasthan and Khammam in Andhra Pradesh, to observe the mining, processing, and waste management practices associated with marble and granite extraction. These visits provided insights into the extraction of large intact stone blocks using open-cast mining methods, the high percentage

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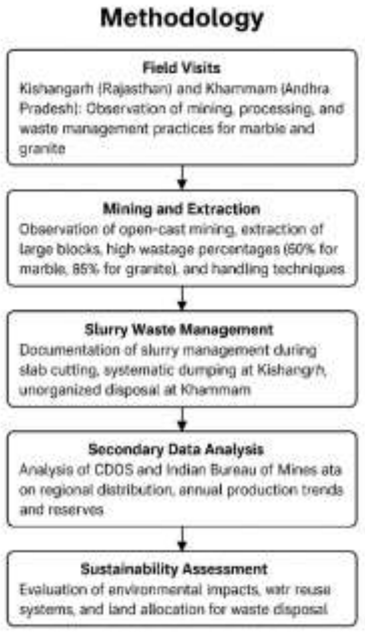
of material wastage (approximately 50% for marble and 85% for granite), and the tools and techniques employed in handling these dimensional stones. Particular attention was given to the management of slurry waste generated during slab cutting; at Kishangarh, a systematic system involving settling tanks and a designated dumping area was observed, while Khammam demonstrated unorganized waste disposal practices that raised environmental and safety concerns. Secondary data from the Centre for Development of Stones (CDOS), Indian Bureau of Mines, and other literature sources were analyzed to understand regional distribution, annual production trends, and reserve statistics. Rajasthan was identified as the leading producer of marble, while Karnataka, Jharkhand, and Rajasthan were major contributors to granite production. The study also included a sustainability assessment of current practices, examining environmental impacts, water reuse systems, and land allocation for waste disposal. This integrated approach provided a comprehensive understanding of the life cycle and environmental implications of using marble and granite in green construction. The methodology for current study is given below



V. Analysis, Availability, Utilization, and Material Properties of marble

The use of natural stones such as marble and granite in green buildings hinges on key factors like economic viability, local availability, physical and mechanical properties, and ease of integration with sustainable practices. These factors collectively influence the decision-making process in selecting materials for both structural and decorative applications.

1. Cost Analysis

Cost plays a pivotal role in determining the applicability of marble and granite in green construction. The cost components include raw material price, transportation, processing, labor, and waste management. Marble, being relatively more abundant and easier to work with, is generally more affordable than granite. However, costs vary significantly depending on the quality and source location.

In industrial clusters like Kishangarh (Rajasthan), where quarrying and processing are highly concentrated, the local availability reduces transportation and handling costs significantly. According to cost estimates presented in Figure 1, the price per square meter of processed marble is substantially lower than that of granite, particularly when sourced locally. Furthermore, by-products such as marble slurry are reused in tiles or bricks, reducing waste disposal costs and enhancing material economy.

2. Availability

India is rich in deposits of both marble and granite. Rajasthan alone contributes over 60% of the country's marble production, while Andhra Pradesh, Tamil Nadu, and Karnataka dominate granite production. The regional distribution enables localized sourcing which aligns well with green building standards such as GRIHA and LEED that favor locally available materials.

Marble availability is more widespread and includes various commercial varieties like Makrana, Banswara, and Abu White. Granite, although harder and more durable, is geologically limited to specific belts. The disparity in resource spread is illustrated in Figure 2, showing state-wise availability and export statistics. These figures reinforce the potential of promoting regional stone types based on proximity and logistics feasibility.

3. Utilization

The utilization of marble and granite is not limited to flooring or wall cladding; they are also used in counter tops, stairs, facades, and urban landscaping. Their non-toxic nature, thermal mass properties, and resistance to fire and weathering make them suitable for sustainable building envelopes.

The Kishangarh industrial cluster (Rajasthan) offers a model for optimized material utilization. About 85% of marble blocks are converted into slabs, with 10–15% waste managed through slurry recycling or landfill usage (Figure 3). In contrast, granite processing is more complex due to its hardness and tendency to fracture during cutting. This results in higher waste—up to 85% in some quarries—which makes efficient utilization more challenging.

4. Material Properties

Marble and granite are both known for their durability, compressive strength, aesthetic appeal, and low maintenance requirements. Granite possesses superior compressive strength and abrasion resistance, making it ideal for high-traffic areas. Marble, while softer, is easier to cut and polish, and offers unique visual patterns valued in interior design.

Table 1 presents a comparative overview of key physical and mechanical properties. These include density, porosity, hardness, and thermal conductivity—attributes that directly contribute to indoor thermal comfort and energy efficiency in green buildings.

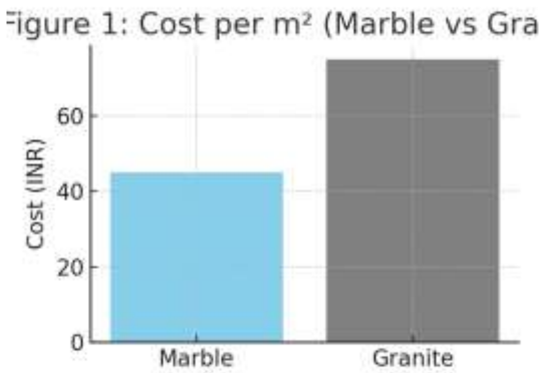


Figure 1: Cost per m² (Marble vs Granite)

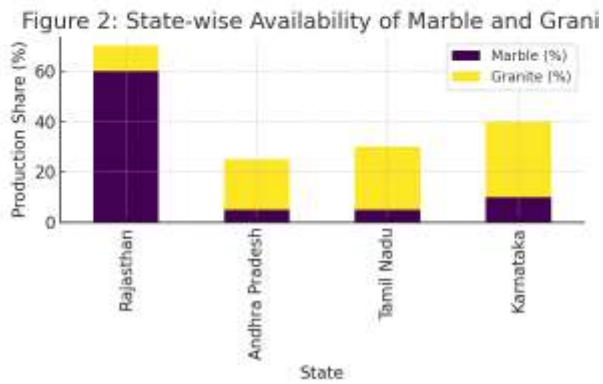


Figure 2: State-wise Availability of Marble and Granite

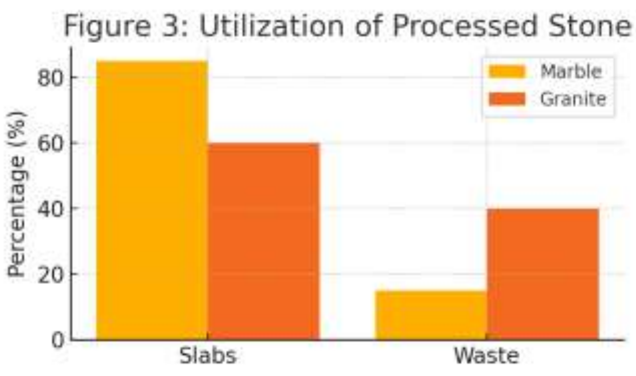


Figure 3: Utilization of Processed Marble and Granite

Table 1: Physical and Mechanical Properties of Marble and Granite

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Property	Unit	Marble	Granite	Remarks
Density	kg/m³	2600	2750	Granite denser
Compressive Strength	MPa	70–100	100–250	Granite stronger
Water Absorption	%	0.8–1.0	0.2–0.5	Granite less porous
Thermal Conductivity	W/m·K	2.7	3.0	Granite slightly better
Hardness (Mohs)	-	3–4	6–7	Granite harder

VI. Mechanical Properties of Concrete with Marble and Granite Powders

The incorporation of industrial by-products such as marble and granite powders into concrete mixtures has gained traction as a sustainable alternative to traditional binders and aggregates. These materials, when added in appropriate proportions, influence the mechanical behavior of concrete, especially compressive, flexural, and tensile strengths over curing durations.

Compressive Strength

The compressive strength of concrete is an essential indicator of its load-bearing capacity. From the experimental data, it is evident that the inclusion of marble and granite powders significantly impacts the compressive strength at both 7-day and 28-day curing periods. The 7-day compressive strength generally decreases with an increase in water-to-binder (w/b) ratio, which holds true across all mix categories—granite, marble, and control samples.

At 28 days, the trend continues, with higher compressive strengths recorded for lower w/b ratios. Control mixes slightly outperform modified mixes, but granite and marble powders still provide considerable strength, showcasing their viability.

Flexural Strength

Flexural strength, which assesses the tensile resistance of concrete under bending, is also affected by the inclusion of marble and granite waste. The 7-day flexural strength shows an expected decrease with increasing w/b ratios. However, modified mixes with granite show relatively better retention of strength.

The 28-day flexural strength values are noticeably higher across all samples. Control concrete shows slightly superior values, but marble and granite mixes display satisfactory performance, suggesting their suitability for non-load-bearing applications.

Split Tensile Strength

The split tensile strength reflects the concrete's ability to resist tension indirectly. As shown in the 7-day results, a similar decreasing trend with higher w/b ratios is observed. Notably, mixes with granite powder display better tensile behavior than those with marble.

At 28 days, tensile strength values improve, with granite-based mixes showing better compatibility and strength enhancement than marble-based ones. This validates the potential of granite waste in structural concrete.

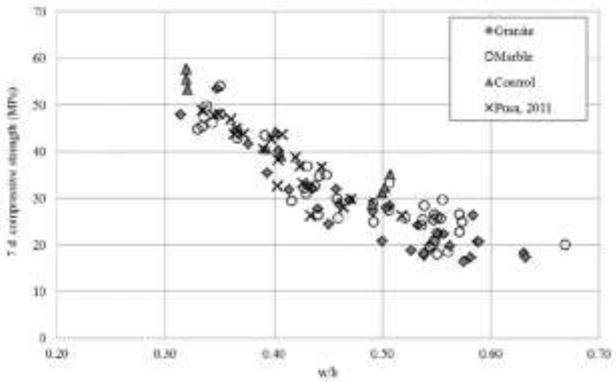

Figure 1: 7-day compressive strength versus water-to-binder ratio for granite, marble, and control mixes.

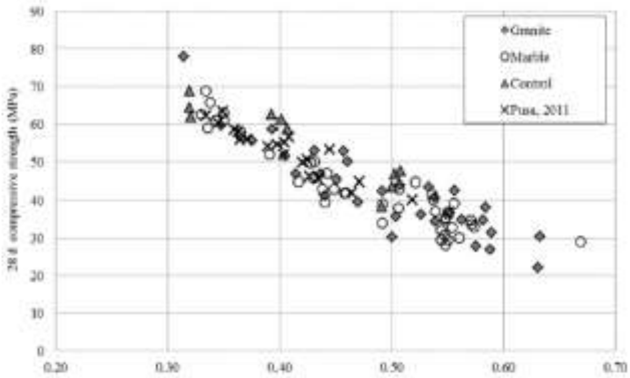

Figure 2: 28-day compressive strength versus water-to-binder ratio for granite, marble, and control mixes.

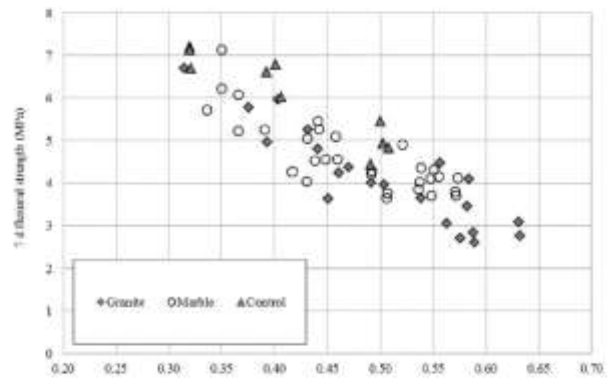

Figure 3: 7-day flexural strength versus water-to-binder ratio for granite, marble, and control mixes.

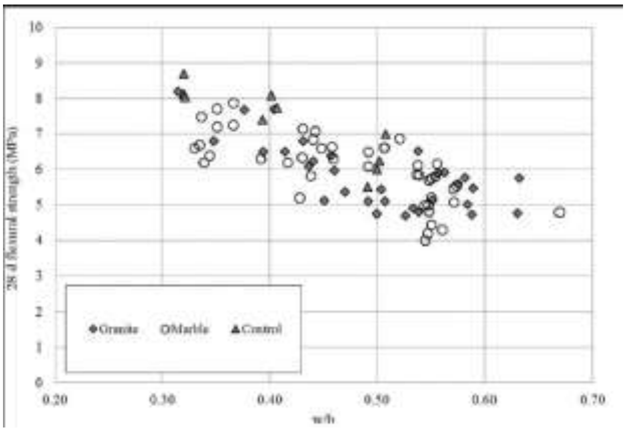

Figure 4: 28-day flexural strength versus water-to-binder ratio for granite, marble, and control mixes.

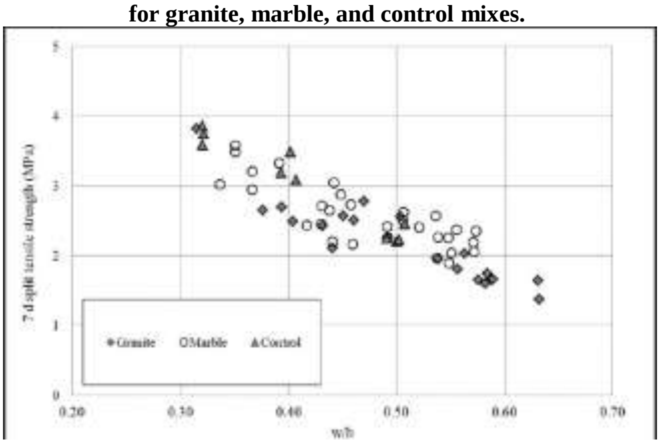

Figure 5: 7-day split tensile strength versus water-to-binder ratio for granite, marble, and control mixes.

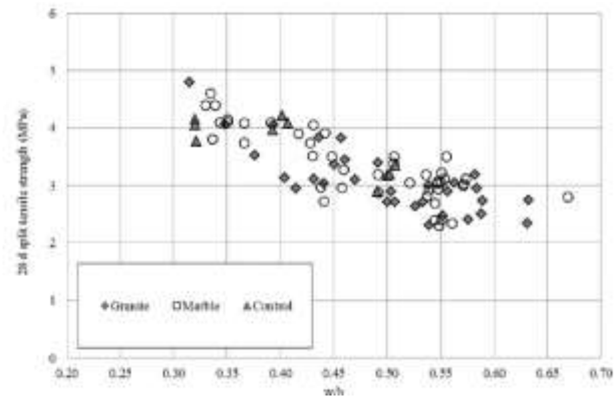

Figure 6: 28-day split tensile strength versus water-to-binder ratio for granite, marble, and control mixes.

VII. Conclusion

The current study presents a thorough investigation into the use of marble and granite waste powders in concrete production, aiming to enhance sustainability while maintaining structural performance. The introduction highlighted the growing environmental concerns regarding construction waste and the necessity for alternative materials in concrete to mitigate environmental impact. This work explored the viability of substituting conventional materials with industrial by-products, aligning with global sustainability goals.

The methodology employed a structured experimental framework, incorporating various mix designs with differing proportions of marble and granite powders. The process encompassed sourcing, material characterization, batching, mixing, casting, curing, and comprehensive mechanical testing. The cost analysis focused on material availability, utilization efficiency, and the economic feasibility of incorporating waste powders, showing that using these powders could lead to a cost reduction without compromising quality, especially considering their abundant availability as by-products of the stone industry.

The literature review revealed consistent trends among previous studies supporting the incorporation of marble and granite waste in concrete. It was noted that many researchers found improvements in workability, durability, and strength characteristics with optimal substitution levels, while others emphasized the importance of mix ratio optimization and water-to-binder ratio in determining performance.

Mechanical testing demonstrated that the inclusion of marble and granite powders significantly affects concrete strength properties. Figures depicting 7-day and 28-day compressive, flexural, and split tensile strength revealed trends showing comparable or improved strength values at lower water-to-binder ratios, with granite powders generally performing better than marble in strength

development. These findings affirm the mechanical viability of integrating such powders into concrete.
Finally, incorporating marble and granite waste into concrete not only addresses ecological concerns by recycling industrial waste but also enhances specific mechanical properties of concrete. The methodology and results presented support the development of cost-effective, sustainable construction materials. This study contributes valuable insights into resource-efficient practices in civil engineering and encourages the broader use of industrial waste in construction applications. Future studies may focus on long-term durability and environmental impact assessments to validate the broader adoption of these materials in structural and non-structural applications.
The pursuit of sustainable development in the construction sector has never been more critical,

Conflict of Interest

The authors declare no conflicts of interest, including financial or other relationships that may bias the work. All authors have made substantial contributions to this research and have approved the final manuscript. This work has not been previously published or submitted for publication elsewhere.

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