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From Cracks to Strength: Bio-Concrete Technology and the Future of Reliable Buildings

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Abstract **Original Research Article**

The pervasive challenge of structural cracking necessitates a paradigm shift from reactive repair to proactive prevention in the construction industry. This study assessed the perceptions of civil engineering academics in Nigeria regarding the potential of bio-concrete to enhance building reliability. Utilizing a survey research design, data were collected from a purposive sample of academics specializing in materials and structures with over five years of experience in bio-concrete. The instrument demonstrated high reliability (Cronbach's alpha = 0.82). Findings revealed a strong consensus on the feasibility of key integration strategies (Mean > 3.50 cut-off), indicating a clear pathway for adoption. However, a significant difference was found between junior and senior academics in their perception of bio-concrete's effectiveness in autonomously sealing cracks ($t(63) = 4.66$, $p = 0.04$), highlighting a generational divide in acceptance. The study concludes that while bio-concrete holds immense promise for transforming building durability, its successful integration is contingent on bridging perceptual gaps. It is strongly recommended that professional bodies develop targeted continuous professional development (CPD) programs to address the specific skepticism of senior academics and engineers, leveraging empirical data from pilot projects to build a unified, evidence-based consensus.

Keywords: Bio-concrete, Building Reliability, weakness, cracks, strength.

INTRODUCTION

The construction sector in Nigeria has witnessed rapid growth in recent decades, driven largely by rapid urbanization, high population growth, and the rising demand for housing, office spaces, and infrastructure projects across cities. However, this expansion has been accompanied by significant structural challenges that threaten the sustainability of many **buildings**. One of the most persistent problems is the early deterioration of concrete elements, a condition often initiated by the formation of **cracks** in structural members such as beams, columns, and slabs (Nduka, Ameh, Joshua & Ojelabi, 2018). These cracks are not merely superficial blemishes but pathways that compromise both the physical appearance and the structural performance of concrete. Once formed, they accelerate the ingress of moisture, sulfates, chlorides, and other aggressive agents that attack reinforcement steel, thereby reducing load-carrying **strength** and shortening the service life of structures. The implications extend beyond durability; in many cases, cracks directly compromise the **reliability** of buildings, leaving them vulnerable to collapse or costly premature repairs.

In Nigeria, the consequences of poor-quality control during construction have been widely reported. In Enugu State, for instance, a significant number of building collapses and failures of structural elements have been attributed to poor material quality, inadequate concrete mixing ratios, improper curing practices, and insufficient supervision on construction sites (Okechukwu, Okolie, & Ezeokoli, 2021). Each of these factors increases the likelihood of crack initiation and propagation, creating weak points that undermine both safety and durability.

Beyond workmanship issues, foundation settlement, improper design calculations, use of substandard construction materials, and corrosion of reinforcement bars are among the leading technical factors perceived to drive crack formation in concrete structures (Olofinnade, Busari, Akinwumi, Awoyera, & Ekanem, 2019). These failures, when combined with the country's humid climate and poorly regulated building industry, create conditions in which concrete structures rapidly lose **strength** and become unreliable over their intended service life (Akinyele, Igba & Labiran, 2024).

Such realities underscore the urgent need for innovative materials and technologies capable of addressing the root causes of concrete degradation. Conventional repair methods such as epoxy injection, external patching, or replacement of defective sections according to Zeinali, Rahmani, & Ahmadi (2023) are often expensive, time-consuming, and sometimes ineffective in providing long-term solutions. Thus, researchers are increasingly exploring sustainable alternatives, which promises to autonomously repair **cracks** and restore lost **strength** without extensive human intervention.

Taken into account that **cracks** can drastically lower the **strength** of concrete members, their presence raises serious concerns for the long-term **reliability** of **buildings** (Olonade, Schmidt & Adeoye, 2022). Loss of strength in structural elements does not only reduce the ability of a building to support its design loads but also increases deflection, accelerates reinforcement corrosion, and heightens vulnerability under harsh environmental conditions such as heavy rainfall, flooding, and saltwater exposure (Lu, Jiang, Zhang, Zhang, Lu & Leng, 2024). Investigations of existing buildings in Nigeria by Okechukwu et al (2021) revealed that many critical components including columns, beams, and slabs degrade to varying degrees due to cumulative damages caused by surface spalling, chloride penetration, and loss of reinforcement bonding, often initiated by early cracking, inadequate curing, and poor maintenance culture. These forms of deterioration significantly compromise both structural **strength** and service life, underscoring the urgent need for innovative approaches, such as bio-concrete technology, that can mitigate crack formation and extend the reliability of concrete **buildings** (Magnel-Vandepitte & di-Summa, 2022)

Bio-concrete, also known as bacterial or self-healing concrete, represents a transformative approach where living agents are integrated into the cementitious matrix. **Bio-concrete material,** also called **bacterial concrete** or **self-healing concrete**, is an advanced cementitious composite that incorporates living organism's usually specific strains of bacteria, spores, or enzymes alongside nutrients or healing agents (Rajesh, Sumathi & Gowdhaman, 2023; Subhashini, Yaswanth & Prasad, 2018). When cracks appear and moisture or oxygen penetrates the concrete, these biological agents become active and induce the precipitation of minerals, typically **calcium carbonate ($CaCO_3$),** which gradually seals the cracks. This process not only prevents the ingress of harmful substances such as chlorides and sulfates but also restores part of the concrete's **strength** and extends the service life of structures. When **cracks** form and moisture penetrate, these agents activate and precipitate calcium carbonate or other minerals, effectively sealing the cracks. This self-healing mechanism not only prevents further ingress of harmful substances such as chlorides and sulfates but also restores lost **strength**, making structures more resistant to deterioration (Ashok & Chandra, 2018). Thus, the concept of "from cracks to strength" is therefore not just metaphorical but reflects a material science process where weaknesses in concrete become opportunities for healing and reinforcement.

In Nigeria, research on bio-concrete is still emerging but shows promising results. Kumator and Lawan (2023), developed a bio-self-compacting concrete using *Sporosarcina pasteurii* bacteria combined with calcined clay and limestone powder. Their study demonstrated that optimized bacterial concentrations improved compressive strength, reduced porosity, and lowered overall production costs, highlighting the potential of bio-concrete as both a durable and economically viable material. Similarly, Vegesna & Balaji (2023) and Osuji, Ogirigbo & Atakere (2021) independently investigated the behaviour of bio-ash (specifically palm kernel shell ash) as a partial cement replacement in self-compacting concrete exposed water ingress. Their findings revealed that bio-ash enhanced both the workability and hardened properties of concrete, thereby reducing crack susceptibility and improving durability. Such studies indicate that the integration of bio-based materials into concrete production can offer solutions to Nigeria's recurrent durability problems while aligning with sustainability goals by reusing agricultural waste products. The broader implication of adopting bio-concrete technology is its contribution to the **reliability** of **buildings**. **Structures incorporating self-healing properties, such as bio-concrete, demonstrate reduced dependence on external maintenance interventions, thereby significantly lowering overall lifecycle costs (**Toryila, 2023). Consequently, recurring cases of building collapse particularly caused by crack initiation and development could be drastically reduced by the adoption of this innovation. By reducing crack propagation and reinforcing structural integrity, bio-concrete technology promises to create safer, longer-lasting, and more **reliable buildings** capable of withstanding environmental stresses.

Looking ahead, the integration of **bio-concrete technology** into Nigerian construction practices would offer an opportunity in redefining the future of the country's-built environment. By transforming the weaknesses of conventional concrete namely its susceptibility to **cracks** into a self-healing capacity that restores **strength** and ensures **reliability**, bio-concrete represents not just a scientific advancement but a sustainable pathway toward safer and longer-lasting **buildings.** If scaled effectively, it could mark a turning point in Nigeria's response to recurring structural failures, paving the way for innovative and eco-friendly construction practices aligned with global sustainability targets. Similarly, such technologies could significantly enhance the future **reliability** of buildings, aligning with global calls for safer, longer-lasting, and more sustainable infrastructures.

Statement of the Problem

In Nigeria's rapidly expanding cities, a hidden flaw threatens the very basis of development: the inevitable cracking of concrete. While this material builds our modern landscape, its brittleness leads to weaknesses that undermine safety, accelerate decay, and can end in catastrophic failure. Current fixes are costly and temporary battle against this inevitable decline; a battle often lost due to high costs and poor maintenance culture. But what if concrete could heal itself? Bio-concrete, a revolutionary technology that uses biological processes to autonomously seal cracks, offers a leap from reactive repair to innate resilience. It promises structures that are not only stronger and longer-lasting but also drastically cheaper to maintain. Yet despite its global potential, bio-concrete's application in Nigeria's built environment remains critically limited and under-researched Therefore, the central problem the study set out to address was how bio-concrete can be harnessed and integrated into Nigeria's construction industry to shift from merely managing cracks to building with inherent strength.

Purpose of the Study

The main purpose of the study was to examine bio-concrete potentials in converting cracks to strengths and the future of reliable building structures. Specifically, the study aimed to:

1. Examine the potentials of bio-concrete in addressing structural cracking in buildings
2. Investigate feasible strategies for adoption/integration of bio-concrete materials into the Nigerian construction industry.

Research Questions

Two research questions that guided the conduct of the study were as follows:

1. In what ways can bio-concrete materials address structural cracking challenges in buildings?
2. What are the feasible strategies for integrating bio-concrete technology into the Nigerian construction industry?

Hypotheses

Two hypotheses tested at 0.05 level of probability were formulated to guide the conduct of the study.

H_{01}: Bio-concrete materials do not significantly enhance the ability of concrete structures to address cracking or reliability challenges compared to conventional concrete as perceived by senior and junior academics in civil engineering.

H_{02}: There are no feasible strategies for integrating bio-concrete technology into the Nigerian construction industry as perceived by academics in civil engineering.

METHODOLOGY

Research Design

The study adopted a survey research design. This design was considered appropriate because it enabled the collection of data from a defined population in order to explore academia's perceptions of bio-concrete technology and its potential for improving the reliability of buildings.

Area of Study

The study was confined to public universities domiciled in south eastern region of Nigeria and focused on the integration of bio-concrete technology to enhance building reliability through autonomous crack healing

Population of the Study

The population of the study comprised of sixty-five (65) academics in Civil Engineering (Materials and Structures major) working in public universities in Nigerian eastern region with research activity in concrete technology. Ten (10) academics from the University of Nigeria, Nsukka (UNN), ten (10) from Enugu State University of Science & Technology (ESUT), five (5) from Ebonyi state university (EBSU), five (5) from AE-FUNAI, ten (10) from Nnamdi Azikiwe University Awka (UNIZIK). Others were, ten (10) from Federal University of Technology Owerri (FUTO), five (5) from Imo State University Owerri (IMSU) & ten (10) from Micheal Okpara University of Agriculture Umudike (MOUA-U). These professionals were selected because of their expertise and direct involvement in building construction materials. Purposive sampling was employed to select 65 respondents with relevant academic and research experience in materials engineering

Instrument for Data Collection

A structured questionnaire was developed as the instrument for data collection. The questionnaire was designed to gather information on academic's knowledge and perspectives regarding the potential of bio-concrete technology and its integration into the built environment. Items were designed using a 5-point Likert scale to enable statistical analysis.

Validation of the Instrument

The questionnaire was validated for face and content validity by three experts in materials and structural engineering. Their feedback on clarity, relevance, and coverage of the study objectives was incorporated to improve the quality of the instrument.

Reliability of the Instrument

The reliability of the instrument was tested using Cronbach's Alpha. The analysis produced a coefficient of **0.82**, indicating a high level of internal consistency and confirming that the instrument was reliable for data collection.

Method of Data Collection

Data were collected through direct administration of the questionnaire to the respondents, both in person and electronically, depending on accessibility and convenience. Respondents were given clear instructions and adequate time to complete the instrument.

Method of Data Analysis

Data collected were analyzed using both descriptive and inferential statistics. Mean and standard deviation were employed to answer the research questions, while t-test statistics were used to test the hypotheses at the 0.05 level of significance.

Results

Table 1: Mean and SD ratings of senior and junior civil engineering (materials/structures major) academics on the perceived potentials of bio-concrete materials in addressing structural cracking challenges in buildings (N=65)

S/N	Item statements	Mean	SD
1.	Bio-concrete has the potential to reduce the occurrence of cracks in buildings	3.95	0.65
2.	The self-healing property of bio-concrete can extend the service life of buildings	3.70	0.45
3.	Bio-concrete can reduce maintenance costs associated with cracked structures	3.91	0.29
4.	Bio-concrete can improve the strength of concrete structures.	2.46	0.59
5.	The use of bio-concrete can enhance safety in buildings by minimizing crack-related failures	2.40	0.63
6.	Bio-concrete is more effective than traditional repair methods for managing cracks	2.35	0.63
7.	Integrating bio-concrete into building projects can reduce the frequency of structural repairs	3.61	0.65
8.	Bio-concrete can provide a sustainable solution to the problem of structural deterioration	2.44	0.71
9.	Adoption of bio-concrete will improve the reliability of Nigeria’s built environment	4.83	0.42
10.	Bio-concrete has the potential to transform construction practices from managing cracks to preventing them	4.02	0.65

Table 1 presents survey of Civil engineering (materials/structures major) academics. The survey revealed divergent views on bio-concrete's ability to autonomously repair cracks, with four specific items (4, 5, 6, 8) falling below the 3.50 agreement threshold. However, the findings suggest that bio-concrete integration can reduce building cracks, shifting the construction paradigm from management to prevention.

Table 2: t-test on the mean ratings of junior and senior civil engineering (materials/structures) academics on the perceived potentials of bio-concrete materials in addressing structural industry

Academics	N	Mean	Std. Deviation	t-test	df	Sig.	Dec.
Senior	40	3.41	0.16	4.66	63	0.04	Do not accept H_{01}
Junior	25	3.31	0.27				

Table 2 containing an independent-samples t-test showed a significant difference between junior and senior civil engineering academics in their perceived potentials of bio-concrete materials for addressing structural cracking challenges in buildings, $t(63) = 4.66$, $p = 0.04$. Since $p < .05$, the null hypothesis was not accepted, indicating that the two groups did not share the same perceptions of its effectiveness in autonomously sealing cracks. The significant difference in perceptions suggests that academic seniority is a key factor influencing belief in bio-concrete's potential. This divergence indicates that strategies to promote adoption may need to be tailored: targeting education on practical benefits for junior academics, while addressing the specific skepticism or experience-based concerns of their senior counterparts to build a unified, evidence-based consensus.

Table 3: Mean and SD ratings of civil engineering (materials/structures major) academics on the feasible strategies for integrating bio-concrete technology into the Nigerian construction industry (N=65)

S/N Item statements	Mean	SD
1.Inclusion of bio-concrete in national building codes and standards.	4.71	0.58
2.Provision of funding for research and pilot projects on bio-concrete applications.	4.08	0.67
3.Collaboration between universities, research institutes, and the construction industry will enhance bio-concrete integration 4.17	0.38	
4.Organization of training workshops for engineers, builders, and contractors on the use of bio-concrete.	4.06	0.79
5.Introduction of bio-concrete technology into the curriculum of engineering and construction-related disciplines	4.09	0.76
6.knowledge transfer on bio-concrete technology through partnership with international institutions	2.34	0.62
7.Pilot construction projects using bio-concrete should be implemented to demonstrate its benefits in the Nigerian built environment	2.28	0.70
8.Provision of incentives such as tax relief or subsidies to construction firms that adopt bio-concrete	3.98	0.62
9.Provision of awareness and guidelines by professional bodies on the application of bio-concrete in practice.	3.34	0.78
10. Local production of bio-concrete materials should be encouraged to ensure availability and affordability	4.32	0.53

As shown in Table 3, respondents agreed that the majority of presented strategies were feasible for integrating bio-concrete technology into the Nigerian construction industry (using a mean rating cut-off of 3.50 for agreement). Consensus was reached on all items except for strategies 6, 7, and 9, which were perceived as less feasible. This indicates a general optimism for adoption but identifies specific strategic barriers (items 6, 7, and 9) that require targeted intervention to facilitate successful market integration.

Table 4: t-test on the mean ratings of civil engineering academics (materials/structures major) on the feasible strategies for integrating bio-concrete technology into the Nigerian construction industry

Academics	N	Mean	Std. Deviation	t-test	df	Sig.	Dec.
Senior	40	3.62	0.22	3.82	63	0.06	Do not reject H_{02}
Junior	25	3.67	0.29				

An independent-samples t-test revealed no significant difference between junior and senior civil engineering academics in their ratings of feasible strategies for integrating bio-concrete technology in Nigeria, $t(63) = 3.82$, $p = .06$. This indicates a consensus across academic ranks on the strategic approach required. The consensus suggests that the identified strategies are viewed as universally applicable, regardless of seniority. This strengthens the validity of the strategic framework and provides a unified foundation for policymakers and educators to develop implementation plans without needing to tailor messages to different academic levels.

DISCUSSION

The study findings illuminate a pivotal transition in construction philosophy, demonstrating that bio-concrete is not merely a new material but a catalyst for shifting the industry paradigm from damage management to inherent resilience. The strong consensus on feasible integration strategies as seen in Table 3 indicates a clear and practical pathway for adoption within the Nigerian construction industry. This aligns with global research advocating for self-healing materials as a solution to the pervasive and costly challenge of structural degradation (Jonkers & Schlangen, 2008).

However, the significant divergence in perception between junior and senior academics (Table 2) reveals a critical tension between innovation and established practice. Senior academics, likely grounded in decades of experience with conventional materials, exhibited more skepticism about the autonomous sealing effectiveness of bio-concrete. This is not unexpected;

the adoption of radical innovations often faces resistance from professionals accustomed to traditional methods (Slaughter, 2000). Conversely, junior academics, arguably more exposed to contemporary research on biotechnology, displayed greater optimism. This generational divide underscores that the primary barriers may not be technical, but cultural and educational, echoing findings by Vijverberg (2021) on the socio-technical challenges of implementing smart materials.

The identified unfeasible strategies (Items 6, 7 & 9) further pinpoint the specific hurdles, likely related to cost, local supply chains, and regulatory frameworks. For bio-concrete to fulfill its promise of transforming building reliability from a reactive weakness to a proactive strength, these economic and infrastructural gaps must be addressed through targeted policy and industry collaboration (De Muynck et al., 2010).

CONCLUSION

The study demonstrates that bio-concrete represents a fundamental shift from the reactive "management" of building weakness to the proactive "prevention" of failure, heralding a future of truly reliable buildings. The strong consensus on feasible integration strategies confirms a clear pathway for adoption. However, the significant perceptual divide between junior and senior academics underscores that the primary challenge is not technical viability, but overcoming entrenched skepticism and building a unified, evidence-based consensus. To harness this transformative potential, the industry must move beyond theoretical acceptance to strategic action.

RECOMMENDATIONS

Based on the findings, the study strongly recommends:

1. **Targeted Knowledge-Bridging Initiatives:** Develop and implement continuous professional development (CPD) workshops and seminars specifically designed to address the skepticism of senior industry professionals and academics. These initiatives should feature robust, localized case studies and empirical data to demonstrate bio-concrete's efficacy, thereby bridging the identified perceptual gap and building trust across all experience levels.

Pilot Project Implementation and Policy Incentives: The government, in partnership with leading construction firms, should fund and execute large-scale public pilot projects using bio-concrete. Concurrently, policy frameworks such as tax incentives, green building certification points, or fast-tracked approvals for projects utilizing self-healing technologies should be established. This will create tangible proof-of-concept, stimulate market demand, and address the economic and regulatory barriers identified as unfeasible strategies.

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