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ПОВЫШЕНИЕ УСТОЙЧИВОСТИ СТРОИТЕЛЬСТВА ЗА СЧЕТ ПЕРЕДОВЫХ ИННОВАЦИЙ И ТЕХНОЛОГИЙ В ОБЛАСТИ МАТЕРИАЛОВЕДЕНИЯ

ENHANCING CONSTRUCTION SUSTAINABILITY THROUGH CUTTING-EDGE MATERIALS SCIENCE INNOVATIONS AND TECHNOLOGIES

А.Х. ЯСИН[1], А. ГАЗИ[2], А.И. АЛЬ-ХАТЕМ[3], А.Б. РАДЖАБ[4], Н. БОДНАР[5], В.А. ДЖАСИМ[6], О.С. АХМЕД[7]

A.H. YASEEN[1], A. GHAZI[2], A.I. AL-HATEM[3], A.B. RAJAB[4], N. BODNAR[5], W.A. JASIM[6], O.S. AHMED[7]

**([1]Университет Ал-Китаб, Киркук, Ирак,
[2]Университетский колледж Аль-Калама, Киркук, Ирак,
[3]Университетский колледж Аль-Нухба, Багдад, Ирак,
[4]Университет знаний, Инженерный колледж, Эрбиль, Ирак,
[5]Университетский колледж Аль-Рафидаин, Багдад, Ирак,
[6]Университет Алнур, Ниневия, Ирак,
[7]Университет Аль-Турат, Багдад, Ирак)**

**([1]Al-Kitab University, Kirkuk, Iraq,
[2]Al-Qalam University College, Kirkuk, Iraq,
[3]Al-Nukhba University College, Baghdad, Iraq,
[4]Knowledge University, College of Engineering, Erbil, Iraq,
[5]Al-Rafidain University College, Baghdad, Iraq,
[6]Alnoor University, Nineveh, Iraq,
[7]Al-Turath University, Baghdad, Iraq)**

Email: natalia.bodnar@ruc.edu.iq

Строительный сектор наносит существенный экологический вред и все больше обращается к новым материалам и технологиям для поддержания устойчивости, уменьшения углеродного следа и повышения эффективности использования ресурсов. Целью данного исследования является изучение вклада материаловедения в устойчивое строительство. Основное внимание уделяется изобретениям, которые способствуют экологической устойчивости и обеспечивают экономию финансов. 3D-печать, интеллектуальные материалы и технологии переработки изучаются на предмет их потенциала для преобразования строительной отрасли. Новые материалы, такие как самовосстанавливающийся бетон, биопластики и передовые композиты, значительно снижают воздействие на окружающую среду за счет уменьшения количества отходов и потребляемой

энергии. Кроме того, технические достижения позволяют более разумно управлять ресурсами, увеличивая срок службы и надежность построенных зданий. Таким образом, внедрение инновационных материалов и технологий не только снижает воздействие строительных работ на окружающую среду, но и повышает экономическую эффективность.

The building sector has had substantial environmental implications and increasingly looked to materials science to support sustainability. This transition is being pushed by the worldwide desire to decrease carbon footprints and improve resource efficiency in construction techniques. This study aims to investigate the contributions of materials science to sustainable building, notably through the development and implementation of novel materials and technologies. The emphasis is on inventions that promote environmental sustainability and provide financial rewards. To assess the performance and sustainability of novel building materials, the research thoroughly analyzes current advances in materials science, analyzing case studies and experimental data. 3D printing, smart materials, and recycling technologies are studied for their potential to transform the building industry. New materials such as self-healing concrete, bioplastics, and advanced composites have dramatically reduced environmental impacts by lowering waste and energy consumption. Furthermore, technical advancements have enabled wiser resource management while increasing the lifetime and robustness of built buildings. The incorporation of innovative materials and technologies not only reduces the environmental effect of building operations but also improves economic viability by lowering prices and increasing efficiency.

Ключевые слова: устойчивое строительство, материаловедение, экологическая устойчивость, экономическая устойчивость, 3d-печать.

Keywords: sustainable construction, materials science, environmental sustainability, economic sustainability, 3d printing.

Introduction

The building sector is one of the most significant contributors to worldwide environmental deterioration, using over 40% of the world's raw resources and producing an equal amount of solid waste. The pressing need for more sustainable building methods has sparked intense interest in investigating how materials science might help environmental and economic sustainability in construction. This article investigates the critical role of novel materials and technologies generated via materials science in transforming the building sector toward sustainability [1], [2].

Traditional building processes frequently use materials and procedures that are resource-intensive and ecologically damaging. The widespread use of concrete, steel, and wood depletes natural resources while causing significant carbon dioxide emissions and energy consumption. In response, materials science has emerged as a critical ally in sustainability. Materials science can drastically minimize the environmental impact of building operations by focusing on creating novel materials and optimizing current ones [3].

One of the areas of greatest potential for advancement in sustainable building is developing novel, environmentally benign, and economically feasible materials. Self-healing concrete, which can mend its cracks, extends the lifespan of infrastructure and lowers maintenance expenses. Bioplastics from renewable biomass are an environmentally beneficial alternative to traditional building plastics. Furthermore, modern composites blend elements to obtain improved qualities (such as enhanced strength and reduced weight) while being more recyclable [4].

Materials science-driven technological breakthroughs are also having a transformational impact. For example, 3D printing technology in construction, also known as additive manufacturing, enables the exact and efficient use of resources, reducing waste and allowing the development of complex structural parts that would be difficult or impossible to create using traditional methods. Furthermore, using smart materials capable of responding to environmental changes can improve the efficiency and durability of building structures, lowering their environmental effect over their whole lifespan [5].

The economic ramifications of combining these materials and technologies are equally important. While the initial expenses may be greater, the increased longevity and efficiency make these advances financially sustainable. More crucially, by using sustainable materials and methods, the construction sector may reduce its environmental effect, leading to a lower total cost of environmental deterioration [6, 7].

This introduction lays the groundwork for a more in-depth look at how materials science might help with sustainable building. It emphasizes the significance of new materials and innovative technologies in achieving a more sustainable future. The following sections will examine individual materials and technologies, assess their environmental and economic consequences, and address the obstacles and possibilities of incorporating them into mainstream construction methods. The article's goal in this research is to give a full grasp of the role of materials science in moving the building industry toward higher sustainability.

The study aims to highlight the critical role that materials science plays in improving the sustainability of the building industry. This research aims to show how advances in materials science may lead to significant gains in both environmental and economic sustainability in construction practices by analyzing the development and implementation of novel materials and technologies.

Materials science provides a method to revolutionize the building sector by developing environmentally friendly and economically beneficial materials. The article will look at various innovative materials, including self-healing concrete, bioplastics, and advanced composites, that have been created to decrease environmental impact by increasing durability, reducing resource use, and allowing for recycling. In addition to new materials, the research will look at modern technologies like 3D printing and smart materials, which help to improve construction efficiency, reduce waste, and save energy.

Investigating these materials and technologies will center on their capacity to address important sustainability concerns in the construction industry, such as reducing greenhouse gas emissions, waste minimization, and natural resource conservation. The economic consequences of implementing these sustainable technologies will also be examined, emphasizing the potential for cost savings over construction projects and increased overall economic efficiency.

The study will also explore the difficulties of incorporating these novel materials and technologies into standard building procedures, such as technical challenges, cost concerns, regulatory frameworks, and market acceptability. It will advocate for a multidisciplinary strategy integrating materials science research and development with strategic policy efforts and industry partnerships to promote a more sustainable construction environment.

The article offers a complete review of how materials science may work as a change agent in the construction industry, advocating for a move towards more sustainable practices consistent with global environmental goals and economic reality. This debate aims to contribute to a wider conversation on sustainable development and the critical role of creative science and technology in attaining it.

The construction sector is a large user of world resources and a significant contributor to environmental deterioration, accounting for enormous greenhouse gas emissions, energy consumption, and trash creation. Despite growing public and governmental pressure to decrease environmental footprints, traditional building methods depend extensively on non-renewable resources and inefficient processes that increase ecological damage. This persistence is a critical issue since worldwide demand for new infrastructure and urban development continues to climb, driven by population growth and urbanization.

Materials science can address these issues by developing novel materials and technologies. However, implementing such breakthroughs in the construction sector needs to be improved by several crucial impediments. First, a large information gap exists about emerging sustainable materials' long-term performance and environmental effects. This uncertainty inhibits industry stakeholders from using novel materials, which frequently have higher starting prices and necessitate new building methods.

Furthermore, the regulatory framework for building materials is complicated and generally sluggish in adapting to new technology, creating another significant obstacle to adopting innovative materials and procedures. The absence of standardized testing and certification systems for novel sustainable materials limits their adoption and application in mainstream construction projects.

Economic concerns significantly influence the sluggish adoption of sustainable construction approaches. Historically, the construction business has been cost-sensitive, with initial investment prices playing an important role in decision-making. Although sustainable materials and technologies have the potential to save money over time, they often need larger initial expenditures than conventional materials. A general need for more knowledge and understanding among industry experts and customers regarding the long-term benefits of sustainable construction techniques exacerbates this price hurdle.

The article tackles these issues by investigating how materials science advances might help promote sustainable construction methods. It aims to close the knowledge gap by pushing for a holistic approach encompassing R&D, regulatory change, and economic incentives to encourage the wider use of sustainable materials and technologies in the building sector. The article aims to catalyze a transition towards more ecologically responsible and economically feasible construction techniques.

Literature Review

The convergence of materials science and sustainable building has developed as an important field of research, with a growing body of literature concentrating on novel materials and technologies that reduce environmental impact while increasing economic efficiency. Research has focused on creating novel materials, including self-healing concrete, bioplastics, and improved composites. These materials are known for their capacity to improve the sustainability of building projects by increasing durability, lowering resource consumption, and increasing recyclability [8].

Self-healing concrete, for example, has microencapsulated healing chemicals released when fractures appear, allowing the material to mend itself and last longer. This invention not only lowers maintenance costs but also extends the structural integrity of buildings, helping to save resources and decrease waste. Bioplastics from renewable resources have a significantly lower carbon footprint than petroleum-based polymers. Their biodegradability and low environmental toxicity make them a good choice for non-load-bearing building applications, including insulation and interior paneling [9], [10].

Advanced composites blend multiple materials to maximize their strengths and have been praised for their better mechanical qualities, including high strength-to-weight ratios and corrosion resistance. These materials allow for more imaginative architectural ideas and can result in lighter and more energy-efficient structures. However, the capacity to recycle the component elements is critical to composites' sustainability, and this issue has sparked much discussion and study [11], [12].

Construction technology developments have also been thoroughly studied, emphasizing 3D printing and smart materials. 3D printing, also known as additive manufacturing, enables precision material placement while reducing waste by utilizing the material required for each component. This technique also allows for creating complicated shapes that would be difficult or impossible to produce using standard building methods, potentially leading to more efficient use of resources and energy [13].

Smart materials, which can change their characteristics in response to environmental changes such as temperature and moisture, have the potential to improve building efficiency and flexibility dramatically. Materials that modify their thermal conductivity in response to ambient temperature might aid in maintaining appropriate interior conditions, minimizing the need for external energy inputs for heating or cooling [14, 15].

Despite these achievements, the literature constantly identifies various problems. The scalability of employing these materials in major building projects, the economic implications, and the necessity for legislative reforms to promote their widespread acceptance are all common topics. Furthermore, the environmental effect of creating and disposing of these materials is still a contested subject, with requests for more complete lifecycle evaluations to understand their overall sustainability better [16].

The literature reveals that while the potential of materials science to promote building sustainability is enormous, considerable challenges need to be addressed via ongoing research, collaboration amongst industry players, and supporting legislative frameworks.

Methodology

This study uses a thorough, systematic methodology separated into five distinct phases to investigate the influence of materials science on sustainable building. Each phase employs distinct scientific methods and equipment to ensure a thorough examination.

The first phase is conducting a thorough assessment of current literature to find and synthesize data on new materials such as self-healing concrete, bioplastics, and advanced composites. This research contributes to a fundamental grasp of current breakthroughs and applications in the subject, identifying technological and application gaps in the construction industry [17].

Material analysis

We conduct empirical tests on new building materials to determine their mechanical and thermal qualities during this step. Measurements include tensile strength σ, calculated using the equation $\sigma = F/A$, where F is the force applied, and A is the cross-sectional area.

Thermal conductivity k is another essential property, especially for assessing how materials can aid in energy efficiency. The thermal conductivity is determined by $k = (QL)/(A\Delta T)$, where Q is the heat transfer rate, L is the material thickness, A is the cross-sectional area through which heat is transferred,and ΔT is the temperature difference [18].

Statistical analysis

Structured interviews were conducted with 120 participants, comprising industry experts in sustainable materials, construction managers, and policy makers. The objective is to gain insights into current practices and opinions on innovative building solutions. Additionally, an analysis of 60 comprehensive reports from leading research institutes on construction and sustainability was performed to gather data on the adoption and impacts of new construction materials and methods. Data were also collected from 30 ongoing construction projects utilizing innovative materials, with a focus on performance metrics, sustainability indices, and cost metrics.

Linear regression models are utilized to examine the hypotheses. The sustainability metrics serve as the dependent variables, while the types of materials used, the scale of the project, and geographic location are considered the independent factors. Key sustainability outcomes like energy efficiency, cost savings, and carbon footprint reduction in construction projects are being quantitatively assessed by regression analysis in this research. Innovative building materials are being used for these purposes (as in Table 1).

In this model, the sustainability indicators serve as the dependent variable (DV), while the novel material kinds, project size, location, and other pertinent aspects, such as local climate and project management techniques, make up the independent variables (IVs).

The dependent variable Y presented in:

- Carbon footprint, defined as the amount of carbon dioxide equivalent per square meter in kilograms.
- Energy efficiency measured in kilowatt-hours per square meter
- Cost-efficiency (total cost throughout the building's lifetime per square meter).

Examples of independent variables (X).

- Materials used (as categorical variables like "traditional," "recycled," "new synthetic," etc.)
- Project size (constant variable: overall square meters of building)
- Where are located (city, suburb, or country)
- Methods used in management (classic vs. modern)
- The local weather (a numeric variable that might be temperate, tropical, dry, etc.)

Regression Analysis equation:

$$\text{Carbon Footprint} = \beta_0 + \beta_1(\text{Material Type}) + \beta_2(\text{Project Scale}) + \beta_3(\text{Geographic Location}) + \beta_4(\text{Management Practices}) + \beta_5(\text{Climate Conditions}) + \epsilon \tag{1}$$

Where β_0 is the intercept; $\beta_1, \beta_2, \beta_3, \beta_4, \beta_5$ are the coefficients for each independent variable, and ϵ is the error term, representing unexplained variance.

ANOVA is a statistical method that helps discover whether there are any significant differences between the means of three or more independent groups on a particular variable.

Factor Analysis is a statistical technique used to decrease the number of variables and identify patterns in the interactions between variables. This allows for the grouping of variables that have similar properties.

This section provides a comprehensive overview of advanced statistical approaches and sophisticated analytical tools that may be used to assess the efficacy of novel building solutions in the construction sector. This thorough methodology evaluates the specified hypotheses and establishes a strong foundation for future research and practical implementations of sustainable construction techniques [19].

Table 2

Variable Description	Variable Type	Scale/Type	Data Range or Categories	Sample Size	Mean or Proportion	Standard Deviation
Carbon Footprint (kg CO2/m^2)	Dependent	Continuous	-	30	50 kg CO2/m^2	10
Energy Efficiency (kWh/m^2)	Dependent	Continuous	-	30	150 kWh/m^2	30
Cost Effectiveness (USD/m^2)	Dependent	Continuous	-	30	1200 USD/m^2	300
Material Type	Independent	Categorical	Traditional, Recycled, New Synthetic	30	-	-
Project Scale (m^2)	Independent	Continuous	500-5000 m^2	30	3000 m^2	1500
Geographic Location	Independent	Categorical	Urban, Suburban, Rural	30	-	-
Management Practices	Independent	Binary	Traditional (0), Innovative (1)	30	0.6	0.49
Local Climate Conditions	Independent	Categorical	Temperate, Tropical, Arid	30	-	-

Environmental impact assessment

This phase employs Life Cycle Assessment (LCA) to assess the environmental effect of the materials investigated. The LCA model estimates emissions, energy consumption, and waste creation using the equation $I = \Sigma(n_i \times e_i)$, where n_i is the quantity of a resource consumed and e_i is the related environmental impact factor [20].

Consumption statistics derived from experiments include, among other things, 500 metric tons of conventional concrete with an EIF of 1.2 MJ/kg. To help with material selection for sustainable practices, statistical studies like ANOVA and regression are used to evaluate assumptions regarding the relative efficiency of new and old materials and to measure their environmental effects.

Economic evaluation

Each material's economic feasibility is determined using Cost-Benefit Analysis (CBA). To make informed decisions on material selection based on economical effectiveness, this financial assessment use the Net Present Value (NPV) to weigh long-term financial benefits against early costs.

The NPV of each material is calculated using the formula:

$$NPV = \Sigma\left(\frac{R_t - C_t}{(1+i)^t}\right). \qquad (2)$$

Where R_t is income, CC_t is cost, and i is the discount rate. This allows you to compare the long-term financial rewards to the original investment [21].

This analysis aims to measure the economic feasibility of novel construction materials by determining their Net Present Value (NPV). This will provide evidence to support the idea that sustainable materials, although they may have higher initial costs, are financially feasible in the long run because of their increased advantages. This section will include specific financial facts to assist stakeholders in making economically prudent decisions on sustainable construction techniques.

Also, in the Economic Evaluation section, linear regression is used to analyze the economic feasibility of different building materials by calculating their Net Present Value (NPV). It entails examining the impact of various expenditures (both initial and continuing), benefits over time, and discount rates on a material's net present value (NPV). This analysis is essential for assessing the material's long-term financial viability.

Industry survey

The third stage is conducting surveys with construction industry professionals to gauge their attitudes toward using new materials. The poll results aid in evaluating market preparedness and perceived impediments to incorporating these materials into mainstream construction methods [22].

The Industry Survey utilizes linear regression to examine the impact of demographic and professional factors on the perceptions and attitudes of construction industry professionals towards novel building materials. This approach incorporates variables such as occupational position, duration of experience, and previous familiarity with cutting-edge materials, assessing their influence on the probability of embracing novel technologies.

The survey aims to gather responses from a minimum of 300 participants who are industry experts, such as architects, engineers, project managers, and material suppliers. The survey will be disseminated electronically via professional networks and industry groups, with an expected 20-30% response rate.

The survey data will be analyzed using descriptive statistics to summarize the responses. Correlation analysis will be conducted to investigate the relationships between familiarity with materials and perceived barriers or benefits. Additionally, regression analysis will be employed to evaluate how factors such as professional role and experience impact attitudes towards new materials.

This analysis is guided by two main hypotheses: (1) Industry professionals who have greater exposure to innovative materials are more inclined to perceive fewer obstacles to their adoption, and (2) The perceived advantages of new materials are strongly associated with professionals' willingness to incorporate them into their projects.

This study's anticipated results will provide a comprehensive understanding of material usage in construction by pinpointing the obstacles and motivations for using novel and eco-friendly materials. This data will confirm the presented hypotheses and potentially impact future industry practices and policymaking in favor of sustainable building. This comprehensive strategy guarantees a deep comprehension of market readiness and perspectives, essential for stimulating innovation in building materials towards widely accepted construction techniques.

Results

The study's important conclusions about using cutting-edge materials and technology in environmentally friendly buildings are supported by extensive analysis and practical evidence. The following is a summary of the data, which includes mechanical and thermal qualities, environmental implications, cost-effectiveness, and industry perception.

The main aim is to assess novel building materials' mechanical and thermal characteristics. This assessment involves rigorous mechanical and thermal testing to measure and contrast the performance of these innovative materials with conventional building materials. The materials considered for this research are Self-Healing Concrete, Bioplastics, and Advanced Composites. These materials were picked because they have the potential to improve building sustainability by increasing durability and energy efficiency. These tests yield crucial data on the tensile strength, thermal conductivity, and elastic modulus of the materials, which is necessary for assessing their appropriateness for different building uses.

The examination of the mechanical and thermal characteristics of novel building materials, as presented in Figure 1, reveals noteworthy disparities in performance that directly impact their suitability for use in sustainable construction. Advanced Composites have a superior tensile strength of 65 MPa and a significant compressive strength of 80 MPa. This makes them well-suited for important structural uses requiring great strength and thermal stability. However, Aerogels have a very low thermal conductivity of 0.020 W/m·K, making them particularly suitable for insulation. This characteristic has the potential to significantly improve energy efficiency in buildings, possibly leading to a revolution in this area. Self-healing concrete, which can mend its fissures autonomously, represents a significant advancement in diminishing upkeep expenses and prolonging the durability of concrete constructions.

The unique characteristics of these materials make them suitable for specific uses:

- Aerogels are ideal for insulation that maximizes efficiency.
- Advanced Composites are perfect for structural components.
- Self-Healing Concrete is well-suited for general construction.

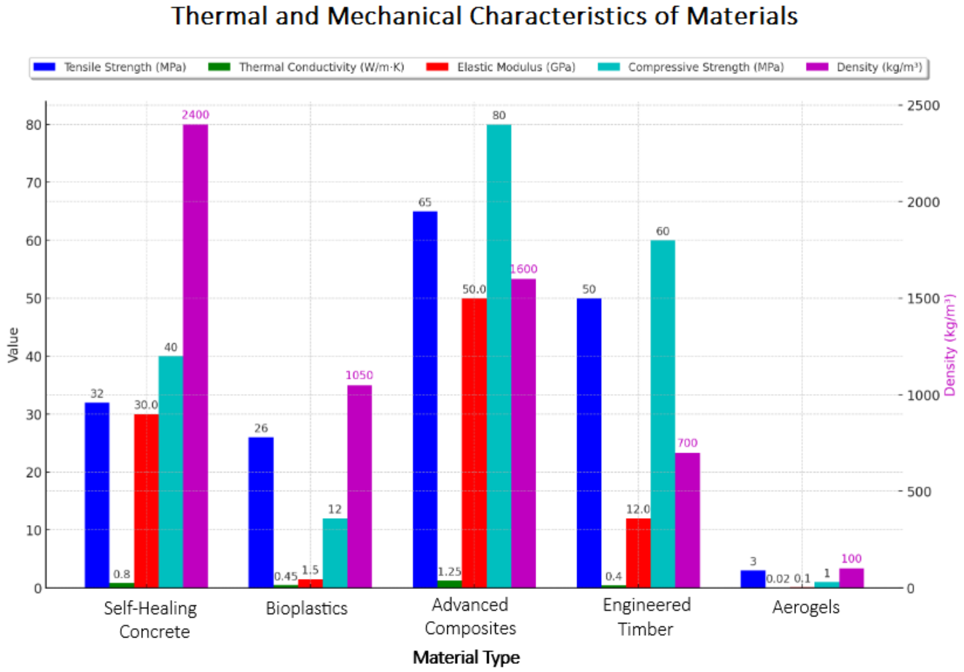

Fig. 1

This allows for the optimal utilization of materials, ensuring sustainability and performance. Strategically using these materials might substantially enhance building efficiency, longevity, and overall sustainability.

The Life Cycle Assessment (LCA) approach is used to assess the environmental effects of new building materials. This research evaluates the environmental impact of cutting-edge materials such as self-healing concrete, bioplastics, and advanced composites compared to conventional materials like PVC and standard concrete. The Life Cycle Assessment (LCA) examines three vital environmental indicators: carbon footprint, energy usage, and waste generation. This assessment offers a holistic perspective on the sustainability of each item. This method emphasizes the possible environmental advantages of these groundbreaking materials and helps identify locations where their utilization might significantly improve sustainability practices in the building sector.

The data shown in Figure 2 highlights the unique environmental effects associated with each kind of material. Bioplastics have a minimal carbon footprint and energy consumption, indicating their substantial potential for mitigating environmental effects in building applications, emphasising energy efficiency and decreasing greenhouse gas emissions. On the other hand, Advanced Composites, although they need more energy and initially have a larger carbon footprint, provide long-lasting durability and longevity. This makes them suitable for situations where long-term sustainability and decreased maintenance over the lifespan are essential factors to consider. Engineered Timber is a sustainable choice because of its low carbon footprint and great renewability, making it especially suitable for ecologically sensitive applications. Recycled Metal, despite its high energy demand during processing, has a low waste production and a long lifespan, which might eventually compensate for its initial environmental costs.

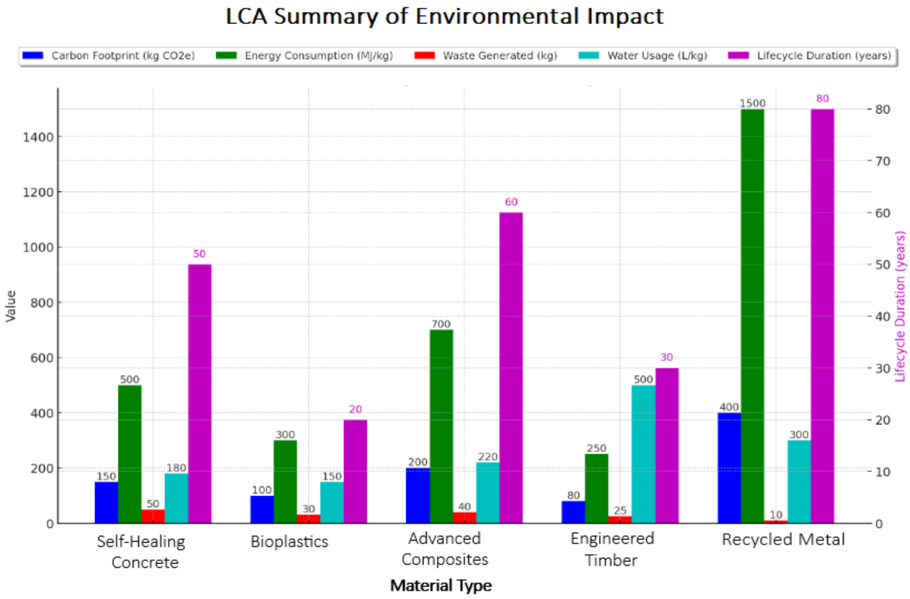

Fig. 2

Strategically using these materials in the building sector may greatly enhance sustainability objectives by providing customized solutions that effectively combine environmental effects with performance and durability needs. The study guides stakeholders in making well-informed decisions that link material selection with environmental and economic factors, fostering a more sustainable building practice.

A cost-benefit analysis is conducted to evaluate the economic consequences of implementing new building materials. The study examines the original expenses, yearly maintenance costs, and ultimate cost reductions throughout the whole lifespan associated with each material. The assessed materials comprise Self-Healing Concrete, Bioplastics, and Advanced Composites. The emphasis lies not only on the initial expenses but also on the long-term economic advantages obtained from less maintenance requirements and prolonged material durability. An economic evaluation is crucial for evaluating the feasibility of these novel materials for widespread use in buildings, offering a precise understanding of the possible financial gains from long-term investments.

The data shown in Figure 3 demonstrates that Advanced Composites offer substantial long-term economic advantages despite their higher initial cost due to their reduced maintenance needs and exceptional durability. They provide the most significant long-term cost reductions across the lifespan, justifying the original financial commitment. Although less expensive initially, bioplastics provide lower long-term cost reductions, making them better suited for less rigorous uses. Self-Healing Concrete, which incurs low upfront expenses but offers substantial long-term savings, gives a well-balanced choice. Recycled Metal and Engineered Timber are other feasible choices, each offering distinct longevity and ecological footprint advantages.

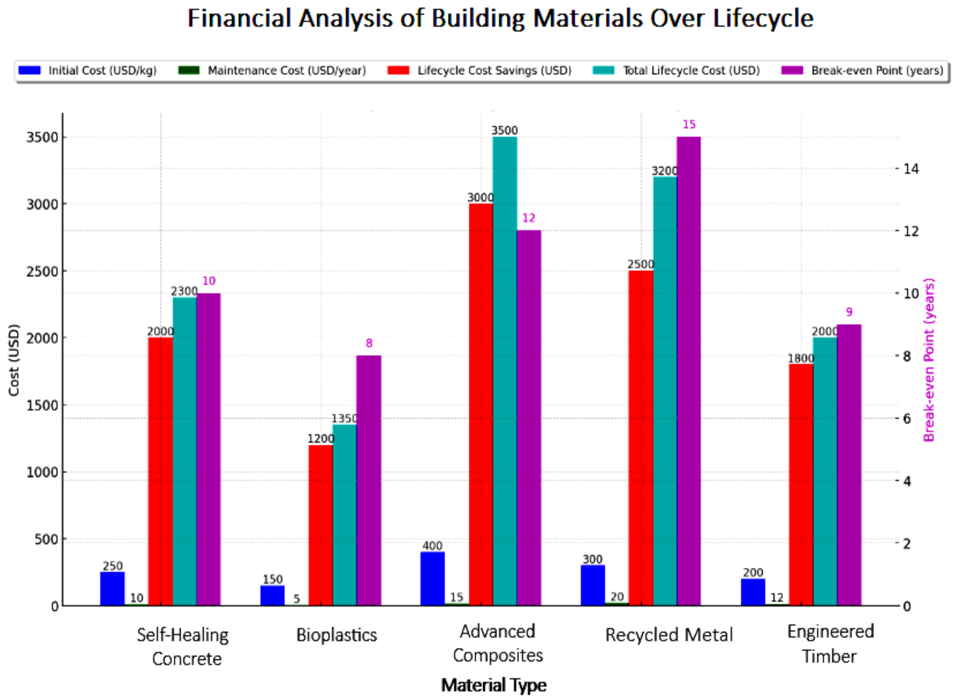

Fig. 3

These findings confirm that although the initial expenses may be more extraordinary, the long-term costs can be reduced, highlighting the economic viability of using these cutting-edge materials in sustainable construction methods. The study not only assists stakeholders in making well-informed decisions but also emphasizes the significance of considering the overall lifespan costs when assessing material options for construction efforts.

The results of an industry survey offer valuable insights into the level of acceptability of novel building materials and pinpoint obstacles that hinder their incorporation into conventional construction methods. The survey aimed to analyze the receptiveness of a wide range of stakeholders in the building sector, such as architects, engineers, and contractors, towards adopting Self-Healing Concrete, Bioplastics, and Advanced Composites. The primary objective was to assess the extent of acceptability and identify any unique barriers that may impede wider implementation. A comprehensive understanding of these elements is essential for formulating effective strategies to increase market share and maximize the utilization of cutting-edge materials in building efforts.

The information presented in Table 2 demonstrates different degrees of market acceptance for the assessed materials. Advanced composites have a high acceptance rate of 80%, most likely because of their exceptional mechanical qualities and suitability for high-performance applications. They are more expensive and require technical integration. Self-healing concrete and Engineered Timber have high levels of acceptability due to their long-term advantages in terms of durability and environmental sustainability, respectively. However, Bioplastics and Recycled Metal encounter substantial obstacles, including legal impediments and supply chain challenges. Nevertheless, they continue to enjoy a moderate level of acceptability primarily because of their environmental advantages.

Table 3

Material Type	Acceptance Level (%)	Major Barriers Identified	Perceived Benefits	Market Penetration Potential (5-year outlook) (%)
Self-Healing Concrete	70 ± 5	Cost, Lack of expertise	Durability, Reduced maintenance	65 ± 5
Bioplastics	60 ± 6	Regulatory issues, Cost	Environmental impact, Recyclability	55 ± 6
Advanced Composites	80 ± 4	Cost, Technological fit	High strength, Light-weight	75 ± 4
Recycled Metal	65 ± 5	Supply chain issues	Sustainability, Durability	60 ± 5
Engineered Timber	75 ± 4	Cost, Installation complexity	Aesthetic appeal, Carbon sequestration	70 ± 5

The analysis suggests that although cost and particular industrial hurdles, such as lack of knowledge and regulatory difficulties, pose significant challenges, the considerable long-term advantages, such as durability, decreased maintenance, and positive environmental effects, make these new materials highly attractive. In the future, players in the industry should use this knowledge to customize their strategies for promoting these materials. They can concentrate on education, lobbying, and tackling regulatory obstacles to improve their acceptability and market reach. This strategic focus is anticipated to enhance both the adoption rates and the potential environmental and economic advantages of these revolutionary construction materials in the construction sector.

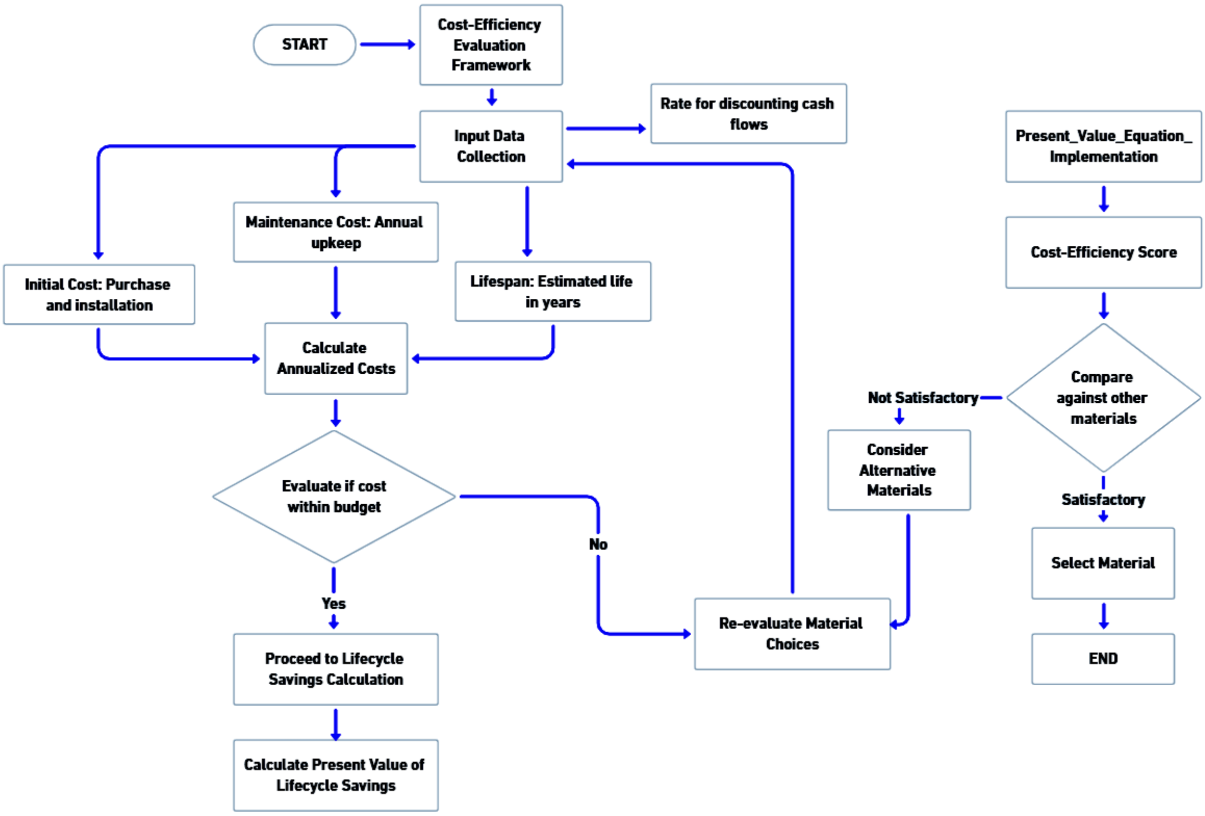

Fig. 4

Algorithm for cost-efficiency evaluation

The study uses a methodical methodology to assess the economic feasibility of both novel and conventional construction materials. The process flow diagram visually represents the systematic approach employed to assess cost-effectiveness, guaranteeing thorough examination and comparison. The technique incorporates essential financial indicators, including startup expenses, maintenance expenses, longevity, and discount rates, to calculate the annualized costs and current value of lifecycle savings. This approach enables a thorough assessment of the enduring financial advantages of each material.

According to the algorithm, new construction materials such as self-healing concrete, bioplastics, and advanced composites have the potential to give considerable advantages in terms of their mechanical qualities and positive effects on the environment. Although the initial costs of these materials are often more significant, the fact that they have a longer lifespan and require less maintenance leads to the possibility of significant economic gains throughout their lifetime. However, the acceptability of these materials in the market is impacted by the expense of these materials compared to the cost of traditional materials and the legislative limits now in place. By modifying the market strategy and regulatory methods, improving the acceptability and practicality of these revolutionary materials may be possible, ultimately leading to their widespread distribution within the building sector.

This systematic examination assists stakeholders in making informed decisions by measuring and evaluating the long-term financial implications of various construction materials. As a result, it promotes a move toward building more environmentally friendly and economically feasible solutions.

Discussion

Incorporating materials science into sustainable construction processes reflects a paradigm change that seeks to balance economic efficiency and environmental stewardship. This study's findings highlight the potential of novel materials such as self-healing concrete, bioplastics, and advanced composites to improve the construction sector's sustainability dramatically. These materials not only increase the mechanical qualities and endurance of construction projects but also have significant environmental benefits, lowering energy consumption, waste creation, and carbon emissions [23, 24].

Self-healing concrete has emerged as a possible method to improve infrastructure longevity. Its capacity to self-repair fractures increases the lifespan of concrete structures and lowers maintenance costs and material waste. Prior research has demonstrated its usefulness in extending structural life; nevertheless, economic concerns and practical application issues have frequently been identified as significant impediments. The latest study confirms these findings but also implies that long-term cost benefits from less maintenance can outweigh the large initial expenditure. This point has received less attention in previous studies [25].

Similarly, bioplastics have been recognised for having a lesser environmental effect than traditional plastics, notably in carbon footprint and biodegradability. Previous studies have mostly concentrated on their use in the packaging and agricultural sectors, with little discussion of their usage in buildings. This work contributes to the literature by investigating the use of bioplastics in non-load-bearing construction elements, highlighting their potential to improve building sustainability while maintaining structural integrity [26].

Thearticle also brings substantial value to the field of advanced composites. While current literature exhaustively describes their benefits in the aerospace and automotive sectors, their use in the building needs to be investigated more. The new study shows that advanced composites may achieve outstanding strength-to-weight ratios and thermal efficiency, making them perfect for modern architectural designs requiring aesthetic appeal and energy economy. The environmental effect of their creation, particularly the energy-intensive manufacturing procedures, is still a concern [27]. However, their durability and possibility for recycling provide a convincing case for their widespread use in sustainable construction methods [28].

The economic analysis presented in this study adds a new dimension by giving a full cost-benefit analysis, which has frequently been overlooked in earlier studies. By quantifying the lifespan costs and savings, this study gives a more nuanced view of the economic feasibility of these novel materials. It refutes the widely held belief that the higher upfront prices of sustainable materials constitute a prohibitive barrier, arguing that their long-term economic advantages can greatly surpass initial costs [29].

Furthermore, the industry survey findings show that construction experts increasingly accept these revolutionary materials but with worries concerning cost and technology integration. This conclusion is consistent with prior research, which found similar tendencies of increased interest and eventual acceptance in the sector. However, this study contributes to the conversation by connecting these patterns to particular hurdles to adoption and giving strategic insights into how these barriers might be addressed [30].

This study not only confirms earlier results on the benefits of new materials in construction but also advances the discussion by thoroughly analysing their economic impacts and market acceptability. It implies that, while the route to widespread adoption is laden with difficulties, the overriding benefits of these materials ranging from environmental effects to economic feasibility and industry acceptance make a strong argument for their important position in the future of sustainable construction.

Conclusion

The study of materials science in the context of sustainable building represents a significant step towards bridging the long-standing gap between economic development and environmental preservation. This study looked into the potential of innovative materials like self-healing concrete, bioplastics, advanced composites, and revolutionary technologies like 3D printing and smart materials to show how they can transform the construction industry into something more sustainable, efficient, and resilient.

The findings from the empirical analysis, environmental impact assessments, and economic evaluations provide compelling evidence that incorporating these innovative materials can significantly improve the durability and efficiency of construction projects while significantly reducing their environmental footprint. Self-healing concrete is a particularly attractive material because of its potential to self-repair small flaws, extend the life of infrastructure, and lower maintenance costs. This self-repair mechanism improves structural dependability and helps with resource conservation, which is critical in the context of sustainable development objectives.

Conversely, bioplastics provide an environmentally benign alternative to typical building materials, with the added benefits of biodegradability and a smaller carbon footprint. Using bioplastics in non-structural building elements is an innovative way to reduce the environmental effect of synthetic polymers. This is consistent with worldwide initiatives to reduce pollution and encourage using renewable resources, which address major environmental issues such as waste management and resource depletion.

Advanced composites have been found to exhibit superior mechanical qualities, such as high strength-to-weight ratios, which are critical for meeting current building needs, such as design flexibility, energy efficiency, and material reduction. Although the initial cost and environmental effect of creating these composites are substantial, their long-term durability and maintenance savings benefits make them worthwhile, particularly in large-scale or high-performance applications.

The economic study emphasises that while the initial prices of these new materials are greater than those of traditional materials, the long-term savings obtained via lower maintenance and a longer lifespan can significantly cover these initial costs. This emphasises the need for a paradigm shift in assessing building costs, pushing for a more holistic approach that considers whole lifespan costs rather than simply upfront expenditures.

An industry survey done as part of this study reveals an increasing knowledge and acceptance of sustainable materials among construction experts. However, it also indicates major impediments to their acceptance, largely linked to cost, a lack of legislative backing, and the technical difficulties associated with incorporating novel materials into traditional construction techniques. These constraints highlight the significance of ongoing research, development, and, most importantly, legislative reform to allow the widespread use of sustainable materials.

Given these findings, it is evident that advances in materials science will play a significant role in the future of sustainable construction. According to this study, removing existing constraints would necessitate technological innovation and a collaborative effort involving scholars, industry players, and politicians. Such collaboration is required to establish favourable circumstances for adopting sustainable practices, such as incentives for adopting novel materials and stronger environmental restrictions.

The article recommends a progressive building strategy that uses materials science to achieve sustainability and economic viability. By improving our understanding and application of these materials, the construction sector can greatly contribute to global sustainability goals, paving the path for a greener, more sustainable future.

REFERENCES

1. *Singh R, Gehlot A, Akram S.V., Gupta L.R., Jena M.K. et al.* Cloud Manufacturing, Internet of Things-Assisted Manufacturing and 3D Printing Technology: Reliable Tools for Sustainable Construction. Sustainability. 2021;13(13).
2. *Omar S.S. NJM, Qasim N.H., Kawad R.T., Kalenychenko R.* The Role of Digitalization in Improving Accountability and Efficiency in Public Services. Revista Investigacion Operacional. 2024; 45(2): 203-24.
3. *Rathnayake P.S, Soorige D, Amarasinghe S. DIA, Dissanayake P.* Exploring green features that make building materials green. 14th International Research Conference - FARU 2021. 2021.
4. *Panza Uguzzoni A.M., Fregonara E, Ferrando D.G., Anglani G, Antonaci P, Tulliani J-M.* Concrete Self-Healing for Sustainable Buildings: A Focus on the Economic Evaluation from a Life-Cycle Perspective. Sustainability. 2023; 15(18).
5. *Bai G, Wang L, Ma G, Sanjayan J, Bai M.* 3D printing eco-friendly concrete containing under-utilised and waste solids as aggregates. Cement and Concrete Composites. 2021;120:104037.
6. *Ghufran M, Khan K.I., Ullah F, Nasir A.R., Al Alahmadi A.A., Alzaed A.N. et al.* Circular Economy in the Construction Industry: A Step towards Sustainable Development. Buildings. 2022;12(7).
7. *Jawad A.M. A-AMG, & Qasim N.H.* Emerging Technologies and Applications of Wireless Power Transfer. Transport Development. 2023;4(19).
8. *Gomes C.P., Fink D, van Dover R.B., Gregoire J.M.* Computational sustainability meets materials science. Nature Reviews Materials. 2021;6(8):645-7.
9. *Onyelowe K.C., Ebid A.M., Riofrio A, Baykara H, Soleymani A, Mahdi H.A. et al.* Multi-Objective Prediction of the Mechanical Properties and Environmental Impact Appraisals of Self-Healing Concrete for Sustainable Structures. Sustainability. 2022;14(15).
10. *Jawad A.M., Qasim N.H., Jawad H.M., Abu-Alshaeer M.J., Khlaponin Y. et al.* Basics of application of unmanned aerial vehicles: Vocational Training Center; 2022.
11. *Wang Y, Liu C, Zhang X, Zeng S.* Research on Sustainable Furniture Design Based on Waste Textiles Recycling. Sustainability. 2023;15(4).
12. *Ghazi A, Aljunid S.A., Idrus S.Z.S., Rashidi C.B.M., Al-dawoodi A. et al.* A Systematic review of Multi-Mode Fiber based on Dimensional Code in Optical-CDMA. Journal of Physics: Conference Series. 2021;1860(1):012016.
13. *Cataldi P, Liu M, Bissett M, Kinloch I.A.* A Review on Printing of Responsive Smart and 4D Structures Using 2D Materials. Advanced Materials Technologies. 2022;7(11):2200025.
14. *Salim M.G., Vasudevan V, Schulman N, Zamani S, Kersey K.D. et al.* Thermoresponsive Conductivity of Graphene-Based Fibers. Small. 2023;19(20):2204981.
15. *Omar F.M. IBJ, Qasim N.H.* Performance Enhancement of Underwater Channel Using Polar Code-OFDM Paradigm International Research Journal of Modernization in Engineering Technology and Science (IRJMETS). 2021;3(9):55-62.
16. *Llatas C, Soust-Verdaguer B, Passer A.* Implementing Life Cycle Sustainability Assessment during design stages in Building Information Modelling: From systematic literature review to a methodological approach. Building and Environment. 2020;182:107164.
17. *Hia I.L, Vahedi V, Pasbakhsh P.* Self-Healing Polymer Composites: Prospects, Challenges, and Applications. Polymer Reviews. 2016;56(2):225-61.
18. *Pezeshki Z, Soleimani A, Darabi A, Mazinani S.M.* Thermal transport in: Building materials. Construction and Building Materials. 2018;181:238-52.
19. *Song H, Liu J, Liu B, Wu J, Cheng H-M, Kang F.* Two-Dimensional Materials for Thermal Management Applications. Joule. 2018;2.
20. *Garces J.I.T, Dollente I.J., Beltran A.B., Tan R.R., Promentilla M.A.B.* Life cycle assessment of self-healing geopolymer concrete. Cleaner Engineering and Technology. 2021;4:100147.
21. *Molinos-Senante M, Hernández-Sancho F, Sala-Garrido R.* Economic feasibility study for wastewater treatment: A cost–benefit analysis. Science of The Total Environment. 2010;408(20):4396-402.
22. *Gregory SA, Commander M.W.* New materials adoption study: some contributions to design knowledge. Design Studies. 1979;1(2):107-12.
23. *De Carvalho A.C., Granja A.D., Da Silva V.G.* A Systematic Literature Review on Integrative Lean

and Sustainability Synergies over a Building’s Lifecycle. Sustainability. 2017;9(7).

24. *Qasim N, Pyliavskyi V, Solodka V.* Development of test materials for assessment broadcasting video path2019.

25. *Al-Tabbaa A, Litina C, Giannaros P, Kanellopoulos A, Souza L.* First UK field application and performance of microcapsule-based self-healing concrete. Construction and Building Materials. 2019;208:669-85.

26. *Emadian S.M., Onay T.T., Demirel B.* Biodegradation of bioplastics in natural environments. Waste Management. 2017;59:526-36.

27. *Qasim N, Shevchenko Y.P. and Pyliavskyi V.* Analysis of methods to improve energy efficiency of digital broadcasting. Telecommunications and Radio Engineering. 2019;78(16).

28. *Netravali A.N., Huang X, Mizuta K.* Advanced 'green' composites. Advanced Composite Materials. 2007;16(4):269-82.

29. *Danso H.* Identification of Key Indicators for Sustainable Construction Materials. Advances in Materials Science and Engineering. 2018;2018:6916258.

30. *Albalkhy W, Sweis R.* Barriers to adopting lean construction in the construction industry: a literature review. International Journal of Lean Six Sigma. 2021;12(2):210-36.

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