A Review of the Economics and Management of Modern Structural Materials and Software in the Construction Industry in Nigeria

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ABSTRACT: *The Nigerian construction industry is undergoing gradual transformation, with increasing attention to modern structural materials and advanced software capable of enhancing efficiency, sustainability, and cost-effectiveness. This study investigates the economics and management of these innovations, emphasizing their potential to reshape the sector. While global literature affirms long-term cost savings, efficiency gains, and sustainability benefits, limited context-specific research exists for Nigeria, where high upfront costs, inadequate infrastructure, limited technical expertise, and inconsistent supply chains remain significant barriers. This research applies a mixed-method approach comprising literature review, comparative economic analysis, and evaluation of relevant case studies to assess feasibility, economic implications, and management requirements for adoption. Findings indicate that modern materials such as high-performance concrete, self-healing concrete, advanced composites, and technologies like BIM and 3D printing can lower lifecycle costs, improve project outcomes, and enhance durability. However, adoption is impeded by limited awareness, financial constraints, inadequate infrastructure, and regulatory gaps. The study recommends targeted government incentives, capacity-building programs, local manufacturing initiatives, and integrated policy frameworks to accelerate adoption. While limitations exist in localized data availability, this research provides critical insights for bridging the innovation gap in Nigeria's construction industry.*

KEYWORDS: *modern, structural, materials, construction*

I. INTRODUCTION

Structural materials in civil engineering form the backbone of load-bearing elements in buildings, bridges, dams, and other infrastructure. Common structural materials include concrete, steel, timber, and masonry, each with its advantages and applications in different types of construction projects. These materials are selected based on their mechanical properties, durability, and ability to withstand various loads and environmental conditions. Because structural materials provide the framework for a structure and are quite resource-intensive, selecting the right one is essential (Alam and Hammad, 2023). The selection of structural materials depends on factors such as the type of structure, environmental conditions, cost considerations, and specific performance requirements (Plati, 2019).

Historically, the Nigerian construction industry has relied on conventional materials such as concrete, steel, wood, and masonry for its projects (Gharehbaghi, 2015). Although these materials have served us well in the past, they are progressively losing their ability to meet the demands of contemporary construction methods. Due to factors such as increasing costs, limited availability, and environmental concerns regarding these traditional materials, the industry is on the verge of a tipping point that is compelling stakeholders to explore alternative options (Orsini and Marrone, 2019). The emergence of modern structural materials such as high-performance concrete (HPC), self-healing concrete (SHC), and advanced composites presents a

transformative opportunity for the Nigerian construction industry. These materials offer several advantages over their conventional counterparts, including higher strength-to-weight ratios, increased durability, and enhanced resistance to environmental degradation (Rajak et al., 2019). Moreover, modern materials often exhibit enhanced performance attributes, like SHC, which can significantly lengthen a structure's life and reduce ongoing maintenance costs (Huseien et al., 2019).

Structural software in civil engineering refers to the use of advanced computer programs and applications that aid in the design, analysis, and management of civil engineering projects (Mei and Wang, 2021). The role of civil engineers is vital in this dynamic world. They have the heavy burden of coming up with ideas, planning, and constructing buildings that not only last a long time but also adapt to the shifting needs and preferences of a growing population (Khan and McNally, 2023). As the demands placed on these professionals grow more complex and extensive, it is becoming more and more imperative that they embrace technological advancements. Nigeria is entering a new era where advancement will require the use of contemporary structural software. The way civil engineers design and evaluate buildings and other structures has been completely transformed by structural software. It enables engineers to carry out elaborate analyses, produce sophisticated models, and optimize designs, resulting in a more effective use of resources and materials. Additionally, structural software facilitates better decision-making throughout the project lifecycle by enabling smooth design data sharing among project stakeholders.

Previous studies and research related to modern structural materials and software, focusing on the need for Nigerian construction industries and civil engineers to advance, have explored various aspects of this topic. Researchers have highlighted the importance of adopting modern materials and software in the construction industry to enhance the efficiency, durability, and sustainability of structures in Nigeria. Several key themes emerge from these studies, including the availability and accessibility of modern materials, the benefits and challenges of their adoption, and the role of software in improving design and construction processes. Nwokediegwu et al. (2024) emphasized the need for Nigerian construction companies to embrace modern structural materials such as HPC and advanced composites to meet the increasing demand for durable and sustainable infrastructure. The study highlighted the benefits of these materials, including improved strength, durability, and reduced maintenance costs. However, it also noted the challenges of high initial costs and limited availability of these materials in the Nigerian market.

Similarly, Kuzina et al. (2018) conducted a study on the availability and accessibility of advanced composites in Nigeria compared to traditional materials used in construction. The study found that while advanced composites offer superior mechanical properties and durability, their adoption in Nigeria is hindered by high costs, limited availability, and a lack of awareness among construction professionals. The researchers recommended increased investment in research and development to promote the use of advanced composites in the Nigerian construction industry. In another study, Freire et al. (2021) discussed the role of 3D printing technology in the construction industry, highlighting its potential to revolutionize the way buildings are designed and constructed. The study emphasized the need for construction companies to invest in 3D printing technology to improve efficiency, reduce construction time, and minimize waste. However, the study also noted the challenges of implementing 3D printing technology globally, including the high cost of equipment and the need for skilled personnel.

Furthermore, Olanrewaju et al. (2020) focused on the use of Building Information Modeling (BIM) software in the Nigerian construction industry. The study highlighted the benefits of BIM in improving collaboration among project stakeholders, reducing errors and rework, and enhancing project outcomes. However, the study also identified barriers to the adoption of BIM in Nigeria, such as the lack of skilled personnel and the high cost of software licenses. Overall, previous studies have underscored the importance of modern structural materials and software in advancing the Nigerian construction industry. While these materials and technologies offer significant benefits, their adoption is hindered by various challenges such as high costs, limited availability, and a lack of awareness and skilled personnel. Addressing these challenges will be crucial in enabling Nigerian construction companies and civil engineers to embrace modern materials and software and effectively face present and future challenges in the industry.

While existing literature emphasizes the long-term benefits of modern structural materials and software, such as cost savings and improved project management, there is limited research specifically addressing the Nigerian context. Studies often focus on developed economies where these materials and tools are more accessible and economically feasible. In Nigeria, barriers such as high upfront costs, supply chain inefficiencies, lack of local production, and insufficient training have not been thoroughly studied. Additionally, there is limited research on the role of government policy and economic incentives in promoting the adoption of these technologies in Nigeria.

The study aims to explore the economics and management of these cutting-edge structural materials and software, highlighting their potential to completely transform the building industry in Nigeria. The objectives of this study are to: analyze the economic impact of adopting modern structural materials in the Nigerian construction industry, evaluate the management practices required for the successful integration of advanced software technologies and to identify the challenges and opportunities associated with these innovations.

II.   METHODOLOGY

The methodology employed in this study adopts a mixed-method approach, combining qualitative and quantitative techniques. It primarily relies on the comprehensive review and critical examination of existing literature to extract relevant insights and analyze patterns, trends, and gaps within the subject matter. This method ensured a balanced integration of theoretical frameworks and empirical findings to provide a robust foundation for the study's conclusions. The primary data source used for this study were compiled from peer-reviewed journals, industry reports, government publications, and technical standards published between 2008 and 2024. Web of Science, Google Scholar, and ScienceDirect databases were searched, with keywords including "modern structural materials," "self-healing concrete," "BIM adoption in Nigeria," and "construction software economics." The selection criteria required that sources provided measu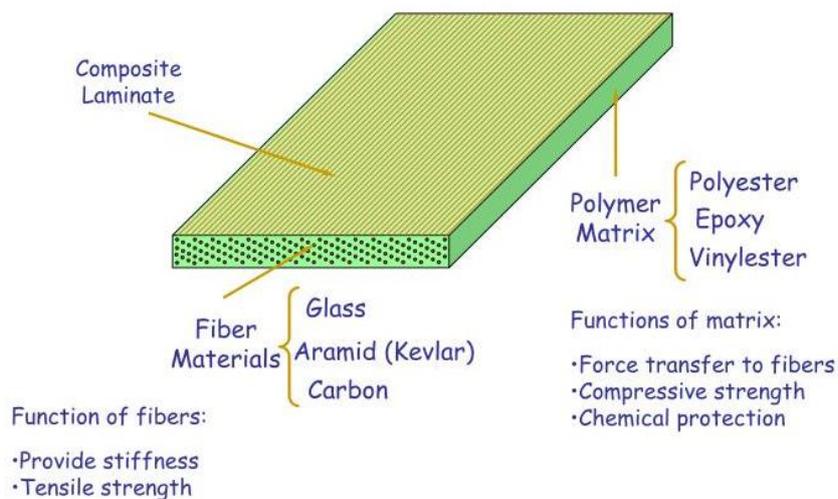rable economic, technical, or operational outcomes; address Nigeria or comparable developing-country contexts and be published in English. Studies that lacked verifiable data or methodological transparency were excluded to ensure quality and reliability.

To improve validity, only peer-reviewed sources and verified industry reports were used in the analysis. Data triangulation was used by comparing economic findings to managerial insights and operational outcomes from multiple case studies. The selection criteria were consistently applied, and data extraction templates were standardized, ensuring reliability.

A.   INNOVATIONS AND ADVANCEMENTS IN STRUCTURAL MATERIALS AND SOFTWARE

Advanced composites, such as fiber-reinforced polymers (FRPs) as shown in Figure 1 and carbon fiber composites, have gained prominence in structural engineering. These materials offer exceptional strength-to-weight ratios, corrosion resistance, and design flexibility, making them suitable for a wide range of applications (De Jong et al., 2021). Advanced composites, such as fiber-reinforced polymers (FRPs), offer high strength-to-weight ratios, corrosion resistance, and ease of installation. These materials have been successfully used in reinforcing and retrofitting structures globally (Hollaway and Teng, 2008). Their application in Nigeria can revolutionize the construction of bridges, high-rise buildings, and other critical infrastructure.

Fig. 1: Labeled diagram of a Fiber-Reinforced Composite

High-Performance Concrete (HPC) formulations have become a standard in modern construction. Incorporating additives like silica fume and superplasticizers enhances the compressive strength and durability of concrete structures, contributing to longer service life and reduced maintenance costs (Smarzewski, 2019). HPC is engineered to provide superior durability and strength compared to traditional concrete. Studies have shown that HPC can significantly reduce maintenance costs and extend the lifespan of structures, making it a cost-effective choice in the long term (Mehta and Monteiro, 2014). In the Nigerian context, the adoption of HPC can mitigate the frequent issues of structural failure and maintenance.

Construction is revolutionized by the prefabrication of structural materials, which offers cost savings, speed, and efficiency (De Jong et al., 2021). Component manufacturing off-site improves quality control while reducing disruptions on-site. This approach has the potential to revolutionize construction by producing inventive, sustainable structures. Sustainability is a common thread running through many of these trends. For instance, the development of Self-Healing Concrete (SHC), which can monitor its reversible strain and damage, as well as repair micro-cracks autonomously, contributes to the longevity and sustainability of structures. One of the most often used materials in civil engineering, concrete is suitable for all types of construction. Concrete has brittle material properties because it is strong in compression but weak in tension (Chiadighikaobi et al. 2022). SHC incorporates materials that can autonomously repair cracks, enhancing the longevity and durability of structures. Recent research indicates that SHC can reduce the lifecycle costs of buildings and infrastructure by minimizing repair needs (Van Tittelboom and De Belie, 2013). For Nigeria, this innovation could address the prevalent problem of poor maintenance culture and infrastructure degradation.

Fig. 2: Installation of prefabricated modular section of a building | Source: pmideas.es From construction to manufacturing

3D printing technologies are revolutionizing the construction industry by enabling the fabrication of intricate structural components (El-Sayegh, et al., 2020). This approach reduces material waste and construction time, offering a cost-effective and sustainable alternative to traditional building methods (Chiadighikaobi et al., 2024). The emergence of 3D printing technology has also influenced the landscape of structural materials. Additive manufacturing allows for the creation of complex structures with high precision, enabling architects and engineers to push the boundaries of design while optimizing material usage. 3D printing technology as shown in Figure 3, enables the rapid and precise construction of complex structures with minimal waste. It has the potential to significantly reduce construction time and labor costs (Buswell et al., 2018). In Nigeria, 3D printing can address housing shortages and provide affordable, high-quality housing solutions.

Fig. 3: A building printed with 3D Printing Technology | Source: fluidconstructions.com/3D-Printing-in-construction

BIM has become a standard in the construction industry, enabling collaborative and data-driven approaches to building design and construction (De Jong et al., 2021). BIM software allows stakeholders to create a 3D model that includes not only the physical aspects of the structure but also crucial information about materials, costs, and schedules. This integrated approach enhances coordination and reduces errors throughout the project lifecycle. BIM is a digital representation of the physical and functional characteristics of a facility. It facilitates better collaboration, visualization, and project management. Research indicates that BIM can lead to cost savings, reduced project timelines, and improved quality (Azhar, 2011). For Nigerian construction firms, BIM adoption can enhance project delivery and stakeholder communication. The advent of cloud computing has facilitated the development of cloud-based structural analysis software. These tools enable engineers to perform complex simulations and analyses without the need for powerful local hardware. The cloud infrastructure provides scalable computing resources, allowing for faster and more accurate analysis of large and intricate structural models.

Structural health monitoring has gained prominence with the integration of machine learning algorithms (Tapeh and Naser, 2023). These algorithms can analyze data from various sensors to detect and predict structural issues, such as fatigue, corrosion, or deformations. Real-time monitoring and predictive analytics contribute to proactive maintenance strategies, increasing the lifespan of structures and ensuring safety (De Jong et al., 2021). Finite element analysis (FEA) software has evolved to provide more accurate and detailed simulations of structural behavior. Advanced algorithms and numerical methods enhance the accuracy of stress analysis, deformation predictions, and failure assessments. This allows engineers to make informed decisions about design modifications and material selection.

B. SUSTAINABILITY ASSESSMENT OF MODERN STRUCTURAL MATERIALS AND SOFTWARE

Many traditional construction materials, such as concrete and steel, have high carbon footprints due to the energy-intensive processes involved in their production. For example, cement production, a key component of concrete, is a major emitter of carbon dioxide. Modern structural materials like high-performance concrete, self-healing concrete, and advanced composites often have lower carbon footprints compared to traditional materials like ordinary Portland cement and steel. For example, high-performance concrete can use supplementary cementitious materials (SCMs) like fly ash or slag, which reduce the amount of cement needed and thus the carbon emissions associated with its production (Amran et al., 2023), (De Jong et al., 2021). Advanced composites can be lighter than steel, reducing transportation emissions, and their production often requires less energy. 3D printing technology software can optimize material use, reduce waste, and streamline construction processes (El-Sayegh, et al., 2020). This can lead to lower energy consumption and carbon emissions compared to traditional construction methods.

Many traditional materials have limited recyclability. Concrete, for instance, is challenging to recycle due to the complexity of separating its

components. Likewise, certain metals may degrade during recycling, reducing their quality. Sustainability is a key focus in the development of modern structural materials. Consequently, many contemporary materials are designed with recyclability in mind. For example, some advanced composites can be easily separated and reused, reducing the need for virgin materials. 3D printing technology also allows for more efficient use of materials, as excess material can be recycled and reused in the printing process. BIM software can facilitate the use of recycled materials by providing detailed information on material properties and compatibility, encouraging the use of sustainable materials in construction projects.

Some modern materials are designed to be more energy-efficient than traditional materials. For instance, advanced composites can be lightweight yet strong, reducing the energy required for transportation and installation (Galishnikova and Chiadighikaobi, 2019). Modern materials can offer enhanced energy efficiency in various ways. For instance, self-healing concrete can reduce maintenance requirements, leading to energy savings over the lifetime of a structure. Additionally, some modern materials, such as those used in 3D printing technology, can be fabricated with greater precision (Hadi P., 2023), reducing material waste and the energy required for construction. BIM software can improve energy efficiency by simulating different design scenarios and optimizing energy performance before construction begins.

Modern materials often have greater durability, reducing the need for frequent maintenance and repair (Agenda I, 2016). This not only reduces the environmental impact of maintenance activities but also improves the overall social sustainability of structures by reducing disruptions to communities. The use of modern structural materials and software can have positive social impacts, such as creating opportunities for local industries to produce and supply these materials, thus boosting the local economy. Additionally, the adoption of modern materials can lead to safer and more comfortable structures for occupants, enhancing their well-being. While modern materials may have higher initial costs, their long-term sustainability benefits, such as reduced maintenance and energy costs, can offset these expenses over the lifecycle of a structure.

III.   RESULTS AND DISCUSSION

A. COST-BENEFIT ANALYSIS OF MODERN STRUCTURAL MATERIALS AND SOFTWARE IN THE CONSTRUCTION INDUSTRY IN NIGERIA

A comprehensive cost-benefit analysis (CBA) of modern materials and software in the construction industry involves examining both the initial costs and the long-term benefits associated with their adoption. This analysis helps stakeholders make informed decisions about whether to invest in these technologies. Modern materials such as high-performance concrete, self-healing concrete, and advanced composites often have higher initial costs compared to traditional materials like ordinary Portland cement and conventional aggregates. Advanced composites, for instance, may involve higher raw material costs and specialized manufacturing processes. The acquisition cost for modern construction software (e.g., Building Information Modeling (BIM), project management tools, 3D printing software) includes licensing fees, subscription costs, and possibly the cost of hardware upgrades. Additional costs might include training for staff to effectively use these new tools.

Construction software improves project management through better planning, scheduling, and resource allocation, reducing delays and cost overruns. BIM, for example, allows for more accurate 3D modeling and clash detection, minimizing errors and rework. Modern materials often require less manual labor due to their superior properties. For instance, high-performance concrete might achieve the desired strength with less material, reducing the volume of work. Software automation streamlines tasks such as documentation, compliance checks, and progress tracking, allowing human resources to focus on more critical tasks.

High-performance and self-healing concretes have longer lifespans and lower maintenance requirements. Self-healing concrete, for example, can autonomously repair cracks, significantly extend the structure's service life and reduce long-term maintenance costs. Advanced composites resist corrosion and environmental damage better than traditional materials, lowering the frequency and cost of repairs. Modern materials often exhibit superior structural performance (e.g., higher strength-to-weight ratios, and better thermal properties), enhancing the safety and functionality of buildings and infrastructure. Efficient use of

materials and precise construction methods reduces waste. For example, 3D printing technology can use exactly the amount of material needed, minimizing offcuts and excess (El-Sayegh, et al., 2020). The recyclability of advanced composites and sustainable sourcing of materials can lead to lower environmental impact. Modern materials often contribute to better energy efficiency in buildings, leading to reduced energy consumption and lower utility bills over time. Construction software can optimize energy use during both the construction phase and the building's operational life.

Companies that adopt modern materials and software gain a competitive edge by delivering higher-quality projects more efficiently. The ability to take on complex projects and offer innovative solutions can attract more clients and justify premium pricing. As the industry moves towards more sustainable and technologically advanced practices, early adopters are better positioned to meet regulatory requirements and market demands (Agenda I, 2016). Software tools enhance risk management by providing more accurate insights into potential issues and enabling proactive measures. Materials with better performance characteristics reduce the risk of structural failures and associated liabilities. Improved project planning and management tools lead to more predictable financial outcomes, reducing the likelihood of budget overruns and economic losses. While the initial investment in modern materials and software can be substantial, the long-term savings in labor, maintenance, and energy costs can result in a favorable ROI (Return On Investment). Case studies have shown that buildings constructed with high-performance materials and managed with advanced software often achieve better financial performance over their lifecycle. Structures built with modern materials and methods tend to have higher market values due to their superior quality, durability, and performance.

From the assessment above, it is derived that although modern structural materials and software are not widely adopted in Nigeria today, they are of more economic benefit than conventional structural materials and software.

A. CHALLENGES IN MANAGING MODERN STRUCTURAL MATERIALS AND SOFTWARE

There are several challenges involved in managing modern structural materials and software, as shown in Table 1, which explains the challenges and also offers vital solutions that can help in the management of structural materials and software in Nigeria.

Table 1: Key Challenges and Proposed Solutions for Managing Modern Structural Materials and Software in Nigeria's Construction Industry

S/N	CHALLENGES	EXPLANATIONS	SOLUTIONS
1	High Initial Costs	Modern structural materials and software often come with higher initial costs compared to traditional options (Agenda I, 2016). This includes the cost of acquiring advanced materials, software licenses, and necessary hardware.	Implement a cost-benefit analysis to showcase the long-term savings and efficiency gains (Agenda I, 2016). Encourage phased implementation to spread out costs and seek financial incentives or grants to support the initial investment.
2	Technical Expertise and Training	The adoption of modern materials and software requires specialized knowledge and skills, which may be lacking in the current workforce (Adepoju, O., & Aigbavboa, O. (2021).	Invest in comprehensive training programs and continuous professional development (Daher, M., & Ziade, F., 2024). Encourage partnerships with software vendors for training and support.

3	Resistance to Change	Resistance from stakeholders who are accustomed to traditional materials and methods can hinder the adoption of modern technologies (Agenda I, 2016).	Conduct awareness campaigns highlighting the benefits of modern materials and software (Agenda I, 2016). Provide case studies and real-world examples demonstrating successful implementation. Engage stakeholders early in the process to address their concerns and gain their buy-in.
4	Supply Chain Availability	Ensuring a steady and reliable supply of modern structural materials can be challenging, especially in regions where these materials are not readily available (El-Sayegh, et al., 2020).	Develop local manufacturing capabilities and establish robust supply chains (Segerstedt, A., & Olofsson, T., 2010). Work with suppliers to ensure consistent quality and availability. Explore the use of alternative materials that can be sourced locally while meeting modern standards.
5	Quality Control and Assurance	Maintaining the consistent quality of modern materials and ensuring software reliability is crucial for project success (Oni S. B., 2025).	Implement stringent quality control processes and regular inspections. Use advanced monitoring and testing techniques to ensure materials meet specified standards (Oni S. B., 2025). For software, ensure thorough testing and validation before full deployment, and maintain regular updates to address any issues.
6	Customization and Adaptability	Modern materials and software often need to be customized to fit specific project requirements and local conditions (Naboni, R., & Paoletti, I., 2015).	Work with vendors to develop customizable solutions. Engage in pilot projects to test and adapt materials and software to specific needs. Ensure flexibility in project planning to accommodate necessary adjustments (El-Sayegh, et al., 2020).
7	Sustainability and Environmental Concerns	Ensuring that the use of modern materials aligns with sustainability goals and environmental regulations (Agenda I, 2016).	Prioritize materials that offer environmental benefits, such as reduced carbon footprint and recyclability (Almusaed, A. et al., 2024). Implement software solutions that support sustainable construction practices, such as energy modeling and resource optimization.

IV.   CONCLUSION

This study reviewed the existing literature on the economics and management of modern structural materials and software and its possible utilization in Nigeria's construction industry, focusing on their potential to improve efficiency, durability, and sustainability. The findings show that while modern materials such as high-performance concrete, self-healing concrete, and advanced composites have higher initial costs compared to traditional materials, they deliver significant lifecycle cost savings through reduced maintenance, extended service life, and improved operational efficiency.

When coupled with advanced construction software like BIM, these technologies further enhance project delivery, minimize waste, and optimize resource use.

The study highlights the importance of training, capacity building, and stakeholder engagement. Effective adoption requires targeted managerial strategies, such as phased implementation, continuous professional development, and the integration of digital tools into standard workflows to improve collaboration, decision-making, and quality control.

Key barriers identified in this study include high capital requirements, inadequate infrastructure, limited technical expertise, and unreliable supply chains. At the same time, opportunities exist in the form of government incentives, local manufacturing of modern materials, technology transfer partnerships, and demonstration projects that showcase the benefits of these innovations in Nigerian contexts.

This work provides evidence-based recommendations that bridge the gap between global best practices and Nigeria's unique construction environment, offering a roadmap for policymakers, practitioners, and investors seeking to modernize the sector. The study is constrained by the scarcity of localized quantitative data on the long-term economic performance of modern materials in Nigerian projects. Additionally, the absence of large-scale, in-country pilot projects limits the ability to generalize findings across all regions of Nigeria.

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