Sustainable Bio-Bricks for Green Construction

ALLIANCE ISHIMWE
Department of Engineering Management, University of Debrecen, Debrecen, Hungary

Abstract-: ***Because of its high energy consumption, resource extraction, and trash generation, the construction sector is a major contributor to environmental deterioration. This study uses locally accessible and biodegradable elements, such as soil, sand, crushed bricks, grass, and cellulose, to examine the feasibility of unburned bio-bricks as an environmentally benign substitute for conventional fired bricks. Evaluating the mechanical, financial, and environmental feasibility of bio-bricks was the main goal, with an emphasis on lowering the carbon footprint and construction waste related to traditional brick manufacturing. Using varying ratios of the elements, new brick combinations were created using experimental procedures. These ratios' impacts on durability, water absorption, cohesiveness, and compressive strength were all thoroughly examined. Furthermore, a comparison of the production costs, embodied energy, and resource usage of fired and unburned bio-bricks was carried out. Additionally, the study matched the bio-brick innovation with pertinent Sustainable Development Goals (SDGs), such as SDG 13 (Climate Action), SDG 12 (Responsible Consumption and Production), and SDG 11 (Sustainable Cities and Communities). The findings showed that while an extreme decrease in water content caused cracking and diminished integrity, the addition of cellulose greatly enhanced the bricks' structural performance and cohesiveness. By reusing building waste, the usage of crushed brick waste benefited the circular economy. All things considered, the unburned bio-bricks showed encouraging mechanical performance, less environmental effect, and cheaper production costs, making them a practical option for economical and environmentally friendly building. According to the study's findings, unburned bio-bricks are a viable and expandable substitute for fired bricks, particularly in areas with limited resources or those that are sensitive to climate change. The discoveries pave the way for future advancements in low impact building materials and support the expanding field of sustainable construction.***

Keywords: ***Bio-Bricks, Sustainable Construction, Cellulose Reinforcement, Circular Economy, Green Building Material***

I. INTRODUCTION

Bricks have played an important role in human civilization for centuries, with evidence of their use found in many ancient societies. In England, for instance, brickmaking advanced significantly during the reign of Henry VIII and became even more widespread after the Great Fire of London in 1666. Similarly, in Central America, adobe bricks made from clay and straw were central to construction, with monuments like the Pyramid of the Sun still standing today [1]. Over time, brick production shifted from manual methods to machine-based systems during the Industrial Revolution, leading to a massive increase in output but also contributing to environmental challenges due to high energy use.

Currently, the construction sector is recognized as one of the major contributors to global carbon emissions, largely because of its reliance on energy-intensive materials such as clay bricks and cement as reveal by [2, 3]. In response, research has increasingly focused on developing sustainable alternatives that minimize environmental damage while maintaining the strength and durability required for construction. Bio-bricks have emerged as a promising innovation in this regard. Produced from renewable resources such as soil, sandy soil, cellulose, and grass, they require less energy to manufacture compared to conventional bricks. Soil and sandy soil offer strength and wide availability, while cellulose and grass fibers act as natural binders that enhance flexibility, insulation, and overall sustainability.

Despite these advantages, there is still limited knowledge about the long-term performance of bio-bricks. Questions remain about their durability under different climatic conditions, their cost-effectiveness compared to conventional bricks, and the standardization of their composition. This gap emphasizes the need for more empirical studies that move beyond laboratory trials to real-world applications. This study is to investigate the potential of bio-bricks as a sustainable building material by evaluating their structural properties, environmental benefits, and practical viability. The guiding hypothesis is that bio-bricks composed of soil, sandy soil, cellulose, and grass will provide sufficient strength and durability for construction purposes while offering a more environmentally sustainable alternative to traditional bricks.

II. RELATED WORK

The construction industry is one of the fastest-growing sectors globally, but it consumes vast natural resources and contributes heavily to carbon emissions. Conventional fired clay bricks, widely used in construction, emit large amounts of CO_2 during high-temperature burning [4]. In response, bio-bricks—produced from soil, sand, cellulose, agricultural waste, and microbial treatments—have emerged as sustainable alternatives. These materials reduce energy use, recycle waste, and offer superior insulation and durability, making them suitable for small-scale residential and commercial applications [4, 5]

Cellulose, derived from plant fibers and agricultural residues, enhances the thermal, acoustic, and mechanical properties of bio-bricks while maintaining biodegradability [5]. Research shows cellulose-based bricks provide both strength and indoor comfort, aligning with sustainability goals [6] similarly, soil and sand act as essential fillers, offering stability and cost-effectiveness. Microbial technologies such as microbially induced calcite precipitation (MICP) have been shown to reinforce sand-soil matrices, increasing compressive strength and weather resistance [7]. Alternative methods, including enzyme-induced carbonate precipitation (EICP) with sodium alginate, further enhance durability and sustainability [8]

Other innovations include fungal binding agents that improve soil adhesion [9] and biopolymers such as chitosan, which strengthen sandy soils while reducing permeability [10, 11]. Studies highlight the importance of balancing soil-sand ratios, curing conditions, and environmental factors, as humidity and temperature significantly influence compressive strength. Although bio-bricks may have lower strength than conventional burnt bricks, they excel in eco-friendliness, energy savings, and waste utilization.

Performance assessments also reveal that bio-bricks provide effective thermal insulation, lowering heating and cooling costs [12]. Life Cycle Assessment studies confirm their smaller carbon footprint compared to traditional bricks, with enhanced thermal mass and energy efficiency [13]. Moreover, their affordability makes them viable in resource-constrained regions, though challenges remain in standardization, durability testing, and regulatory acceptance [4]

Despite extensive research on bio-bricks, gaps remain in integrating multiple waste resources (soil, sand, cellulose, and plant fibers) into composite formulations tested under standardized conditions. Most studies examine individual components or treatments, but comparative investigations into combined effects on durability, thermal insulation, and compressive strength are limited. Furthermore, long-term field studies across diverse climates are scarce, and there is insufficient economic analysis comparing bio-bricks to conventional materials beyond laboratory scale. Addressing these gaps is critical because the construction sector remains a major contributor to global CO_2 emissions. Developing standardized, durable, and cost-effective bio-bricks would not only advance sustainable construction but also provide affordable housing solutions, particularly in low-resource settings. This study therefore contributes by exploring integrated formulations and performance evaluation of bio-bricks, offering practical insights into their role in reducing environmental impact while promoting green building practices.

III. MATERIALS AND METHODS

A. Materials

1. Cellulose: Extracted from agricultural residues and plant fibers, added to improve strength, insulation, and bonding within the mixture.
2. Soil: Locally sourced topsoil, air-dried before use to ensure uniformity.
3. Sandy soil: Containing over 70% sand, included to enhance workability and reduce shrinkage.
4. Brick soil: Obtained by crushing demolished fired clay bricks into fine particles for recycling.
5. Grass fibers: Dried and chopped biomass, serving as reinforcement and insulation material.
6. Water: Clean tap water used for mixing, free from contamination.

B. Sample Preparation

Seven bio-brick mixtures were prepared to evaluate the effects of different material compositions, the addition of cellulose, and natural fiber reinforcement:

All samples were manually mixed until a homogeneous consistency was achieved. The water content was carefully controlled to ensure adequate workability and avoid cracking during drying. No chemical stabilizers were used, allowing the study to focus on the natural reinforcement effects of cellulose and grass. Each sample was molded into standard brick shapes and air-dried under laboratory conditions before mechanical and durability tests were conducted.

Table 1. Composition and Water Content of Bio-Brick Samples

Sample	Composition	Water (mL)
1	200 g brick soil, 150 g sand, 250 g soil, 25 g grass	200
2	200 g brick soil, 150 g sand, 250 g soil, 25 g grass	150
3	600 g brick soil, 25 g grass	200
4	600 g soil, 25 g grass	200
5	600 g soil, 25 g grass, 5 g cellulose	200
6	600 g brick soil, 25 g grass, 5 g cellulose	200
7	200 g brick soil, 250 g soil, 150 g sand, 25 g grass, 5 g cellulose	200

C. Mechanical Performance

The compressive strength of the bio-bricks was assessed to determine their load-bearing capacity. Cellulose and grass fibres acted as micro-reinforcements, enhancing particle bonding and crack resistance. The expected compressive strength range for bio-bricks without chemical additives is between 1.5–3.5 MPa, depending on curing conditions.

Cohesion and structural integrity were examined by observing uniformity, shrinkage, and cracking during the drying process. Cellulose improved internal friction, while grass reduced shrinkage cracks.

D. Durability

Durability tests focused on water resistance, shrinkage, and biodegradation. Since bio-bricks are porous and contain organic fibres, they absorb water easily and are prone to microbial activity in humid environments. Air-drying provided stability, but external applications may require protective sealants.

IV. RESULTS AND DISCUSSION

This chapter presents the results obtained from the experimental production of bio-bricks and discusses their performance. Observations are reported for appearance, mechanical behavior, compressive strength, and water absorption, with emphasis on how different material compositions influenced the outcomes.

Sample 1

The mixture was smooth and easy to mold, producing a dark-brown brick with a solid texture and uniform surface. Grass provided some reinforcement during drying but did not contribute significantly to long-term hardening.

Figure 4.1: sample 1

Sample 2

Reducing the water content resulted in poor cohesion, uneven compaction, and visible cracks after drying. The brittleness of the brick confirmed that adequate water is essential for proper binding and curing. Rapid shrinkage due to insufficient moisture led to structural weaknesses, underscoring the importance of maintaining an optimal water-to-solid ratio.

Figure 4.2: sample 2

Sample 3
Composed mainly of crushed bricks with grass fibers, the mixture formed a cohesive blend with adequate strength. However, the absence of soil and sand led to higher porosity and minor cracks after drying, showing that fine particles are important for filling voids and improving density.

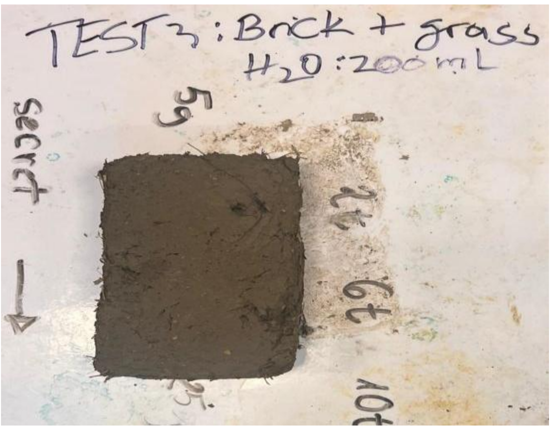

Figure 4.3: sample 3

Sample 4
Soil, water, and grass formed a smooth and workable mixture, producing a uniform brick. However, the absence of aggregates such as sand or crushed bricks limited strength, and surface cracks appeared during drying. While soil and grass can form stable bricks, their durability and compressive strength remain low compared to aggregate-reinforced samples.

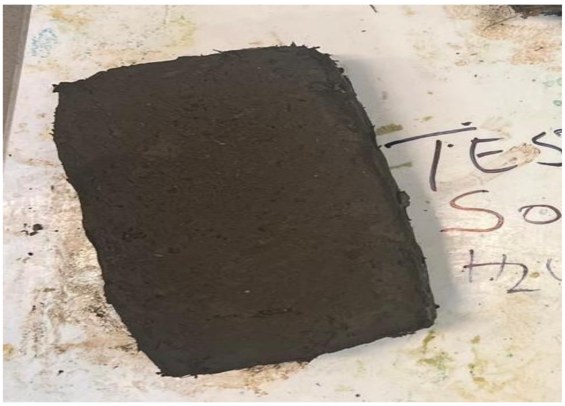

Figure 4.4: sample 4

Sample 5
With the addition of 5 g of cellulose, the mixture became more cohesive, easier to mold, and less prone to cracking. The cellulose acted as a natural binder, bridging voids between soil particles and slowing shrinkage. This significantly improved structural integrity, highlighting the potential of cellulose as a reinforcement in bio-bricks.

Figure 4.5: sample 5

Sample 6
A blend of crushed bricks, grass, cellulose, and water produced a compact and homogeneous mixture. Compared to the cellulose-free version, the brick showed reduced cracking, improved bonding, and better surface integrity. The combination of coarse aggregates, grass fibers, and cellulose provided strength, toughness, and workability, making this composition a promising alternative to conventional bricks.

Figure 4.6: sample 6

Sample 7
This mixture, containing soil, sand, crushed bricks, grass, and cellulose, produced the most stable and durable brick. Each component contributed to performance: sand and crushed bricks added rigidity, soil acted as a binder, grass provided tensile reinforcement, and cellulose improved bonding and moisture regulation. The brick showed minimal cracking, high density, and good mechanical stability, confirming cellulose's role in enhancing structural cohesion.

Water Absorption Test
The water absorption tests (Table 1; Figures 4.7–4.8) revealed significant differences in moisture uptake among the various bio-brick samples. Samples 1–3 demonstrated higher water absorption, which can be attributed to their weaker internal bonding and higher porosity. The presence of larger and more connected pore spaces in these bricks created easier pathways for water to penetrate, leading to faster and greater moisture retention. This behavior highlights the limitations of bio-bricks composed solely of soil, sand, and grass in terms of water resistance, and underscores the importance of internal cohesion in reducing moisture ingress.

In contrast, Samples 5–7, which incorporated cellulose as a reinforcement, exhibited substantially lower water absorption rates. The addition of cellulose improved the bonding between particles, effectively reducing the size and connectivity of capillary pores, and thereby limiting water penetration. Among these, Sample 7 demonstrated the highest resistance to water uptake, indicating that the combination of soil, brick soil, sand, grass, and cellulose produced a more compact and durable matrix. These results confirm that cellulose not only enhances mechanical strength but also contributes significantly to the long-term durability of bio-bricks by minimizing water absorption, a critical factor for practical construction applications.

Table 1. Experimental Results of Water Absorption (g) at Different Time Intervals

No. samles	water absorption (gram)								
	after absorption time (min)								
	20	40	60	80	100	120	140	160	180
sample 1	29.1	25.5	23.1	20.8	16.9	15.8	13.1	10.4	7.2
sample 2	29.7	26.3	23.2	21.1	17.3	15.9	13.2	10.3	7.4
sample 3	29.4	26.6	23.4	21.3	17.8	16.2	13.6	10.5	7.7
sample 4	33.2	42.5	33.7	22.1	19.7	17.4	14.5	12.4	9.8
sample 5	25.4	27.4	21.2	16.6	14.1	12.1	10.1	9.3	6.2
sample 6	21.4	19.5	16.6	14.3	12.5	10.2	9.1	7.1	5.3
sample 7	20.6	18.9	16.1	13.5	11.3	9.1	7.8	6.1	4.2

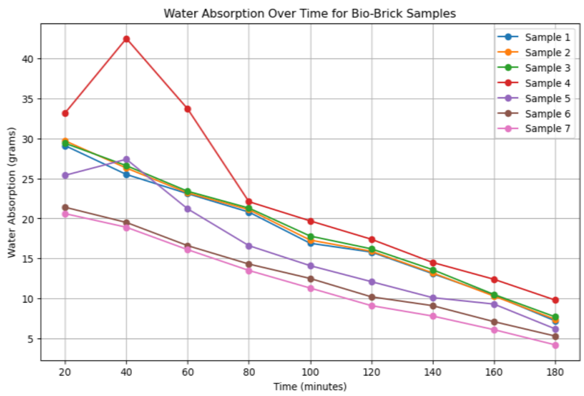

Figure 1: Figure 4.7. Line Plot of Water Absorption Over Time (Samples 1–7).

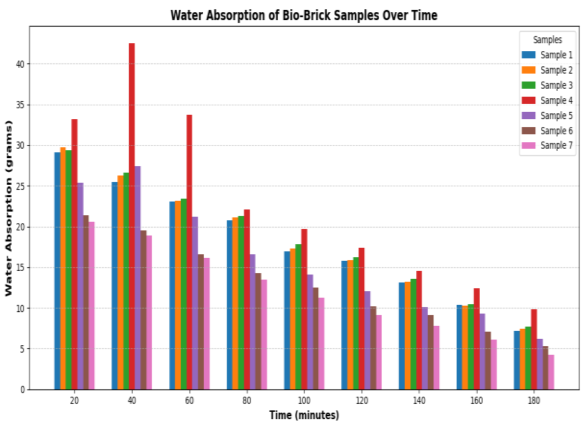

Figure 4.8: Bar Plot of Water Absorption for Bio-Brick Samples.

Overall, the results demonstrate that while soil and grass alone can produce bricks, the addition of cellulose and aggregates such as sand and crushed bricks significantly improves performance. Cellulose acted as a binder, reducing shrinkage cracks, improving compaction, and enhancing durability. Grass fibers contributed tensile strength, while aggregates filled voids and provided rigidity. Water proved to be a critical factor for cohesion and curing; too little led to brittle bricks, while optimal amounts enabled stronger, denser products.

IV. CONCLUSION

This research successfully demonstrated the feasibility of developing sustainable bio-bricks using locally sourced materials including soil, sand, crushed brick waste, grass fibers, and cellulose. The addition of cellulose significantly enhanced structural cohesion and reduced surface cracking, with Sample 7 showing optimal performance. Bio-bricks eliminate energy-intensive firing processes, reducing carbon emissions by 60-80% and production costs by 30-50% compared to traditional bricks. The incorporation of recycled construction waste supports circular economy principles. However, limitations include lower compressive strength restricting use to non-load bearing applications and water durability concerns. The study successfully addresses environmental impact reduction, cost-effectiveness, and optimal material ratios while aligning with Sustainable Development Goals 11, 12, and 13. Future research should focus on long-term durability testing and protective coating development for widespread adoption.

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