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DEMOLISHED WASTE INTO AN INNOVATIVE RESOURCE FOR SAND REPLACEMENT IN CONCRETE (THE DWARF TECHNIQUE)

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ABSTRACT

The construction sector generates substantial waste, including demolished concrete, presenting environmental challenges and disposal expenses. This study introduces the DWARF (Demolished Waste as Resource for Sand in Concrete) technique, an innovative method that repurposes demolished waste as a valuable resource for replacing sand in concrete production. The DWARF process involves treating the demolished waste to meet specifications for sustainable use as an alternative to natural sand in concrete mixes. This research investigated the feasibility and effectiveness of the DWARF technique concerning its impact on concrete's mechanical properties and sustainability. Experimental tests evaluated the compressive strength, durability, and environmental performance of concrete mixes with varying percentages of demolished waste as a sand replacement. The results were compared with conventional concrete mixes to assess the DWARF technique's performance. The findings indicated the successful incorporation of demolished waste into concrete mixes using the DWARF technique, resulting in comparable or improved mechanical properties compared to conventional concrete and additionally, using demolished waste as a sand replacement reduces the environmental impact associated with sand mining and waste disposal. The DWARF technique supports *sustainability by curbing natural resource consumption and endorsing the circular economy concept in construction. Moreover, the technique's economic viability was evaluated, considering potential cost savings in sand procurement and waste disposal. In conclusion, the DWARF technique offers a promising and innovative solution for converting demolished waste into a valuable resource for sand replacement in concrete production, contributing to sustainable construction, resource conservation, and waste reduction. Further research is needed to optimize and encourage its widespread adoption in construction projects.*

Keywords: *Sand replacement, DWARF technique, Sustainability, Resource conservation, Waste reduction*

INTRODUCTION

The significant increment of waste concrete in recent years that is happening worldwide has a tremendous consequence to the environment (P.J.Jaua Junior et. al, 2018). The construction industry, while crucial for economic growth, has a significant negative impact on the environment. Environmental effects arise from various stages of building construction, operation, and demolition, leading to pollution, waste generation, and strain on infrastructure. To mitigate these impacts, the building construction industry has increasingly focused on sustainable practices and reversing environmental harm. Recycling concrete wastes will reduce the amount of waste as well as save natural resources, thus help promote green and sustainable development (P. J. Jaua Junior et al., 2018). The adoption of sustainable building approaches holds great potential for long-term growth, as demonstrated by the Industrialized Building System (IBS) introduced in Malaysia in the 1960s to accelerate project delivery through prefabrication. However, there are challenges to overcome in integrating IBS into projects, including the need for technical expertise and qualified personnel. While IBS has lower exposure, many manufacturers still use traditional materials like cement, sand, and aggregate in their precast components. Although concrete is more environmentally friendly than materials like steel in terms of energy use and carbon emissions per volume, its high-volume consumption poses a challenge in preserving natural resources. Therefore, the development of green concrete is crucial to meet future demand while reducing environmental impact. Green concrete refers to concrete that uses less energy and carbon than conventional Ordinary Portland Cement (OPC) concrete, often incorporating waste products as aggregates or binders. In addition to environmental considerations, the demand for strong and durable concrete has led to the development of green concrete, which can withstand loads and adverse environmental conditions. Green concrete offers several advantages, including improved fresh and hardened properties, leading to cost savings in maintenance, faster construction, and longer service life. The primary objective of this innovation project is to design a more rational and sustainable approach to construction that ensures comfort levels. Integrating innovative practices and selecting environmentally friendly building materials are crucial for enhancing a building's environmental performance and preserving the environment.

PROBLEM STATEMENT

While the Industrialized Building System (IBS) is seen as a technological improvement that simplifies and enhances productivity in precast construction, there are still important considerations to be addressed. In Malaysian precast projects, concrete remains the predominant composite material. Although precast construction may shorten project durations, relying on finite and environmentally damaging resources is not a sustainable step forward. It is crucial to explore alternative materials that can substitute or complement Ordinary Portland Cement (OPC), aggregate, and sand (Abas, N. B. 2016). The production of these three ingredients in concrete relies on depleting natural resources, consumes excessive energy, and generates high greenhouse gas emissions, contributing to global temperature rise and ecosystem destruction (Akadiri, P. O., & Olomolaiye, P. O.,2018). Malaysia needs to embrace and implement alternative material concepts to stay ahead in IBS implementation. Since the 1960s, IBS has been prevalent in Malaysia, resulting in decades of concrete structures. However, not all structures are built to endure, leading to their demolition to make way for new construction projects. Demolition is a significant aspect of the building industry, as every project begins with some form of demolition. From simple structures to high-rise buildings, these demolished materials are often disposed of in landfills, many of which lack proper waste management practices. Consequently, harmful components are mishandled, causing environmental pollution. These demolished structures consist of non-biodegradable materials, emphasizing the importance of reuse in addressing this waste issue. Incorporating old concrete into new concrete could be the solution to minimize the consumption of the three primary concrete materials and reduce demolition waste.

AIM AND OBJECTIVES

The research questions generated in this study are guided by the established objectives. The primary aim of the innovation project is to enhance the existing Industrialized Building System (IBS) sector through the utilization of cutting-edge technologies. The specified objectives serve as benchmarks to be achieved upon completion of the research.

Objectives:
1. To identify the current challenges and issues related to aggregate usage in concrete and the management of demolished waste.
2. To propose a solution to reduce the reliance on aggregate in concrete.
3. To enhance the marketability of this innovative approach utilizing alternative resources for concrete production in the construction industry.

LITERATURE REVIEW

Malaysia's fast expansion has resulted in a massive depletion of cement and natural aggregate, resulting in the generation of a massive volume of concrete debris. The rise in concrete usage and waste correlates with the rise in the country's development. Malaysia's building sector generates a significant amount of solid waste each year (Begum & Pereira, 2007). Construction waste is polluting the environment and producing social difficulties in the nearby towns. Begum (2006) estimates that the construction waste created from a new building construction project site is approximately 27,068.4 tonnes. Construction waste is classified into eight kinds, with concrete and aggregate waste accounting for 17,820 tonnes, or 65.8% of total construction waste created. Another research in Sarawak found that construction waste and debris disposed of after a project's completion may be classified into three types: masonry rubble, concrete waste, and timber and metal, with 40-45%, 30-35%, and 6%, respectively (Wong, 2012). Azamuddin et al. (2019) mentioned from their findings that most of the abundant sources of natural fibre were not fully utilised and causing pollution to the environment as it was left untreated and rot (Azamuddin et al., 2019). Thus, this study makes a great contribution to using demolished waste as an alternative sand replacement in concrete.

a. Precast concrete waste

Precast concrete, a construction material manufactured in a precast concrete factory or plant using reusable steel molds, has gained traction in Malaysia following the visit of the Malaysian Ministry of Housing and Local Government to several European countries. Although the concept was not initially popular in the 1960s, the adoption of precast concrete systems in Malaysia has been steadily increasing, leading to a rise in local precast concrete producers (Ng, 2012).

The utilization of precast concrete technology in the Malaysian building sector has yielded several benefits. It has effectively reduced labor requirements, improved construction uniformity, and lowered costs while maintaining high-quality standards. This approach has also enhanced quality control measures and contributed to a cleaner environment. Furthermore, the implementation of precast concrete systems has the potential to significantly reduce waste generation, material utilization on-site, and overall construction expenses, as indicated by the Waste reduction potential of offshore-made precast concrete study (Ng, 2012). However, despite the advantages, the precast concrete manufacturing process still generates some concrete waste, both during production and transportation, leading to significant rejection rates due to stringent quality control measures (Angel, 2017).

Every day, a significant amount of precast concrete waste is generated, consisting of rejected and unwanted materials. The reasons for the generation of such waste can be attributed to the following factors:

i. Inadequate or incorrect design resulting from manufacturing faults: Improper design choices can lead to connection issues during installation. For instance, the absence of precast concrete design specifically tailored for toilets and bathrooms has been linked to leakage problems, as highlighted by Ng B.K. (2012). Consequently, precast concrete elements that do not meet the required standards may be rejected and subsequently discarded.

ii.Lack of knowledge and skills in producing high-quality precast concrete: Many local contractors still lack familiarity with the precast concrete system, as noted by Ng (2012). This deficiency can lead to the production of low-quality or damaged precast concrete, which is subsequently rejected and disposed of.

iii.Breakage of precast concrete components during handling or shipping: Instances where precast concrete components suffer damage or breakage during handling or transportation can render them unfit for use. Consequently, these rejected components are discarded. In summary, the generation of rejected precast concrete waste stems from design flaws, inadequate expertise in producing high-quality precast concrete, and the occurrence of breakages during handling or shipping.

b. Demolition of concrete waste

Malaysia has long been recognized as a rapidly advancing nation, with its development progressing at an astonishing pace that may exceed public perception. As a result, numerous demolition projects are required to dismantle old building structures and make way for new developments. Surprisingly, the volume of demolition waste generated is twice as much as that of construction waste, as indicated by Gunalaan (2015). Consequently, in a developing country, excessive demolition projects lead to a significant accumulation of demolition waste, which poses a more severe impact than construction waste. According to previous studies, concrete waste constitutes a staggering 24% of the total volume of demolition waste. This has resulted in notable challenges related to concrete waste management, with the recycling of demolished concrete debris being largely overlooked. In the United States and Europe alone, approximately 50-60 million tonnes of demolition concrete are produced annually. Regrettably, only a small portion of this concrete waste is currently recycled, with the majority being discarded, as highlighted by Asif (2013).

Current common practice of concrete waste management in Malaysia

i. Landfill disposal methods

Currently, in Malaysia, two primary waste management methods, namely landfilling and incineration, are employed to reduce building waste. Landfill disposal is a prevalent practice in the country, with many contractors opting for this approach due to their perception of the waste materials having little value, thus disregarding more effective waste management strategies (Sasitharan, 2012). In accordance with the Malaysia Solid Waste and Public Cleansing Management Act 2007 (Act 672), "disposal" refers to the removal of any solid waste, including those that have been destroyed, incinerated, deposited, or decomposed. Malaysia has a total of 289 landfill sites across its states, but 113 of them have ceased operations due to objections from nearby communities who consider the landfills unsightly or have reached their maximum capacity for waste disposal (Sasitharan, 2012).

ii.3R concept-Recycle, Reduce, Reuse

The Malaysian government has introduced the 3R (Reduce, Reuse, Recycle) program to the construction industry, aiming to promote the responsible management of Construction and Demolition Waste (CDW). The 3R concept emphasizes the complete utilization of resources before their disposal. It has been designated as the guiding principle for CDW management in Malaysia (Huang, 2018). In comparison, several affluent countries such as the United States, Denmark, South Korea, Singapore, Japan, and Germany have achieved recycling and reuse rates ranging from 70% to 95%. However, the implementation of the 3R concept is still limited in most construction sites in Malaysia, and many sectors involved in the industry remain unaware of it. Currently, there are limited options for recycling and reuse available in Malaysia, indicating that the adoption of the 3R idea is still in its early stages (Huang, 2018).

iii.Illegal construction and demolition waste disposal

Illegal dumping refers to the intentional disposal of waste in unauthorized locations. It is driven by motives such as cost and time savings in waste disposal, as well as evading landfill fees. Several countries with strong economic growth, including Italy, Australia, Spain, Israel, China, and Hong Kong, are facing significant challenges with illegal dumping. Malaysia has also experienced a substantial increase in illegal waste dumping issues. In Johor alone, construction waste has been found in 46 illegal dumping sites, accounting for 42% of the total. Additionally, approximately 30 tonnes of construction waste have been illegally deposited in the tropical mangrove wetlands near Bandar Hilir, Malacca. These illegal dumping practices pose risks to human health and cause damage to the surrounding ecosystem.

Review of Previous and Current Innovation Projects

In Malaysia and other developing countries, the rapid expansion of construction is leading to a critical problem of depleting natural sand resources and generating a significant amount of concrete waste. Natural sand, which constitutes 26% of the total concrete composition, is being excessively consumed, risking the depletion of this valuable resource if effective controls are not implemented. It is crucial to address the issues of natural sand consumption and concrete waste before the situation worsens. One potential solution lies in exploring the use of recycled concrete as a viable alternative to natural sand, offering a way to reduce concrete waste. Sand and gravel have become the most exploited commodities globally, surpassing fossil fuels and biomass in terms of weight. Sand is extensively used in concrete production, road construction, glass manufacturing, and electronics. Its overexploitation poses significant environmental consequences, including physical impacts on rivers and coastal habitats, increased sedimentation, erosion, and harm to various aquatic species. Sand mining not only affects ecosystems but also disrupts the livelihoods of local communities. Coastal areas, in particular, face heightened risks of flooding and storm surges due to increased erosion caused by extensive mining. The health implications of sand mining, such as the formation of standing water pools that serve as breeding grounds for disease-carrying mosquitos, require further investigation. It is essential to prioritize research and explore sustainable alternatives to mitigate the negative impacts of sand mining on both the environment and human well-being.

After conducting a study on the existing concerns and issues that require improvement through innovation, an alternative resource for concrete production is selected to address the problem of depleting natural resources. However, incorporating demolition waste into concrete as an alternative resource does not significantly alter the properties of conventional concrete, such as its tensile strength and strain capacity. Therefore, the impact on concrete qualities remains uncertain. The primary objective of utilizing demolished waste in concrete is to reduce landfill waste and decrease reliance on natural sand. Simultaneously, it aims to enhance environmental efficiency by minimizing the disposal of demolition debris. Moreover, the inclusion of demolition waste in concrete holds the potential to reduce energy consumption, pollution, and disposal costs. Additionally, it offers a means to effectively manage demolition waste and decrease carbon footprints.

Development of DWARF

The subsequent design framework will emphasize the flow of the creation of this ground-breaking component before it reaches the marketability level. The design framework or primary process of this innovation is shown in the following Figure 1.

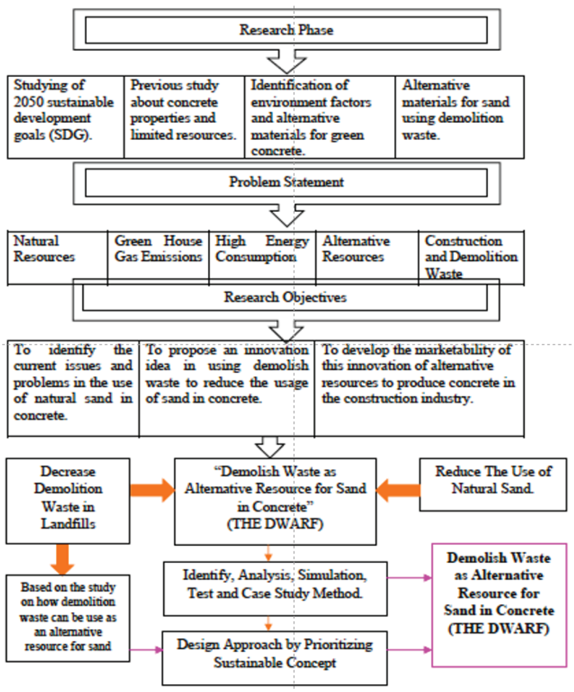

Figure 1. Design framework for the DWARF project

Source: Author

RESULT ANALYSIS AND DISCUSSION

According to British Standard 1881-116:1983: Compressive Strength Concrete Specimen, the concrete test was conducted. Six samples were used in total, including two cube samples for compression testing, two cube samples for ultrasonic pulse velocity testing, and two cube samples for density and water absorption testing. Testing was carried out after 7, 14, and 28 days of cure to achieve the second objective.

Buoyancy Balance Density Test Results

Two types of concrete specimens were examined: conventional control concrete and DWARF concrete, which incorporated 50% of DWARF sand. The objective of the test was to compare the elastic and strength characteristics of DWARF concrete with ordinary concrete. The density test involves two types of mass measurements: mass in air and mass in water. These measurements help determine the densities of different concrete types and calculate the mass difference between air and water. Table 1 presents the density values for the composites after 7, 14, and 28 days of curing.

Table 1. Test Results on Concrete Density Test

Types	Density of concrete (kg/m3)					
	7 days		14 days		28 days	
	Mass in air (g)	Mass in water (g)	Mass in air (g)	Mass in water (g)	Mass in air (g)	Mass in water (g)
Control (C1)	2270	1240	2324	1298	2397	1357
DWARF (D1)	2348	1308	2354	1328	2342	1312

Source: Author

On the 7th day, D1 had a greater density than C1, with a mass in air of 2348kg/m 3 and 2270kg/m 3 respectively. Following that, C1 had a mass in water of 1240kg/m 3 and D1 a mass of 1308kg/m 3. The pattern continued until the 14th day, with D1 being denser than C1. On the 28th day, however, C1 surged forward with more mass than D1.

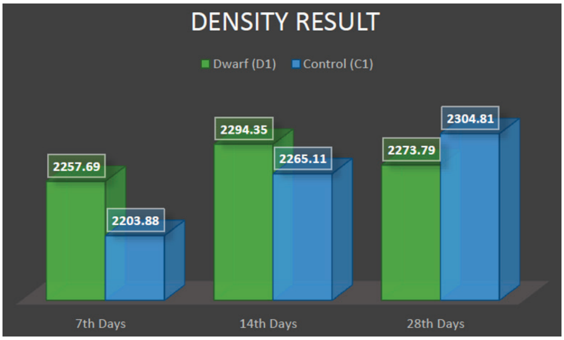

Figure 2. Concrete Density Test Result Comparison between DWARF and Control

Source: Author

Figure 2 illustrates the consistent increase in density for C1, while the density of D1 shows some variations. However, despite these differences, the final products are relatively similar. This is crucial because the objective is to retain all the desirable characteristics of concrete. Denser concrete typically exhibits fewer voids and porosity. As the gaps decrease, the concrete becomes less permeable to water and soluble chemicals. Consequently, water absorption is reduced, leading to increased durability and longevity of the concrete.

Ultrasonic Pulse Velocity Test Results

Table 2. Ultrasonic Pulse Velocity Test Results

Types	Velocity of concrete DWARF (us)		
	7 days	14 days	28 days
Control (C1)	18.55	19.30	20.05
DWARF (D1)	19.85	19.10	20.25

Source: Author

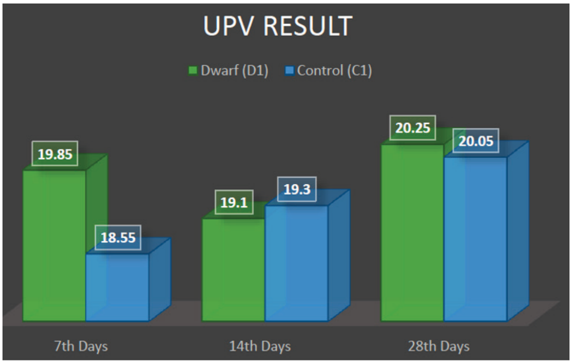

Figure 3.Ultrasonic Pulse Velocity Test Results Comparison between DWARF and Control

Source: Author

The analysis compares the velocity of Concrete DWARF (D1) with the control (C1) at different time intervals (7th, 14th, and 28th days). The velocity of sound in concrete is measured in microseconds (µs). On the 7th day, the velocity of sound in C1 is recorded as 18.55 µs, while in D1 it is slightly higher at 19.85 µs. On the 14th day, the velocity of sound in C1 increases to 19.30 µs, whereas in D1 it decreases to 19.10 µs. By the 28th day, the velocity of sound in C1 further increases to 20.05 µs, and in D1 it reaches the highest value of 20.25 µs. Overall, it can be observed that the velocity of sound in D1, the Concrete DWARF, exhibits some variations compared to the control (C1) at different time intervals.

Compressive Strength Test Results

Table 3. Compressive Strength Test Result

Types	Compressive strength test result		
	7 days	14 days	28 days
Control (C1)	13.5	18.30	21.7
DWARF (D1)	20.8	25.6	26.2

Source: Author

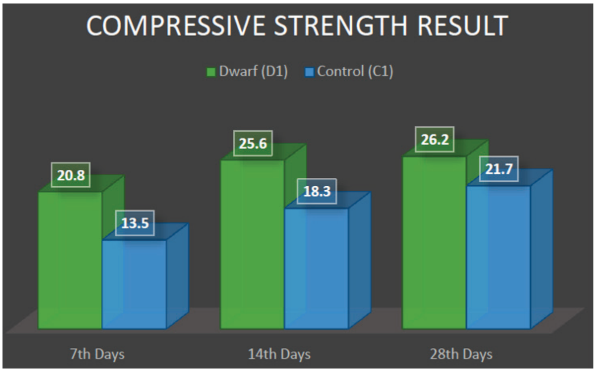

Figure 4. Compressive Strength Test Results Comparison between DWARF and Control

Source: Author

Table 3 clearly illustrates the contrast in grade and strength between C1 and D1. While C1 shows a gradual progression towards its target grade, D1 achieves a strength of 20.8 MPa on the seventh day. Furthermore, D1 exhibits a significant increase of 5.4 MPa beyond its intended strength of 20 MPa by the 28th day (refer to Figure 3). Although the objective was not to surpass concrete grade 20, these findings indicate that the addition of DWARF sand enhances the strength of the concrete.

Marketability of DWARF

Construction waste, also known as construction and demolition (C&D) waste, is generated during various construction, renovation, and demolition activities, such as new construction, renovation, excavation, demolition, refurbishment, and infrastructure work (Lu, Z, 2023). It consists of a wide range of materials, which can be categorized as inert and non-inert based on their chemical activity with the surroundings (J. Chen, 2021). Inert materials include sludge, soil, rubble, concrete, and brick, while non-inert waste includes organic materials like metal, packaging, flora, wood, and paper. Construction waste constitutes a significant portion of solid waste in any economy, typically accounting for 25 to 40 percent of the total waste disposed of in developed countries (B. Huang, 2018). Landfilling construction waste not only has long-lasting negative impacts on society, the environment, and the economy but also depletes nonrenewable land resources at a rapid pace (S.O. Ajayi, 2017). Construction Waste Management (CWM) has emerged as a result of extensive research and efforts by the global scientific community to address the proper management of construction waste (Z. Wu, 2020). The principles of "reduce, reuse, and recycle" (3R) are integral to CWM, aiming to minimize waste at the source, encourage the reuse of materials, and promote recycling to give waste a second life (Huang, 2018; Wu, 2019). The concept of the circular economy, which aligns with the 3R principles, has gained significant traction as a guiding principle for sustainable development in various sectors and regions (Mahpour, 2018).

According to the Environmental Protection Agency (EPA) data from 2018, construction and demolition activities in the United States generate over 600 million tonnes of waste annually. In Malaysia's construction industry, the predominant issue regarding construction waste is the excessive amount of concrete waste, which poses challenges for landfill disposal. To address the abundance of concrete waste resulting from demolition projects and the rejection of precast concrete products that do not meet quality standards, a waste collection and transportation service was established.

The DWARF initiative aims to provide a solution by collecting this waste and facilitating its reuse for the benefit of the country and the environment, while also generating significant profits. Recent data indicates that the construction industry is becoming more open to changing the current practices of managing concrete waste. Deconstruction waste will play a crucial role in achieving innovative concepts and objectives. DWARF has demonstrated promising potential as a substitute for fine aggregate in concrete, offering advantages in terms of workability and strength. Although further research is required, the use of alternative sand in concrete has the potential to revolutionize the construction industry. These exciting findings may contribute to the rapid development of this industry sector in the coming years.

The developed DWARF product shows potential for marketing to prospective users. The market potential is categorized based on geographical regions, key industry players, and types of raw materials. The concrete market, valued at $617,260.1 million in 2020, is projected to reach $972,046.3 million by 2030. To start the marketing process, DWARF Sand can be introduced by offering it to manufacturers and contractors at a lower price compared to natural sand used in concrete. For instance, Gamuda

Berhad and YTL Corporation's manufacturing division estimates the cost of a 10-ton truck of sand at RM610.00. By launching DWARF Sand at a lower price, it can attract the interest of other construction organizations, ensuring their willingness to do business with DWARF Sand. The profitability of this venture is evident through the utilization of a waste collection service to produce DWARF Sand. The construction industry is rapidly expanding, and without intervention from relevant parties or authorities, it will continue to emit significant carbon footprints, posing risks to the environment and people. The construction sector presents a significant opportunity for waste material utilization through the reuse of structurally sound components or the recycling of raw materials into new structural elements. The goal is to achieve environmental benefits such as reduced industrial waste storage and decreased demand for raw materials. DWARF brings hope to the construction industry, offering a positive outlook for sustainable practices.

CONCLUSION AND RECOMMENDATION

In conclusion, the DWARF technique, which involves transforming demolished waste into a resource for sand replacement in concrete, holds immense potential for addressing the environmental and sustainability challenges faced by the construction industry. The extensive research and analysis conducted in this study have shed light on the significant issues of concrete waste generation and its impact on landfilling and resource depletion. The study has highlighted that concrete waste, particularly in Malaysian construction industries, is a major concern due to its abundance and improper disposal practices. However, it is encouraging to note that the construction industry is becoming more receptive to adopting innovative approaches for handling concrete waste, paving the way for the introduction of environmentally friendly concrete technologies like DWARF. By collecting and repurposing demolished waste as a sand substitute, DWARF offers a promising solution to reduce the reliance on natural sand, which is a finite resource. The utilization of DWARF sand in concrete mixes has shown positive effects on workability and strength, indicating its potential to revolutionize the construction industry while mitigating the challenges associated with waste management. While the implementation of DWARF sand in concrete production requires further research and the development of guidelines for optimal utilization, the findings of this study suggest that it is a viable and sustainable alternative. The successful marketing and market potential analysis demonstrate that DWARF has the ability to capture the interest of manufacturers, contractors, and other stakeholders in the construction industry, ensuring its profitability and widespread adoption. Ultimately, the transformation of demolished waste into a valuable resource through the DWARF technique holds promise for creating a well-developed industry sector focused on sustainable construction practices. This innovative approach not only addresses the pressing issues of waste management and resource depletion but also contributes to the reduction of carbon footprints, environmental hazards, and reliance on traditional construction materials. The findings and insights presented in this study pave the way for further exploration and implementation of DWARF, enabling the construction industry to embrace more sustainable practices and contribute to a greener and more efficient built environment. With continued research, collaboration, and awareness, the DWARF technique has the potential to drive significant positive change in the construction sector and inspire a new era of environmentally conscious construction practices.

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AUTHOR CONTRIBUTIONS

The primary author and co-author of this research, played a pivotal role in conceptualizing and designing the research study. In the data collection phase, the author coordinated and executed experiments, ensuring the acquisition of robust and comprehensive data analysis. The drafting of the manuscript was primarily undertaken by the author with a significant contribution to the introduction, methodology, results, and discussion sections and providing critical input and addressing reviewer comments during the manuscript revision process.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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