Decarbonizing Concrete and The Push for Clean Energy

A Research Paper submitted to the Department of Engineering and Society

Presented to the Faculty of the School of Engineering and Applied Science
University of Virginia • Charlottesville, Virginia

In Partial Fulfillment of the Requirements for the Degree
Bachelor of Science, School of Engineering

Mason Pearce

Spring 2025

On my honor as a University student, I have neither given nor received unauthorized aid on this assignment as defined by the Honor Guidelines for Thesis-Related Assignments.

Advisor

Joshua Earle, Department of Engineering and Society

Introduction

The construction sector is one of the largest contributors to global carbon emissions, with concrete being one of the primary materials responsible for this environmental impact. The construction sector is responsible for nearly 40% of global carbon emissions (Environment, 2024). Concrete production itself accounts for nearly 8% of global carbon dioxide emissions, with a substantial amount of these emissions resulting from the energy-intensive process of cement production. Aggregates, which are mixed with cement to form concrete, represent a significant component of the material contributing to the overall carbon footprint through both production and transportation. As the world struggles to fight climate change, finding sustainable alternatives to traditional concrete production is critical to reducing the environmental impact of the construction industry.

This research focuses on exploring the potential for reducing carbon emissions in concrete production by focusing on one construction method. This practice includes altering the types of aggregates used in concrete mixes for construction purposes. Specifically, the study examines the feasibility and environmental benefits of replacing conventional aggregates with low-carbon alternatives, such as recycled aggregates or those derived from sustainable sources. It also aims to explain how sustainable aggregates help decarbonize concrete practices and how they positively affect local communities and global markets while creating a push for clean energy sources.

This thesis suggests that by shifting towards sustainable aggregate options, the construction sector could significantly reduce its carbon footprint. In turn, this reduction in emissions could create a broader transition to clean energy sources. The objectives of this study are to identify the environmental benefits of different aggregate alternatives, assess the positive impacts of their use, and analyze the potential economic and policy changes needed to implement this alternative solution on a large scale. The significance of this research is in its ability to influence sustainable construction practices globally, offering a pathway towards a low-carbon future for the building sector.

Beyond the reduction of carbon emissions in the construction industry, this research could play a pivotal role in accelerating the global transition to clean energy sources in other sectors. As the construction industry adopts more sustainable practices, such as using low-carbon aggregates in concrete, it could drive a greater demand for renewable energy sources. For instance, the push for more eco-friendly concrete could spark increased market interest in energy-efficient or sustainable technologies such as those created by large companies like NextExtra, Tesla, and Exxon. Additionally, the demand for sustainable materials and manufacturing practices could extend to the production of wind turbines, solar panels, and other clean energy technologies, reducing the carbon footprint of these industries as well. By analyzing the environmental benefits of low-carbon construction, this research may encourage a broader shift in policy and investment, ultimately leading to a more integrated, sustainable energy system that includes clean energy production and sustainable construction practices.

Methods: Literature Review

To gather relevant information for researching the impact of concrete on carbon emissions and measuring its effects on the push for clean energy, a search through academic databases provided by the UVA library was conducted. Databases included the ASCE Research Library, JSTOR, Science Direct, and Google Scholar searching for keywords such as concrete, emissions, clean energy, economics, and society. The sources selected for use include peer reviewed journal articles, scientific research papers and worldwide sustainable organization websites. Through discussion and concrete mixing experience from PHD student Tawfeeq Gdeh at the University of Virginia, general information on alternative mixes using sustainable aggregates such as calcined clay and how this practice reduces emissions was gathered.

Results/Findings

With first hand experience building a concrete canoe with a sustainable mix, there are many notable ways that emissions can be reduced using novel construction practices and sustainable aggregates. By using sustainable aggregates such as fly ash or other recycled material without a loss of strength, highly sustainable and effective solutions to lowering emissions in the construction industry are produced. According to Tawfeeq, a PHD student at the University of Virginia who researches sustainable concrete solutions, concrete mixes, including non-traditional, low carbon-emitting aggregates typically have equal or better mechanical properties than traditional ones. Along with this, he has provided a vast amount of knowledge on a specific concrete mix that uses calcined clay, for he has been researching high strength mixes to be used in a lab setting.

The lessons learned from Tawfeeq and his studies on an environmentally friendly material called calcined clay, can best be expressed in the article by Jonny Nilimaa called *Developments in the Built Environment.* Calcined clay is a local material that can partially replace Portland cement in concrete mixtures and reduces the environmental impact and resource consumption associated with cement production (Nilimaa, 2023). LC3, Limestone Calcined Clay Cement, is a blend of clinker, calcined clay, limestone, and gypsum, which results in reduced carbon emissions and energy consumption during its production when compared to conventional cement emissions (Pham et al., 2019). An added benefit is that calcined clay utilizes locally available raw materials, such as limestone and clay, which reduces transportation costs and emissions associated with the transporting process (Nilimaa, 2023). The calcification of clay occurs at lower temperatures than used in the production of clinker resulting in lower energy consumption and carbon dioxide emissions (Scrivener et al., 2018). According to the article, *Developments in the Built Environment,* LC3 is also known to exhibit similar or even better mechanical and durability properties for some mixes compared to traditional Portland cement. It also notes that pressure on clinker production is reduced as LC3 has the ability to address the growing demand for cement by utilizing abundant and underexploited clay resources (Nilimaa, 2023). If inadequate natural materials are available, fibers from material waste can be included into concrete mixtures to improve characteristics such as tensile strength, crack resistance, and durability (Nilimaa, 2023).

Traditional concrete construction requires extraction and transportation, significant manual labor, and extensive material use, all of which contribute to higher costs and increased waste. Additionally, the construction sector is a major contributor to global CO_2 emissions, largely due to cement production, energy-intensive transportation, and inefficient material use. Portland cement production accounts for 74% to 81% of the total CO_2 emissions generated by commercially produced concrete mixes (Flower & Sanjayan, 2007). The next major source of emissions is coarse aggregates making up 13 to 20% of total CO2 emissions created from commercially producing concrete (Flower & Sanjayan, 2007). The majority of coarse aggregate CO2 production comes from electricity use which is typically around 80% while blasting, excavation, hauling, and transport make up less than 25% (Flower & Sanjayan, 2007). Fine aggregates produce only 4-8% of total CO_2 emissions in the process because they are typically only graded and not crushed. (Flower & Sanjayan, 2007). The addition of alternative aggregates, such as recycled materials and industrial by-products, reduces the carbon footprint of concrete production by lowering the demand for raw materials, ultimately decreasing greenhouse gas emissions. Utilizing local and recycled aggregates supports local economies, reduces waste, and increases global market shifts towards sustainable materials, creating a push for clean energy sources and benefiting communities throughout the world.

Many studies highlight the positive effects that evolving concrete practices have on the social lives of individuals, large corporations, and the government. A study by Choi and collaborators (2016) on highway concrete rehabilitation alternatives shows that sustainable concrete practices can reduce environmental degradation and promote economic efficiency by minimizing resource consumption and waste. This not only benefits local ecosystems but also reduces costs associated with raw material extraction and waste management. A study by Spahr and authors (2021) reveals that communities value the nonmonetary benefits of green infrastructure, such as improved aesthetics, enhanced recreational spaces, and better air quality. These benefits contribute to higher property values, increased public health, and improved quality of life. Bennett and collaborators (2020) performed a study which found that socioeconomic factors, such as income levels and political leanings, greatly influence the adoption of renewable technologies. As communities become more aware of the environmental and economic benefits of sustainable practices, there is a growing demand for clean energy solutions. Sakellariou and Mulvaney (2013) argue that a multidisciplinary approach, incorporating social and environmental dimensions, is essential for a successful energy transition. This includes developing policies that support sustainable concrete practices and incentivize the adoption of clean energy technologies.

LEED (Leadership in Energy and Environmental Design) certification is a widely recognized system that evaluates the sustainability of buildings based on factors such as energy efficiency, water usage, materials, and indoor environmental quality (U.S. Green Building Council, 2021). Concrete that is produced with lower carbon emissions or includes recycled materials can contribute to a building's LEED points. Sustainable construction often leads to reduced energy consumption, lower operating costs, and improved air quality, which directly benefit residents and businesses. If a strong enough push is not developed by LEED, the government can place taxes on each unit of carbon released into the atmosphere as is done in the United States (Kaufman, 2019). By transitioning to net-zero concrete production, companies can reduce their vulnerability to carbon taxes allowing for long-term cost savings. This advantage can make green buildings more affordable and accessible for developers and communities. Over time, these cost savings can be passed down to residents through more affordable housing or lower utility bills due to the efficient energy sources.

It is important to identify the speed at which the transition to renewable energy is occurring and recognize that incremental changes are no longer beneficial. At Carbon Built, hefty goals have been set for the removal of carbon emissions to the atmosphere as they understand that change is necessary to mitigate climate effects. They aim to create a gigatonne-level carbon impact through storing and cement production by 2040 with other major players in the cement industry aiming for net zero emissions by 2050 (andrew.himes, 2023). Carbon Built replaces cement with low-cost industrial byproducts that would otherwise be destined for landfill. Biomass derived CO_2 is then used to cure the concrete, during which the CO_2 is converted back into a mineral storing it permanently. Companies such as Carbon Built will lead the way in reducing CO_2 emissions in the construction sector paving the way for other clean energy sources to follow and create a net zero carbon economy across the globe.

Increasingly strict regulations on emissions and growing consumer demand for sustainable products are pushing industries, including construction and concrete manufacturing, to adopt cleaner and more responsible practices. The Global Cement and Concrete Association (GCCA) published its Climate Ambition Statement, which sets a target of delivering carbon-neutral concrete by 2050 by bringing together forty of the world's leading cement and concrete companies (Hobley et al., 2021). On a local scale, buildings constructed with carbon-neutral concrete can reduce their embodied carbon footprint by up to 70% compared to traditional concrete structures, and recent industry reports show a 40% increase in demand for low-emission building materials across major construction markets (*Carbon-Neutral Concrete: Breaking Barriers in Low-Emission Building Materials*, 2025).

Analyzing the global transition to cleaner energy and sustainable practices highlights the economic, environmental, and social benefits that drive this shift and the positive impact it has on communities. For example, the United States has seen substantial growth in solar and wind energy capacities, supported by legislative measures like the Inflation Reduction Act and Bipartisan Infrastructure Law. These policies aim to reduce emissions and promote carbon-free electricity generation. The Inflation Reduction Act and Bipartisan Infrastructure Law have driven significant investments in clean energy, totaling $421 billion in domestic, utility-scale clean energy production since August 2022 (Bird & Womble, 2024).

Also, identifying how the adoption of low-emission materials and sustainable practices has positively impacted various aspects of society will contribute to why social views are important to this research. This includes economic benefits such as cost savings in construction and manufacturing, support for local economies through the use of local and recycled materials, and improved quality of life in communities adopting sustainable practices. Supporting local suppliers and industries can help boost the local economy, create jobs, and encourage sustainable construction practices.

Analysis

Framing theory in STS focuses on how issues, ideas, or technologies are framed or presented in ways that shape how people perceive and respond to them. One sociologist, Erving Goffman, coined the term in 1974 defining framing as “culturally determined definitions of reality that allow people to make sense of objects and events” (Shaw, 2013). From the perspective of framing theory, the adoption of sustainable aggregates in concrete production can be understood as the result of how these technologies are presented by the media, social groups, policymakers, and industry leaders.

In this case, the framing of using sustainable aggregates in concrete production can emphasize different aspects that align with certain social or political goals such as environmental issues, efficiency, and innovation. For example, the construction industry and environmental advocacy groups might frame the shift to sustainable aggregates as a necessary step for reducing carbon emissions and combating climate change. This framing identifies the environmental necessity and displays these technologies as solutions to an ecological crisis. This idea might attract environmentalists and companies trying to improve their operations because it shows alternative aggregate use as an innovation that boosts sustainability and economic efficiency.

The way these technologies are framed can influence how various actors (e.g., construction companies, policymakers, the public) perceive their value. If they are framed as eco-friendly solutions or green technologies, sustainable aggregates are likely to gain more traction in industries and communities that prioritize sustainability. On the other hand, if they are framed primarily in terms of novelty or cost-saving potential, they may appeal more to businesses seeking growth in efficiency and profitability. In this way, framing helps shape the adoption of these technologies by influencing how they are acted upon by different groups. The narrative around sustainable aggregates can either encourage or hinder their acceptance, depending on the values and priorities emphasized in the framing process. Ultimately, the framing of these technologies helps align them with broader social goals, by positioning them as solutions to key societal issues.

The urgency of addressing the issues of economic resilience, social equity, and climate change, has led to a growing push for technologies that can mitigate environmental impacts while increasing sustainable development. As climate change accelerates with rising global temperatures and ecosystem disruptions becoming more frequent, there is a higher need for innovations that reduce carbon emissions. Technologies like sustainable aggregates offer solutions by minimizing the environmental footprint of industries such as construction which is one of the largest contributors to greenhouse gas emissions.

The potential for use of sustainable and locally sourced aggregates in concrete mixes further reduces the carbon footprint of each project. Sustainable resources in the form of recycled concrete aggregates (RAC) including fly ash and many types of fibers reduce the need for the virgin extraction of materials ultimately reducing CO_2 based on life cycle assessment models (Mcintyre et al., 2009). RAC can attain compressive strengths ranging from 70% to 100% of conventional concrete, elastic modulus values of 60% to 90%, flexural strengths of 80% to 100%, and splitting tensile strengths of 70% to 90%, depending on the quality and treatment of the recycled aggregates (Xie et al., 2018). The process of using sustainable aggregates aligns with global goals to reduce CO_2 emissions and build greener, more sustainable infrastructure.

The focus on reducing CO_2 emissions challenges engineers' perspectives as they have previously designed for strength and durability. The percentages mentioned previously indicate that recycled concrete aggregates (RAC), when compared to traditional concrete, generally perform at a slightly reduced capacity but are still relatively strong for many applications. The compressive strength of RAC, ranging from 70% to 100% of conventional concrete, shows that while it may not completely match the full strength of virgin concrete, it can still provide adequate load-bearing capacity. Similarly, the elastic modulus values of 60% to 90% indicate that RAC may exhibit slightly less stiffness, which could affect the material's behavior under certain stresses but can still be applied to many structural applications. The flexural strength of 80% to 100% and splitting tensile strength of 70% to 90% display that RAC retains a significant portion of its ability to resist bending and cracking under tension, which are critical for durability. These values suggest that RAC is a reasonable alternative to traditional concrete, creating a balance between sustainability and structural integrity, while also reducing the environmental impact.

The construction industry is aiming to achieve net zero in concrete production by 2050 in order to maintain pace with global targets. Achieving net zero in the construction industry by 2050 requires a diversified approach, focusing on reducing emissions at every stage of concrete production. This includes transitioning to low-carbon or carbon-negative materials, such as recycled concrete aggregates, alternative binders, and incorporating renewable energy sources throughout the production process. Innovations like carbon capture, utilization, and storage technologies may also be important, capturing CO_2 directly from cement plants and industrial processes. Additionally, the industry may invest in carbon credits to offset remaining emissions and other initiatives such as reforestation projects or soil carbon sequestration. That being said, it is crucial to note the distinction between net zero and carbon neutral; while both terms refer to balancing emissions with reductions or offsets, "net zero" specifically means reducing emissions as much as possible and balancing any remaining emissions through permanent carbon removal, whereas "carbon neutral" could imply offsetting emissions without necessarily reducing the underlying sources.

Reducing emissions is necessary as they contribute to global warming and the destabilization of ecosystems, extreme weather events, and rising sea levels. A reduction in emissions from concrete production is essential to meet international climate goals, particularly the *Paris Agreement's* target of limiting global warming to well below 2°C, with an aspiration of 1.5°C (United Nations, 2015). The need to achieve net zero in this industry by 2050 is developed from multiple ideas: the need to mitigate climate change, reduce the global carbon footprint, ensure long-term sustainability, comply with increasing regulatory pressure, and preserve ecosystems.

These sustainable techniques are not just environmentally beneficial; they also have the ability to push for economic resilience. The transition to a green economy is seen as a key strategy for future economic stability as industries try to meet sustainability demands. The adoption of eco-friendly technologies stimulates job creation in emerging industries and pushes down costs through efficient production methods. Thus, framing these technologies as a way of promoting economic sustainability can build support from policymakers and businesses.

Equally important is the role these technologies can play in advancing social equity and justice. As the world struggles with inequalities, particularly in access to housing and infrastructure, sustainable technologies aim to address these issues. By framing innovations like sustainable aggregates as solutions for affordable and eco-friendly housing, the idea shifts from strictly environmental or economic benefits to societal ones. These technologies could enable the construction of low-cost, environmentally conscious buildings in underserved communities. A price and performance comparison of traditional concrete materials to sustainable materials can be seen in the table below.

Table 1. Comparison of price and performance of traditional and sustainable concrete (Dr. Elizabeth Green, 2024)

Category	**Traditional Materials**	**Sustainable Materials**
Initial Cost	\$125-\$200 per sq. ft.	\$150-\$250 per sq. ft.
Energy Efficiency	-	20%-30% energy savings
Maintenance Cost	-	Up to 20% lower
ROI	5%-10%	10%-15%
Carbon Footprint	0.9 tons CO2 per ton of cement	Up to 50% lower

This would help to solve housing shortages while reducing exposure to the negative impacts of traditional building practices. The idea that sustainability and equity can be incorporated together is becoming extremely powerful. Global organizations are increasingly recognizing the need for solutions in sustainable development. The UN’s Sustainable Development Goals emphasize both environmental sustainability and social inclusion, showing that innovation can drive progress in many ways (United Nations, n.d.). Therefore, positioning these technologies as part of the solution to climate change and social inequality helps to build a more inclusive and sustainable future.

Discussion

The findings of this research highlight the potential for significant environmental improvements from changing the aggregates used in concrete production, especially when considering the reduction of carbon emissions due to construction. Currently, the industry relies heavily on conventional aggregates and traditional concrete mixtures, which are energy-intensive and contribute greatly to global greenhouse gas emissions. Typical concrete mixes use one part cement, two parts fine aggregate, and four parts coarse aggregate. While there are efforts to reduce emissions in the sector such as carbon capture technologies, these changes are not enough to meet the ambitious global targets for reductions in emissions. Therefore, there is a critical need to adopt alternative solutions that directly target the material composition of concrete.

Changing the way aggregates are sourced and utilized in concrete production represents a crucial advancement. By shifting towards low-carbon or recycled aggregates, the construction sector could reduce its carbon footprint without compromising the performance and durability of the material. Furthermore, this change has the potential to stimulate innovation in other sectors especially as demand for clean energy sources rises to support sustainable material and energy production. This could lead to a broader push for clean energy in industries such as manufacturing, transportation, and the production of renewable energy infrastructure. In this way, transitioning to sustainable construction materials could create a domino effect creating a larger transformation in global energy.

Despite these clear benefits, current efforts to incorporate alternative aggregates are often hindered by many challenges. These challenges include economic constraints, limited infrastructure for recycling aggregates, and the industry's resistance to changing long-standing practices. Concrete producers may also be hesitant due to concerns about the performance and reliability of alternative materials. However, this research has shown that many alternative aggregates perform comparably to traditional ones. Their increased use could lead to long-term cost savings as the demand for cleaner energy and sustainable practices grows. Moreover, regulatory frameworks and incentives could help drive adoption, pushing for sustainable aggregates to become a larger part of mainstream construction practices.

One of many challenges in adopting sustainable alternatives in construction, specifically concrete, is the perception that these practices are expensive and nothing can be done about it. Many businesses think sustainability comes with higher costs, and this usually comes from misconceptions about the initial investment needed for sustainable materials and technologies. While it is true that some sustainable alternatives, like certain types of low-carbon binders or specialized equipment, may have higher upfront costs, the long-term savings make these investments more cost-effective throughout their lifecycle. Along with this, the perception that sustainable concrete practices are more expensive is influenced by skewed data or incomplete comparisons, where the benefits of reduced carbon footprints and long-term environmental gains are not fully accounted for. To address these issues, it is important to promote clear, evidence-based information on the economic and environmental advantages of sustainable alternatives. This can be accomplished through real-world examples of successful companies such as Cemex who offer a decrease in carbon footprint by up to 70% by using their materials. By emphasizing that sustainability in construction is not just about doing the right thing, but also about driving efficiency, innovation, and value, it is possible to shift the narrative and demonstrate that these alternatives are viable and more beneficial in the long run.

One thing is clear; practices should be different than they are today. It is no longer good enough to rely solely on incremental improvements in production methods. A larger shift is required, where sustainability is incorporated into the materials that create modern infrastructure. The construction industry must recognize that the environmental and economic threats are too high to continue with business in this modern way. Policymakers could implement stricter regulations on carbon emissions from construction materials and provide financial incentives for companies to adopt low-carbon alternatives. In addition, increased investment in research and development is necessary to improve the performance and scalability of sustainable aggregates.

Ultimately, the transition to sustainable construction practices is a critical piece to fighting climate change and the idea that sustainable alternatives are not practical. By incorporating innovative materials, such as low-carbon aggregates in concrete, and fostering collaboration between the construction and energy sectors, a more sustainable future that reduces carbon emissions can be formed. Applying sustainable concrete to renewable energy structures offers several benefits. First, low-carbon concrete can significantly lower the carbon footprint of construction, especially when used in building infrastructures like wind turbine bases, solar panel mounts, or energy storage facilities. This reduction in emissions extends beyond construction, as sustainable concrete is also used in energy-efficient buildings that can be powered by renewable sources. Additionally, sustainable concrete tends to be similar in strength or more durable, reducing the need for maintenance or replacement over time. This durability also ensures that the materials used in renewable energy infrastructure are resilient and long-lasting. Furthermore, these concrete materials usually have better recycling potential, supporting the principles of a circular economy by minimizing waste and allowing for the reuse of materials in the future.

While the idea of sustainable aggregates can be universally applied, the specific materials used and the methods for sourcing them may vary based on regional availability and local environmental regulations. For example, concrete may be tailored to local conditions, taking into account factors like regional climate, geological resources, and technology. This adaptability makes sustainable aggregates a flexible solution, but successful widespread implementation will depend on uniting practices across different regions and encouraging innovation to overcome material constraints.

References

andrew.himes. (2023, August 6). *CarbonBuilt: The Age of Incrementalism Must Come to a Close*. Carbon Leadership Forum. https://carbonleadershipforum.org/carbonbuilt/

Bennett, J., Baker, A., Johncox, E., & Nateghi, R. (2020). Characterizing the Key Predictors of Renewable Energy Penetration for Sustainable and Resilient Communities. *Journal of Management in Engineering*, *36*(4). https://doi.org/10.1061/(asce)me.1943-5479.0000767

Bird, L., & Womble, J. (2024). State of the US Clean Energy Transition: Recent Progress, and What Comes Next. *Www.wri.org*. https://www.wri.org/insights/clean-energy-progress-united-states

Carbon-Neutral Concrete: Breaking Barriers in Low-Emission Building Materials. (2025, February 6). Theconstructor.org. https://theconstructor.org/architecture/carbon-neutral-concrete-breaking-barriers-in-low-emission-building-materials/577169/

Choi, K., Lee, H. W., Mao, Z., Lavy, S., & Ryoo, B. Y. (2016). Environmental, Economic, and Social Implications of Highway Concrete Rehabilitation Alternatives. *Journal of Construction Engineering and Management*, *142*(2). https://doi.org/10.1061/(asce)co.1943-7862.0001063

Dr. Elizabeth Green. (2024, July). *Traditional vs. Sustainable Building Materials: Cost And Performance - Sigma Earth*. Sigma Earth. https://sigmaearth.com/traditional-vs-sustainable-building-materials-cost-and-performance/

Flower, D. J. M., & Sanjayan, J. G. (2007). Green house gas emissions due to concrete manufacture. *The International Journal of Life Cycle Assessment*, *12*(5), 282–288. EBSCOhost. https://doi.org/10.1065/lca2007.05.327

Hobley, A. R., Mcleod, D., & World Economic Forum. (2021, July 13). *A net-zero world needs zero-carbon concrete. Here's how to do it*. World Economic Forum. https://www.weforum.org/stories/2021/07/a-net-zero-world-needs-net-zero-concrete/

Kaufman, N. (2019, April 2). *What You Need to Know About a Federal Carbon Tax in the United States*. Center on Global Energy Policy at Columbia University | SIPA. https://www.energypolicy.columbia.edu/publications/what-you-need-to-know-about-a-federal-carbon-tax-in-the-united-states/

Mcintyre, J., Spatari, S., Maclean, H., & Asce, M. (2009). Energy and Greenhouse Gas Emissions Trade-Offs of Recycled Concrete Aggregate Use in Nonstructural Concrete: A North American Case Study. *Journal of Infrastructure Systems*, *15*(4). https://doi.org/10.1061/%CD%91ASCE%CD%921076-0342%CD%912009%CD%9215:4%CD%91361%CD%92

Nilimaa, J. (2023). Smart materials and technologies for sustainable concrete construction. *Developments in the Built Environment*, *15*, 100177–100177. https://doi.org/10.1016/j.dibe.2023.100177

Pham, H., Kim, S.-Y., & Luu, T.-V. (2019). Managerial perceptions on barriers to sustainable construction in developing countries: Vietnam case. *Environment, Development and Sustainability*, *22*, 2979–3003. https://doi.org/10.1007/s10668-019-00331-6

Sakellariou, N., & Mulvaney, D. (2013). Engineers and the Renewable Energy Transition: Challenges and Opportunities. *Journal of Professional Issues in Engineering Education and Practice*, *139*(1), 12–18. https://doi.org/10.1061/(asce)ei.1943-5541.0000128

Scrivener, K., Martirena, F., Bishnoi, S., & Maity, S. (2018). Calcined clay limestone cements (LC3). *Cement and Concrete Research*, *114*, 49–56. https://doi.org/10.1016/j.cemconres.2017.08.017

Shaw, E. (2013). Frame analysis. In *Encyclopædia Britannica*. https://www.britannica.com/topic/frame-analysis

Spahr, K. M., Smith, J. M., McCray, J. E., & Hogue, T. S. (2021). Reading the Green Landscape: Public Attitudes toward Green Stormwater Infrastructure and the Perceived Nonmonetary Value of Its Co-Benefits in Three US Cities. *Journal of Sustainable Water in the Built Environment*, *7*(4). https://doi.org/10.1061/jswbay.0000963

U.S. Green Building Council. (2021). *What is LEED certification?* U.S. Green Building Council. https://support.usgbc.org/hc/en-us/articles/4404406912403-What-is-LEED-certification

United Nations. (n.d.). *The 17 sustainable development goals*. United Nations. https://sdgs.un.org/goals

United Nations. (2015). *The Paris Agreement*. United Nations. https://www.un.org/en/climatechange/paris-agreement

Xie, T., Gholampour, A., & Ozbakkaloglu, T. (2018). Toward the Development of Sustainable Concretes with Recycled Concrete Aggregates: Comprehensive Review of Studies on Mechanical Properties. *Journal of Materials in Civil Engineering*, *30*(9). https://doi.org/10.1061/(asce)mt.1943-5533.0002304