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OPTIMAL RESOURCE MANAGEMENT BY DEVELOPING CONTEMPORARY ECO MATERIALS AND SUSTAINABLE STRATEGIES

Ivan Stevović[1*], Snežana Stajić[2], Tatjana Ćirković Mitrović[2]

[1] Innovation Center of the Faculty of Mechanical Engineering, University of Belgrade, Belgrade, Republic of Serbia
[2] Institute of forestry, University of Belgrade, Belgrade, Republic of Serbia

[*] Corresponding author: istevovic@mas.bg.ac.rs

Abstract: Optimal resource management and the integration of ecological materials into sustainable strategies represent the basic approach to environmental protection and the efficient use of natural and processed resources on the Globe. Ecological materials, characterized by minimal environmental footprint, recyclability, and renewability, enable implementation of circular economy principles in construction, industry, and everyday life. Their use contributes to reducing pollution, lowering energy consumption in production processes, and extending the lifecycle of products through reuse and recycling. This paper analyzes key aspects of the reuse of materials, with a focus on management strategies that ensure sustainable ecology material flows within economic systems. In particular, the role of management in designing policies that promote the transition from linear to circular models is emphasized. Sustainable strategies must include life cycle assessment (LCA) and eco-design to minimize negative impacts on ecosystems while maintaining economic competitiveness. Moreover, the selection of ecological materials affects the quality of life and health of the population, aligning environmental and social objectives with economic development goals. The results of the analysis conducted in this paper indicates that successful integration of ecological materials into resources management requires cooperation of researchers, producers, consumers, and policymakers, as well as education that raises awareness about environmental protection and responsible material use. Implementing these approaches contributes to building a resilient society based on sustainability, circular economy, and optimal resources management.

Keywords: management, environmentally friendly materials, sustainability, reuse of materials, circular economy.

1. INTRODUCTION

Environmental degradation, climate change, and scarcity of natural resources are the bigest researches multidimensional challenges of the 21st century [1]. Traditional linear economic models based on the extraction, use, and disposal of materials are unsustainable, resulting in increased pollution, waste accumulation, and the depletion of non-renewable resources. In this context, ecological materials emerge as an essential component of sustainable development, representing materials with minimal environmental footprint, high potential for recycling and reuse, and renewability that supports the circular economy concept [2].

The energy sector, construction sector, manufacturing industry and various branches of the economy are increasingly integrating ecological materials to reduce carbon emissions and improve environmental performance. Moreover, ecological materials influence social dimensions such as human health, safety, and quality of life, thereby linking environmental and socio-economic objectives. Their systematic implementation requires the development of adequate management strategies, policies, and interdisciplinary approaches, ensuring the alignment of environmental protection with economic competitiveness.

The main objectives of this research are:

– To define ecological materials and their key characteristics relevant for sustainable development.

– To analyze their role within circular economy strategies and resources management.

– To evaluate management approaches that support the integration of ecological materials into production and consumption systems.

– To identify benefits, barriers, and opportunities related to the use of ecological materials in different sectors.

– To propose recommendations for enhancing the contribution of ecological materials towards building a sustainable society

2. METHODOLOGY

The methodological holistic approach to the research of this manuscript encompasses a complex and organized procedure, starting from logical principles and principles according to established objectives. For the purpose of creating this manuscript, the following general and special scientific methods are applied:

– Systematized data collection and analysis of the latest existing, world-recognized scientific results in the field of ecology materials in the context of sustainable strategies and optimal resources management, environmental protection and sustainable development, with special emphasis on forest renewable resources;

– Methods of induction and deduction, analysis and synthesis, as well as the method of analogy;

– The collected data are processed by statistical methods using Microsoft Excel and IBM SPSS Statistics 24 software packages.

The methodological framework of this manuscript is based on a qualitative literature review combined with comparative analysis. Sources included peer-reviewed scientific journals, international reports from UNEP, EU, and OECD, as well as national policy documents on circular economy and sustainable materials management. The analysis was conducted in the following steps:

– Identification and classification of ecological materials based on environmental impact assessment and life cycle analysis (LCA);

– Comparative analysis of management models that incorporate ecological materials in circular flows;

– Research of case studies illustrating successful implementation of ecological materials in the construction and industrial sectors;

– Synthesis of findings to formulate recommendations for policymakers and stakeholders.

3. RESULTS

The analysis revealed that ecological materials include natural renewable materials such as for example bamboo, hemp, cork, and wood from certified sustainable forests, as well as innovative recycled materials like recycled plastics, aluminum, and glass aggregates used in construction and many other different sectors. Life cycle assessments indicate that the environmental impact of ecological materials is significantly lower compared to conventional alternatives, particularly regarding greenhouse gas emissions, energy consumption, and waste generation.

Management strategies that integrate ecological materials often involve the following components:

Eco-design that prioritizes material selection with minimal environmental impact;

Closed-loop production processes where waste is reintroduced into the production cycle as a resource;

Policies promoting extended producer responsibility (EPR) and incentives for companies that utilize ecological materials;

Consumer education campaigns that raise awareness about the benefits of ecological materials and encourage sustainable consumption choices.

One positive practice is in the construction sector, where it is found that replacing conventional concrete components with recycled aggregates can reduce CO_2 emissions by up to 30% [3].

On other positive practice is within the packaging industry [4], where switching from virgin plastics to recycled plastics and biodegradable materials resulted in waste reduction and improved public per-

Table 1. *The results achieved by eco-friendly materials application*

Project name	Country	Eco material used	Results achieved
The Bamboo Tower	Indonesia	Bamboo	CO_2 reduction by 50%, low cost
Ford Plant Fiber Composites	USA	Plant fiber composites	10% weight reduction, fuel savings
Geopolymer Pavement Trial	Australia	Geopolymers	40% CO_2 reduction vs. cement

ception of brands. These outcomes demonstrate that ecological materials contribute to sustainability goals at both microeconomic and macroeconomic levels.

The main results achieved by some eco-friendly materials application are presented in Table 1., selected as per countries and as per case studies [5], [6], [7].

3.1. Analyse of CO_2 Emissions and Physical Properties-Traditional vs. Eco-friendly Materials

The comparison between some traditional most often used materials in civil engineering and adequate alternative environmentally friendly solutions is done. CO_2 emissions are selected as the main indicator of the level of how much the material is environmentally friendly. Figure no 1. presents the graph with comparison of CO_2 emissions (kg CO_2 per ton) of three conventional construction materials (Portland cement, steel rebar, fired clay bricks) with three eco-friendly alternatives (geopolymer cement, bamboo reinforcement, compressed earth blocks) [8]. The results shows that eco-materials reduce emissions by 60–90%, supporting sustainability goals in construction.

Key physical and environmental properties of selected conventional and ecological construction materials are presented in Table 2. Values are average estimates based on available scientific literature and industry reports [9].

The label "(parallel)" next to bamboo in the Table 2 refers to the direction of loading — specifically, along the grain (fiber direction) of the bamboo, since the diference in longitudinal and in transverse

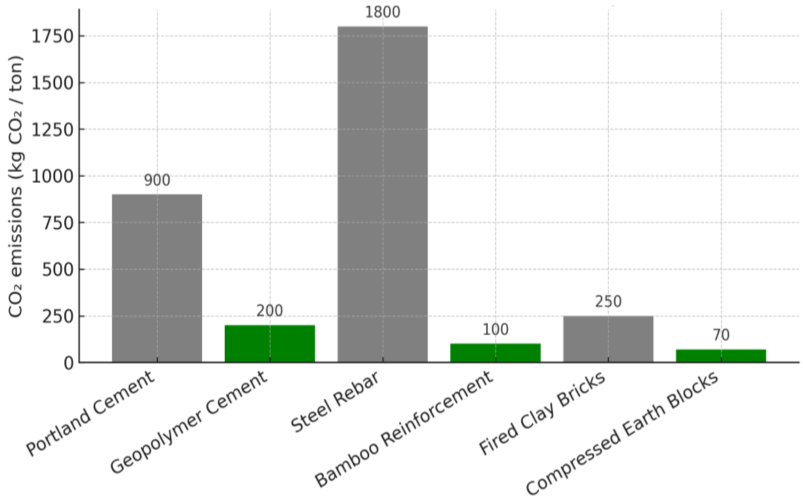

Figure 1. *CO_2 emissions comparison for contemporary eco-friendly materials vs. conventional materials*

Table 2. *Comparison of Conventional and Ecological Construction Materials*

Material	Carbon footprint (kg CO_2/kg)	Thermal conductivity (W/m·K)	Density (kg/m³)	Compressive strength (MPa)	Tensile strength (MPa)	Specific gravity	Cost (€/ton)
Portland cement	0.85–0.95	0.29–1.00	1500–1600	25–45	2.5–4.0	3.15	100–120
Steel rebar	1.85–2.10	45–60	7800	>250	>450	7.85	500–700
Fired clay bricks	0.22–0.45	0.6–1.0	1600–1800	10–20	~1.5	2.0	60–100
Geopolymer cement	0.05–0.25	0.25–0.35	1300–1600	40–60	3.5–5.0	2.2–2.5	90–110
Bamboo reinforcement	0.01–0.05	0.2–0.4	600–800	40–80 (parallel)	100–370 (parallel)	0.6–0.8	50–150
Compressed Earth Blocks (CEB)	0.02–0.06	0.25–0.45	1700–2000	2–7	~0.5	1.8–2.0	30–60

direction is always knowen [10]. This is the orientation in which bamboo exhibits its highest mechanical strength, both in compression and tension.

Bamboo is an anisotropic material, which means that its mechanical properties vary depending on the direction of the applied force:

– Parallel (along the fibers): Bamboo is very strong when loaded along the direction of its fibers — that is, lengthwise. This is the typical loading direction in structural applications.

– Perpendicular (across the fibers): Bamboo is much weaker when loaded across the fibers. In this direction, it is not suitable for structural use due to its low resistance.

In construction, bamboo is always used in ways that align forces with the grain, to maximize strength and safety. Therefore, the values listed in the table are for the parallel direction, which is most relevant for practical engineering purposes.

The adoption of ecological materials in construction responds to the urgent challenges of climate change, resource depletion, and environmental degradation. Comparative analysis shows that materials like geopolymer cement, bamboo reinforcement, and compressed earth blocks (CEB) have substantially lower carbon footprints than traditional materials such as portland cement, steel rebar and fired clay bricks.

For instance, geopolymer cement production can reduce CO_2 emissions by up to 80% compared to portland cement, while bamboo, as a fast-renewable resource, offers high tensile strength combined with low specific gravity and affordable cost. Compressed earth blocks, manufactured locally and without firing, allow low-energy building with good thermal mass and acceptable structural performance.

Beyond environmental benefits, these materials often require less energy for processing, enable local manufacturing, stimulate rural economic development, and enhance community resilience through sustainable infrastructure. They also contribute to healthier indoor environments due to their natural composition and absence of harmful chemical emissions.

Promoting ecological materials is therefore not only an environmental imperative, but also a strategic economic and social opportunity in the transition to circular and low-carbon economy.

3.2 Life Cycle Cost Analysis – Traditional vs. Eco Materials

Life Cycle Assessment (LCA) is a standardized methodology (ISO 14040, ISO 14044) for quantifying and evaluating the total environmental impacts of a product, process, or system throughout its entire life cycle—from raw material extraction, production, and distribution, through use, to end-of-life disposal or recycling. It accounts for both direct and indirect environmental aspects, including greenhouse gas emissions, energy and water consumption, waste generation, and other relevant parameters.

Life Cycle Cost (LCC), on the other hand, is an economic approach to evaluating the total cost of ownership of a product, infrastructure, or process over its entire life cycle. LCC includes initial capital costs, operation and maintenance costs, as well as decommissioning or recycling costs at the end of the life span. It is standardized under ISO 15686-5 and is widely applied in engineering, infrastructure, and energy projects as a decision-support tool.

The integration of LCA and LCC forms the basis for strategic decision-making that optimizes both environmental and economic aspects. While LCA answers the question "What is the environmental impact of this solution?", LCC answers "What is the total cost over time?". Their combined application enables the identification of solutions that minimize both ecological footprints and long-term costs, which is essential for optimal resource management**.**

In the context of building materials, *cost (Initial Cost)* refers to the initial price paid for acquiring and installing a material, typically measured per unit (e.g., per cubic meter or per ton). For traditional materials like portland cement, steel, and fired clay bricks, this cost is usually lower at the point of purchase. However, it does not account for environmental or maintenance impacts over time.

For eco materials (such as geopolymer cement, bamboo, or compressed earth blocks), the initial cost may be higher, but the total life cycle cost is lower due to reduced environmental impact, lower energy use, durability, and easier end-of-life reuse or biodegradability [11].

Another case study of positive world practice is related to the hemp concrete wall application [12]. Walls made of hemp concrete are very interesting from environmental and sustainability point of view.

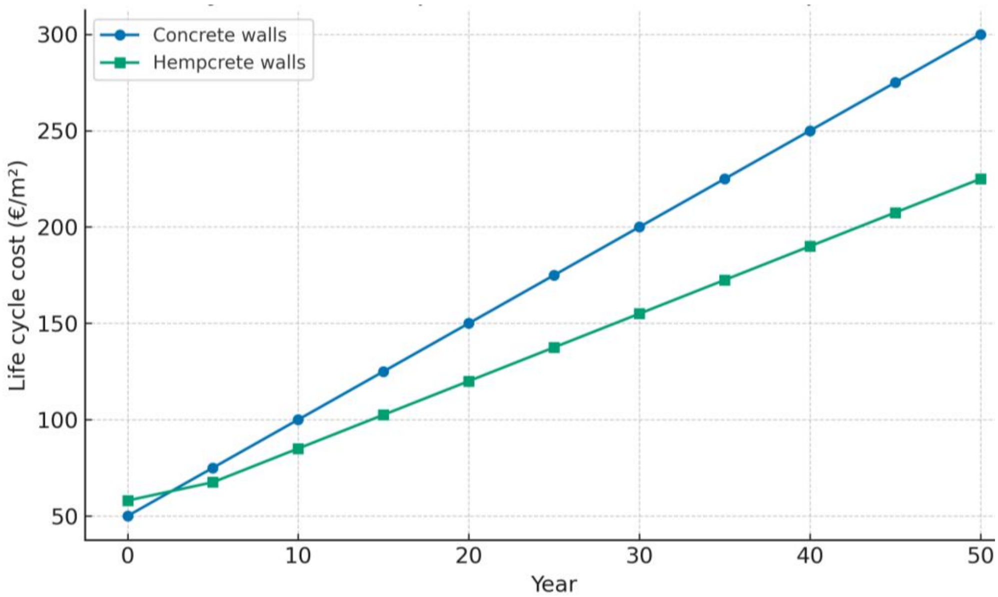

Figure 2. *Life cycle cost comparison: concrete vs. hempcrete walls; Source: Ip & Miller (2012)*

The comparison between life cycle cost of conventional concrete wall and the wall made of hemp concrete is researched. The results are shown on Figure no 2

The graph presents life cycle costs (€/m² over 50 years) of traditional concrete walls versus hempcrete walls. Although initial costs of hempcrete are ~15% higher, the life cycle cost becomes lower by year 3 due to reduced heating/cooling energy. At year 50, hempcrete walls are ~30% cheaper cumulatively.

3.3 Waste Reduction Potential – Eco-material Adoption Scenario

Eco material adoption scenario is also researched through the waste reduction potential criteria in the field of civil engineering and architecture materials [13]. The results show that the maximum waste reduction potential is realized if gypsum boards, then bricks, then concrete and than remaining other materials are replaced by adopted eco materials. Figure no 3. presents the pie chart with the percentage reduction

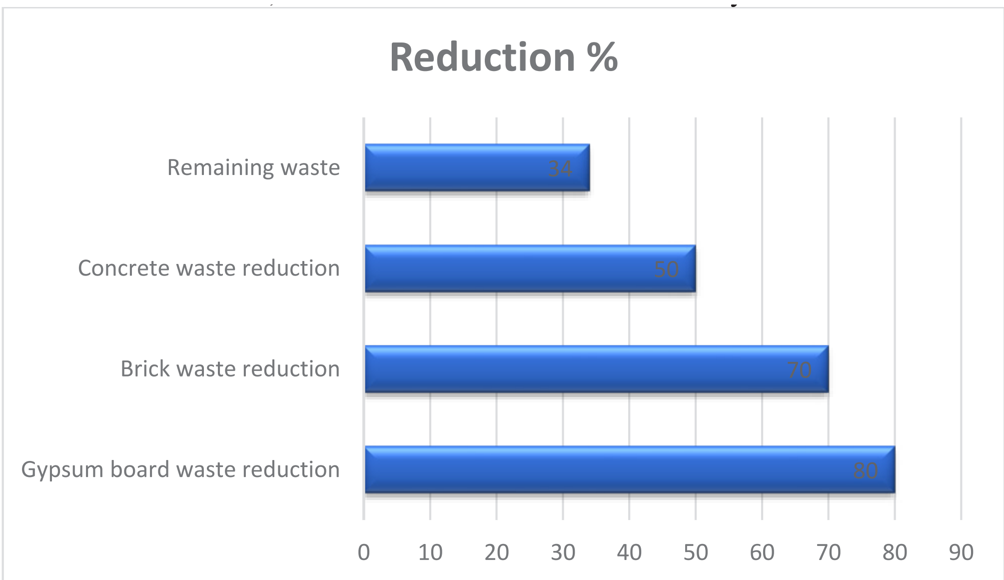

Figure 3*. Construction waste reduction potential. Source: Osmani & Villoria-Sáez (2019).*

in construction waste (by mass) if eco-materials are adopted in urban residential construction. Overall, total construction waste is reduced by ~55%.

In the context of sustainable urban construction, several eco-friendly materials are especially researched through the waste reduction potential criteria. They are increasingly recognized as effective substitutes for conventional high-waste materials such as gypsum boards, bricks, and concrete. Alternative eco material for gypsum board replacement is *magnesium oxide boards (MgO boards)* [14]. MgO boards are non-toxic, resistant to fire and moisture, and can be produced with lower energy inputs. Their recyclability and lower embodied energy make them a superior eco-alternative. Comparable strength and fire resistance to gypsum boards exist, but with significantly less construction site waste.

Adequate eco alternative for fired clay brick replacement are c*ompressed earth blocks (CEBs)* and g*eopolymer bricks (GPB)* [15]. CEBs use locally available soil with minimal cement or lime, avoiding the high-temperature firing required for traditional bricks. Geopolymer bricks, derived from industrial by-products (fly ash, GGBFS), drastically reduce CO_2 emissions. GGBFS (Ground Granulated Blast Furnace Slag) is a by-product of the steel manufacturing process, used as a supplementary cementitious material that enhances durability and significantly lowers the carbon footprint of construction. Main performance are high thermal mass, adequate compressive strength, and excellent insulation properties.

Eco replacements for concrete are *Geopolymer Concrete (GPC)* and *Hempcrete.* GPC [16] reduces carbon footprint by 80–90% compared to portland cement concrete. Hempcrete, while not load-bearing, is excellent for insulation and low-rise applications. GPC has similar compressive strength and durability to conventional concrete. Hempcrete offers moisture regulation and carbon sequestration.

Other eco materials researched through the waste reduction potential criteria are b*amboo (for reinforcement), recycled timber and bio-composite panels* [17]. Bamboo shows high tensile strength and rapid renewability. Recycled timber and bio-composites (e.g., hemp-lime, flax fiber panels) reduce the need for virgin raw materials. Structural and aesthetic performance depends on engineering design but often exceeds minimum building code requirements.

4. DISCUSSION

This chapter discusses global examples of eco-materials application, sustainability impacts, supports and provides decision makers and policy recommendations for Serbia and Republika Srpska.

4.1 Bamboo as Environmentally Friendly Structural Material

Bamboo has emerged as a promising ecological material in sustainable construction due to its extrimly rapid renewability, high strength-to-weight ratio, and carbon sequestration potential. Its role in green architecture (Figure 4) and circular economy models has expanded, particularly in Asia, Latin America, and increasingly in Europe. The results presented in Table 2. exhibits excellent mechanical properties of bamboo. Moisture content in bamboo varies between 8–15% (air-dried). Its chemical composition (60–70% cellulose, 20–25% hemicellulose, and 5–10% lignin) contributes to its durability and mechanical strength when properly treated. The

Figure 4. Bamboo structures – real bamboo frame architecture LIT

cost of bamboo is significantly lower than steel or concrete in regions where it is locally available. Its lightweight structure reduces transportation costs and foundation requirements. Lifecycle assessments (LCA) show bamboo construction reduces embodied carbon emissions by up to 60% compared to conventional materials [18].

Analyzing the literature [19] the comparison between the tensile strength of steel rebar and tensile strength of the bamboo is done and presented in Figure 5.

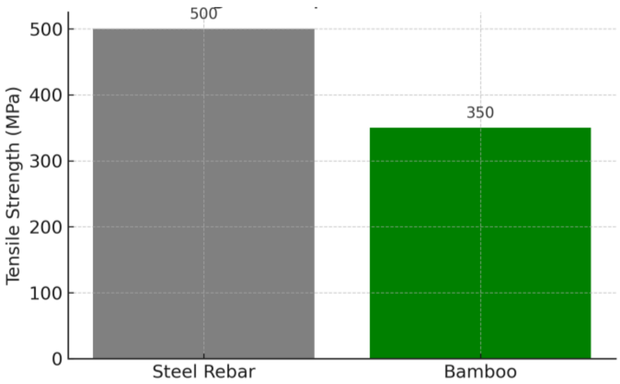

Figure 5. *Tensile strength comparison: steel vs. bamboo*

Bamboo is rapidly renewable (harvestable in 3–5 years), biodegradable, and sequesters large amounts of CO_2 during growth. It aligns with circular economy principles by enabling reuse, local production, low-energy processing, and minimal waste generation. Modular design and prefabrication of bamboo components further enhance construction efficiency.

Using bamboo reduces pressure on timber resources, lowers the demand for energy-intensive materials (like cement and steel), and creates rural employment. It supports the UN SDG 11 (Sustainable Cities) and SDG 12 (Responsible Consumption and Production).

Bamboo is used as a renewable structural material in Indonesia [20] due to its high tensile strength, fast growth, and carbon sequestration potential. The Green School in Bali [21] uses over 95% bamboo in its structure, reducing CO_2 emissions by ~70% compared to reinforced concrete buildings.

4.2 Concrete made of hemp

Hempcrete (concrete made of hemp) is a bio-composite material made from the woody core of the hemp plant (*hemp shives*), mixed with a lime-based binder and water. Unlike traditional concrete, it does not include portland cement, resulting in a significantly lower carbon footprint, which is actually Negative and it is -110 kg CO_2/m^3 [22].

Hempcrete exhibits low density (275–600 kg/m³), high vapor permeability, and low thermal conductivity (0.05–0.12 W/m·K), making it suitable for thermal insulation. However, its compressive strength (0.3–1 MPa) is much lower than conventional concrete, rendering it unsuitable for load-bearing structural applications without reinforcement.

Hempcrete is considered carbon-negative as the hemp plant absorbs more CO_2 during its growth than is emitted during production. While the production cost may be higher due to supply limitations and specific processing, long-term energy savings and environmental benefits support its economic viability.

Main advantages of hempcrete are: biodegradable, excellent thermal and acoustic insulation, regulates indoor humidity and reduces CO_2 emissions. Disadvantages are low mechanical strength, requires structural support for load-bearing use and higher upfront costs in some markets

Hempcrete is best applied in wall infill systems, roof insulation, and non-load-bearing blocks, particularly in passive and energy-efficient housing. It is ideal for eco-renovation projects but not for high-rise construction without composite structural solutions.

Hempcrete is a promising ecological building material that aligns with circular economy principles. Its wider adoption can help reduce greenhouse gas emissions, decrease cement dependency, and promote sustainable resource management [23] in the construction industry.

Hempcrete has been applied in residential housing in the UK [24], providing high insulation and negative carbon footprint due to CO_2 sequestration during hemp growth. For example, the Adnams Brewery distribution center used hempcrete [25], resulting in 35% energy savings annually.

4.3 Strategic Recommendations

Based on world best practices, the following recommendations are proposed for Serbia and Republika Srpska:

– Introduce subsidies and tax incentives for eco-materials production and use.

– Develop national standards for eco-materials to ensure safety and market adoption.

– Integrate eco-materials in public procurement for big infrastructure projects.

– Support research and development, as well as pilot projects on local eco-materials.

4.4. Benefits, barriers, and opportunities of eco materials usage

Although ecological materials offer numerous environmental and economic benefits, their implementation is often limited by market barriers, regulatory gaps, and insufficient awareness among consumers and producers. Challenges include:

– Higher initial costs associated with production and certification of ecological materials.

– Lack of standardized quality criteria for certain recycled materials.

– Resistance to changing traditional production processes due to required technological adaptation.

– Limited infrastructure for collection, sorting, and processing of recyclable materials in many regions.

To overcome these barriers, integrated policy frameworks are necessary, combining regulatory instruments (such as material bans or mandatory recycled content requirements), economic incentives (tax breaks, subsidies), and educational programs targeting all stakeholders. Collaboration among governments, industry, research institutions, and civil society is critical to promote innovation in ecological materials and ensure their widespread adoption.

5. CONCLUSION

The use of environmentally friendly construction materials such as bamboo, hempcrete, compressed earth blocks (CEBs), and geopolymer cement is a key component of strategies aimed at reducing greenhouse gas emissions and preserving natural resources. Bamboo, with its extremely rapid growth and high carbon sequestration capacity, significantly lowers net CO_2 emissions compared to conventional timber or steel structures. Hempcrete combines a negative carbon footprint—due to CO_2 absorption during plant growth—with excellent thermal insulation properties, thereby reducing operational energy consumption over a building's lifetime. CEB technology, relying on locally available soil and minimal material processing, eliminates the need for high-energy firing processes, drastically reducing both emissions and transportation costs. Geopolymer cement, developed from industrial by-products such as fly ash and ground granulated blast furnace slag (GGBFS), achieves up to 80% lower CO_2 emissions compared to Portland cement, while providing high durability and resistance to chemical degradation.

The integrated application of eco-materials not only mitigates global warming by lowering emissions during production but also enhances energy efficiency and extends the service life of buildings, thereby delivering multiple benefits within the framework of sustainable development and the circular economy.

The transition to a sustainable economy requires rethinking the way materials are produced, used, and managed. Ecological materials represent a key enabler of this transition, facilitating the implementation of circular economy principles and reducing the environmental footprint of human activities. Their use in construction, manufacturing, and consumer products contributes to pollution reduction, resource conservation, and improvement of health and wellbeing.

However, for their potential to be fully realized, it is essential to strengthen management strategies that integrate ecological materials into value chains through eco-design, life cycle assessments, and closed-loop models. Policymakers must establish supportive regulatory and economic environments that encourage companies to adopt ecological materials, while consumer awareness must be raised to drive market demand.

Future research should focus on developing innovative ecological materials with enhanced performances, improving recycling technologies, and creating business models that maximize economic and environmental benefits. Through these approaches, ecological materials will become central to building resilient, sustainable societies capable of facing environmental, economic, and social challenges of the coming decades.

6. ACKNOWLEDGMENT:

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OPTIMALNO UPRAVLJANJE RESURSIMA RAZVOJEM SAVREMENIH EKO MATERIJALA I ODRŽIVIH STRATEGIJA

Sažetak: Optimalno upravljanje resursima i integracija ekoloških materijala u održive strategije predstavljaju osnovni pristup očuvanja životne sredine i efikasno korišćenje prirodnih i prerađenih resursa na zemaljskoj kugli. Ekološki materijali, koji se odlikuju minimalnim ekološkim otiskom, mogućnošću reciklaže i obnovljivošću, omogućavaju primenu principa cirkularne ekonomije u građevinarstvu, industriji i svakodnevnom životu. Njihova upotreba doprinosi smanjenju zagađenja, smanjenju potrošnje energije u procesima proizvodnje i produženju životnog ciklusa proizvoda kroz ponovnu upotrebu i reciklažu. Ovaj rad analizira ključne aspekte ponovne upotrebe materijala, sa fokusom na strategije menadžmenta koje obezbeđuju održive tokove ekoloških materijala unutar ekonomskih sistema. Posebno se naglašava uloga menadžmenta u kreiranju politika koje podstiču tranziciju sa linearnog na cirkularne modele. Održive strategije moraju uključiti procenu životnog ciklusa (LCA) i eko-dizajn, kako bi se minimizirali negativni uticaji na ekosisteme uz očuvanje ekonomske konkurentnosti. Takođe, izbor ekoloških materijala utiče na kvalitet života i zdravlje stanovništva, usklađujući ekološke i socijalne ciljeve sa ciljevima ekonomskog razvoja. Rezultati analiza sprovedenih u ovom radu ukazuju da uspešna integracija ekoloških materijala u upravljanje resursima zahteva saradnju istraživača, proizvođača, potrošača i kreatora politika, kao i edukaciju koja podiže svest o zaštiti životne sredine i odgovornoj upotrebi materijala. Primena ovih pristupa doprinosi izgradnji otpornog društva zasnovanog na održivosti, cirkularnoj ekonomiji i optimalnom upravljanju resursima.

Ključne reči: menadžment, ekološki materijali, održivost, ponovna upotreba materijala, cirkularna ekonomija.

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