A REVIEW OF COMPRESSED STABILIZED EARTH BLOCK AS A SUSTAINABLE BUILDING MATERIAL FOR LOW-COST HOUSE SETTING IN BANGLADESH

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ABSTRACT

The growing need to decrease carbon emissions and resource consumption is driving a revolutionary shift in the building industry toward environmentally friendly approaches. When designing a low-cost house, engineers have the challenge of minimizing both construction and material costs. One of the solutions is to use a traditional housing material, soil as compressed stabilized earth blocks (CSEB) using engineering techniques.CSEBs are made with locally available resources in Bangladesh and are easy to construct where no burning is required that reduce the emission of hazardous gases like Carbon (C), carbon dioxide (CO_2), Methane (CH_4), Carbon mono-oxide (CO), Nitrous oxide (N_2O), Nitric oxide (NO). This review article aims to evaluate the suitability of CSEBs in Bangladesh's context. Different compaction techniques, the use of different types of stabilizers, soils in CSEB, the use of various fibers to reinforce CSEB, and the curing process will be discussed in this review article. Moreover, a brief comparison of the strength, density, water absorption, cost, and environmental effects of CSEB with that of normal-fired clay brick (FCB) will be discussed to evaluate the suitability of CSEB for its use in the low-cost housing of Bangladesh. This study used online databases for literature review and found that CSEB could perform better in low-cost house settings. The findings of the study encourage the use of CSEBs in low-cost house settings in Bangladesh.

Keywords: *Compressed Stabilized Earth Block (CSEB), compaction techniques, Stabilizers, Fired clay bricks(FCB), Low-cost house settings.*

1. INTRODUCTION

As the entire world is dealing with the increasing need for affordable solutions to housing, the need for sustainable and cost-effective building materials has become more apparent, particularly in densely populated nations such as Bangladesh. The building sector is critical to economic progress, but it also places a considerable strain on natural resources and the environment. To solve this issue and satisfy the housing demands of a fast-growing population, new building materials that are both sustainable and affordable should be investigated.

For years, local soil had been combined with water and other natural materials and used in earthen construction to build strong, long-lasting structures (Sameh, 2014). But as time evolved the construction sector moved toward stronger and energy-consuming materials like concrete, fired clay bricks (FCB), etc. However, the energy and resource crisis in recent decades has triggered the construction industry to slowly move back to earthen buildings. Experimental stabilized earth construction projects have been successful in addressing urban housing crises in developing countries such as India, Sudan, South America, and both northern and southern Africa (Zami, 2011). Because of the drawbacks of pure earthen buildings, including their low compressive strength and susceptibility to moisture, earth blocks have been created (Sameh, 2014).

Three types of Earth Blocks are there. One is Compressed Earth Block (CEB), another is Stabilized Mud Block (SMB) and the other one is Compressed Stabilized Earth Block (CSEB). (S.Kamalakannan, 2019 ; Reddy & Gupta, 2006)**.** All types of Earth Blocks are eco-friendly but among them, CSEBs are more eco-friendly (Kamal, 2023). CSEBs are created by blending mud from the area with a little cement, water, and additional ingredients like sand, lime, or fly ash. After being compacted into blocks of various sizes and shapes, the mixture is then exposed to the sun to dry and solidify. CSEBs are lighter and offer better thermal insulation that provides a good thermal mass to low-cost house settings (Laouni et al., n.d.). Since no burning is required, it lessens carbon emissions as well which proves CSEB is an eco-friendly construction material (Asha Sapna & Anbalagan, 2023). This article will discuss different compaction techniques of CSEB, the use of different types of stabilizers, soils in CSEB, the use of various fibers to reinforce CSEB, structural performance (compressive strength, tensile strength, density, water absorption rate, durability), physical and mechanical properties of CSEBs, advantages & disadvantages of using CSEBs and the curing process along with a comparison with fired bricks in the context of Bangladesh to evaluate the suitability of using CSEB in low-cost house settings of Bangladesh.

2. HOUSING PATTERNS OF BANGLADESH

Bangladesh, which is sometimes referred to as a deltaic plain, is not as level and homogeneous as it may appear. Even more distinct microclimatic zones exist throughout the nation as a result of the varied geography and complicated climate. People have developed several inventive house patterns (about 25) taking into account local resources, tradition, history, and indigenous construction skills to live in this diverse area. Bamboo and mud make up the majority of the native materials, with some extra usage of wood, jute, straw, reeds, and corrugated iron. Although the housing layout remained repetitively the same for generations, some experimental innovation by individual households has recently been firmly established in that region. It was only in the late nineteenth century- that rural architecture began to change both structurally and in the use of housing materials (Banglapedia). Traditional and more natural building materials are gradually being replaced by factory-made, imported building materials such as CI sheet, cement, steel, fired clay bricks (FCB), plastics, and so on, which are frequently responsible for the degradation of built environment quality, limiting the use of local technology and manpower, and thus influencing the rural environment and economy (Khan et al., 2018 n.d.).Fig 2 shows a housing pattern in Bangladesh where MthO, MthS, MthC, MthD, MthSP, MthST, MID, MIO, MTO, MTS, and MIS stands for different types of mud housing (Rashid, 2019).

Fig 1: Traditional Mud house

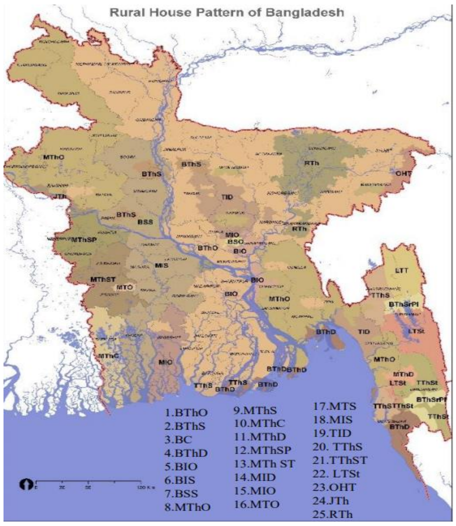

Fig 2: Housing pattern of Bangladesh (Rashid, 2019)

Increasing Use Of FCB In House Constructions And Its Demerits

Because of the sufficient supply of clay, cost-effectiveness, and traditional construction traditions, burnt clay bricks' popularity in Bangladesh has increased significantly (Rahman, 2020 n.d.). These bricks have high thermal qualities, local production prospects, and an attractive appearance (Shibib et al., 2016 n.d.). Bricks have good compressive strength typically ranging from 10 Mpa to 140 MPa (Shibib et al., 2016 n.d.). However, there are specific guidelines for FCB's compressive strength. The minimum compressive strength requirement for severe weather is 21 MPa, for moderate weather, it is 17 MPa, and for normal weather (Interior) is 10 MPa (ASTM C62). Bricks are mostly used as wall masonry, For that water absorption of FCB must be less to work well. BNBC suggests that a first-class brick shall not absorb more than 1/6th (16.67 percent) of its dry weight (BNBC-2020). However, the tensile strength of bricks is very low (Maroušková & Kubát, 2017).

Despite having numerous advantages, the production of FCB has a hazardous impact on the environment. Only in the Chittagong region of Bangladesh, approximately 780 tons of coals are used in a single brickfield every year, producing 393.8 tons of Carbon (C), 1443.9 tons of carbon dioxide (CO_2), 6.3 tons of methane (CH_4), 55.13 tons of carbon mono-oxide (CO), 0.09 tons of Nitrous oxide (N_2O), 1.02 tons of Nitric oxide (NO) annually(Mohammad Alim Ullah Khan & Alak Paul, n.d.). The emission of those toxic gases is one of the primary reasons for the greenhouse effect.

3. COMPRESSED STABILIZED EARTH BLOCKS (CSEB)

CSEBs are getting popular nowadays all over the world for low-cost house settings (Bredenoord & Kulshreshtha, 2023a). However, using CSEB in high-performance construction is yet a challenge. The performance of the CSEB is greatly dependent on its materials and construction process.

Fig 3: CSEB

Suitable Type of Soil and Stabilizer for CSEB

The selection of soil type is crucial for producing high-quality compressed stabilized earth blocks (CSEBs). Tropical red soils, which contain kaolinite clay, are preferred for CSEB production due to their durability and long-term performance. The presence of clay in the soil enhances the performance of CSEBs, and soil that has been sieved through a 4.75 mm sieve is the preferred choice (Nagaraj et al., 2014). However, It is also important to take into account factors such as soil plasticity and gradation when selecting soil for CSEBs (K. S. Jagadish, n.d.; Nagaraj et al., 2016; Venkatarama Reddy, 2012).

Stabilization of CSEBs is necessary for improving their properties and durability (Bell, 1996). Cement and lime are commonly used to stabilize CSEBs. Ordinary Portland Cement (OPC) is suitable for stabilizing soil that has low clay content, with a Plasticity Index (PI) of less than 15% and LL of less than 40% (Shubham Raj, 2016; Little & Nair, n.d; Mujahid et al., 2011). It is also suitable for soil with a required size smaller than 0.425 mm (No.40 sieve) (Little & Nair, n.d; Mujahid et al., 2011). On the other hand, lime is recommended for stabilizing soils that have a high clay content or a plasticity index greater than 15% (GUETTALA et al., 2013; Osula, 1996). A combination of cement and lime is also used for CSEB stabilization. A study found that a ratio of 4% cement and 4% lime produced long-term high-strength CSEBs (Nagaraj et al., 2014).

It is important to note that if cement is used as a stabilizer the percentage of cement binder should not exceed 10% of the dry weight of the soil, as this can make the manufacture of CSEBs unprofitable (Mujahid et al., 2011).

Compaction Techniques for Producing CSEB

Compaction is an essential process for Compressed Stabilized Earth Blocks (CSEB) as it is necessary to achieve the required compression for the blocks. The compacting process significantly improves the performance of CSEB (F. V. Riza et al., 2010). By increasing the compacting stress from 5 to 20 MPa, the compressive strength can be improved by up to 70% (GUETTALA et al., 2013). Compaction reduces voids in CSEB, resulting in fewer weaker planes in the blocks (Lahbabi et al., 2023). Additionally, compression enhances the bonding of the soil particles.

The compaction of CSEBs can be done in two ways, either by hand or by mechanical compression (Thennarasan Latha et al., 2023)). Hand compaction of CSEB is done using a proctor hammer weighing 2.6 kg in laboratory tests (Shubham Raj, 2016). Hand compaction is a cheaper and simpler method, but it takes up a lot of time and may not produce high-performing CSEB. On the other hand, mechanical compaction is more convenient and saves time, making it suitable for factory production. The quality of CSEB is also influenced by the compaction effort. CSEBs made of laterite soil have better compressive strength and lower water absorption rates compared to those made of clay. Laterite soil CSEBs perform best when compacted at 2000 Psi, while clay CSEBs perform better at 4000 Psi (Abdullah et al., 2017).

Curing Process for CSEB

CSEB goes through a critical curing procedure to achieve maximum durability and strength. Water and Air curing are the primary processes to produce CSEB (Malkanthi et al., 2020a). Following an initial drying process, the blocks are stacked with enough space between them to allow for air circulation. Curing requires 7 to 28 days sometimes more, during which the blocks are maintained moist by spraying or coating with damp materials like wet gunny bags, moist soil, etc (James et al., 2016; F. V. Riza et al., 2010; Shubham Raj, 2016; Thennarasan Latha et al., 2023). Extreme weather protection, quality control inspections, and environmental monitoring are all critical during the curing period. During water curing two basic chemical reactions: a primary reaction involving cement hydration with water and a secondary reaction involving clay minerals and the freed lime from the initial reaction (Houben, n.d.)

H_2O C-S-H + C_4ASH_{12} + $Ca(OH)_2$
(Cement) (Calcium Silicate Hydrate) (mono-sulphoaluminate)

C-S-H and C_4ASH_{12} are both known to have a high binding capability. The binding forces they create are responsible for interweaving and embedding the gravel and sand fractions in the soil fabric, forming a robust network (Abu et al., n.d.). Consequently, when silica flour is added to cement, a crystalline with a needle shape, would appear in the final hydration result. To create a perfect, well-proportioned network structure in the cured cement, the needle-shaped crystals are mixed and connected to each other, which aids in the cement's ability to retain a high compressive strength (Ahmed et al., 2018).

(a) Secondary reaction involving freed lime and clay:

S + $Ca(OH)_2$ $\longrightarrow$ C-S-H + C-A-H
(Clay) (Calcium hydroxide) (Calcium silicate hydrate) (Calcium aluminate hydrate)

The two major products of this reaction (C-S-H and C-A-H) have binding capacities similar to those of the first reaction. This process is mostly pozzolanic, with gelatinous amorphous hydrates also contributing to the block's hardening. The reaction is gradual, but it is affected by the amount and quality of clay, as well as the amount of free lime available. The OPC's lime saturation factor (LSF) limits the quantity of calcium hydroxide emitted (Abu et al., n.d.). The top limit is restricted primarily to regulate the quantity of free lime in the cement paste, which is otherwise linked with unsoundness and unwanted expansion.

This careful procedure assures that the CSEBs achieve the needed strength, making them a durable and sturdy solution for construction while adhering to environmentally responsible standards.

Use of different types of fibers in CSEB:

Various types of fibers, including natural fibers like straw or jute, synthetic fibers such as polypropylene, recycled fibers, and even steel or glass fibers, can be incorporated into CSEBs. These fibers serve diverse purposes, such as improving tensile strength, reducing cracking, enhancing durability, minimizing shrinkage cracks, and reinforcing structural integrity for increased load-bearing capacity. The use of natural fiber is found cost-effective and sustainable. The incorporation of 0.85% coconut fiber is found to be effective in the improvement of the strength properties of CSEB (Shubham Raj, 2016). Adding 0.5 to 1.0 percent of Sugarcane Bagasse Fiber (SCBF) by weight to CSEB can significantly enhance the mechanical properties of the CSEBs without reducing their durability (Kumar & Barbato, 2022) Banana fiber-reinforced Compressed Earth Blocks achieved 6.16 MPa compressive and 1.06 MPa flexural strength, while the fiber was bridging the failure plane (Marwan Mostada, 2016) Incorporation of Pineapple Leaf Fiber, Alfa fibers, sisal, and date palm fiber is also found effective in the performance improvement of CSEBs (Vodounon et al., 2019a; Ajouguim et al., 2021; Labiad et al., 2022; Abdeldjebar et al., 2018).
The strategic use of different fibers in CSEBs offers a versatile approach to address specific construction challenges and enhance the overall performance of the blocks, catering to diverse construction needs and sustainability goals.

Performance of CSEB

The performance of a brick is often referred to as its usability in practical life. The compressive strength is the most universally accepted value for determining the quality of bricks. However, water absorption rate, density, and durability values are also important parameters to evaluate the usability of bricks. The performance parameters of CSEBs are described below:

(a) Compressive Strength:

Factors affecting the CSEB’s strength are cement content, types of soil (plasticity index), compaction pressure, and types of compaction (F. V. Riza et al., 2010). Two types of compressive strength tests are tested. One is a dry compressive strength test and the other one is a wet compressive strength test (Islam et al., 2020). Compressive strength determination in wet conditions yields the weakest strength value. The growth of pore water pressures can be attributed to the reduction in compressive strength under saturation conditions (F. V. Riza & Rahman, 2015). Earth blocks must have an average compressive strength of at least 20 kgf/cm² for Class 20 and 30 kgf/cm² for Class 30 according to Indian Standards (Agarwal, n.d.) and also according to the international compressed earth block codes, a CSEB should have a minimum dry compressive strength of 2 MPa (ASTM E2392, 2016; AFNOR,2001; NMAC, 2016). There is no standard testing procedure for the compressive strength of CSEB. However typical direct compressive strength tests or unconfined compressive tests are used to evaluate the performance of CSEB.

(b) Tensile Strength:

The tensile strength of CSEBs is very low. Splitting tensile strength is used to assess the tensile strength of these materials since a direct tensile test cannot be carried out on brittle materials like brickwork (Vodounon et al., 2019b). When a building's load-bearing masonry walls are subjected to an earthquake, they may encounter in-plane and out-of-plane forces that cause them to suddenly collapse. Split tension tests are carried out on masonry panels to determine the tensile strength of masonry because a state of pure shear results in diagonal tension and compression. According to the code requirement, the modulus of rupture strength of CSEB of 0.34 MPa is acceptable (NMAC, 2016).

(c) Density:

The mass of the blocks per unit volume, including both solid and pore spaces, is referred to as the bulk density of earth blocks. It is a significant factor that affects the blocks' weight, strength, and thermal characteristics. Blocks with higher bulk densities often have greater strength and load-bearing capability (Vincent Rigassi.).Most researchers found that the density of CSEBs is within the range of 1500 to 2000 kg /m^3 (F. V. Riza et al., 2010). But for gaining desired strength SLS 1382 specifies the minimum density of the block as 1750 kg/m³ (Malkanthi et al., 2020b). The density of brick can be determined through standard procedures such as ASTM C140 (Loo, 2022) The lighter weight of the block significantly increases the workability of the construction process and decreases the labor cost.

(d) Water absorption rate:

Brick's capacity to absorb water is a major worry since it will affect the material's use under the influence of the weather. The water absorption rate of mud blocks refers to how much water they can hold when exposed to moisture. Some of the factors that influence how quickly mud blocks absorb water include the porosity of the blocks, the curing conditions, and the makeup of the mud mixture. Mud blocks frequently absorb more water than other building materials like concrete or bricks because of their porous texture. And more water absorption refers to more voids. As per Indian standards, the earth block should not absorb more than 15% of its weight (IS 1725 (1982) of Indian Standards).

(e) Durability:

Durability is a fundamental aspect of any material or structure, representing its ability to withstand environmental, mechanical, and chemical stresses over time. For areas with high rainfall intensity (like Bangladesh), durability is an important concern. Durability is associated with stabilizer content, clay content, and compacting stress in various trials (F. V. Riza et al., 2010). As long as they are not wet, durable stabilized clay material structure may be achieved. When materials are subjected to long-term saturation and exposed to varying environmental conditions, difficulties develop. It was also discovered that the presence of unstabilized material was likely to be very damaging to the durability. As CSEBs are stabilized they provide a pretty good durability (Ipinge, 2012).

The mechanical properties of CSEBs found in different literature and online data sources are listed in Table 1.

Table 1: Properties of CSEBs

Properties	Values
Dry compressive crushing strength (@ 28 days)	3-7 MPa
Wet compressive crushing strength (@ 28 days, after 24 hours immersion)	1.5-4 MPa
Tensile crushing strength, dry (on a core @ 28 days)	0.5-1 MPa
Bending crushing strength, dry (@ 28 days)	0.3-1 MPa
Shear crushing strength, dry (@ 28 days)	0.2-0.6 MPa
Apparent bulk density	1750-2000 kg/m^3
Total water absorption	8-15%
Coefficient of thermal expansion	0.010-0.015 mm/m℃
Shrinkage	0.2-1 mm/m
Permeability	1.10^{-5} mm/sec

Production Cost of CSEB:

The costs of producing Compressed Stabilized Earth Blocks (CSEBs) include raw materials, labor, equipment, utilities, transportation, site preparation, quality control, overhead, and production scale. However, the labor costs for CSEB manufacture are between 40 and 45% of the overall cost (Auroville Earth Institute, n.d.). That clarifies that the material cost of CSEBs is low. The materials used in CSEBs are vastly available in Bangladesh. So, there shouldn't be any increase in CSEB's production due to a lack of material supplies. Most of the time, CSEBs are less expensive than burned bricks and concrete blocks. A finished cubic meter of CSEB masonry is always cheaper than burnt bricks in Auroville (a CSEB manufacturing company), costing between 15 and 20% less (Auroville Earth Institute, n.d.).

Advantages and Limitations of CSEB

Advantages of CSEB:

a. **Cost-effective:** CSEBs are frequently less expensive than typical building materials like burned bricks or concrete blocks. The raw materials are frequently available locally, which reduces transportation costs. A study stated that CSEBs are 15% cheaper than FCBs (Bredenoord & Kulshreshtha, 2023b). By using Compressed Stabilized Earth Blocks (CSEBs), construction costs can be reduced by 20 to 50% (Akhter et al., 2018; Comparison of Construction Cost of Buildings Using CSEB and Fired Clay Bricks, n.d.).

b. **Environmentally friendly:** CSEBs typically require less energy to manufacture than burned bricks or concrete blocks (Kamal, 2023). Furthermore, using locally sourced materials helps lessen the environmental impact of shipping.

c. **Energy efficiency:** CSEBs offer great thermal mass and serve as natural insulation (Laouni et al., n.d.). This can help buildings save energy by maintaining appropriate temperatures and eliminating the need for additional heating or cooling.

d. **Limiting deforestation:** Firewood is not required for the production of CSEB. Therefore, the adoption of CSEBs will save the world's forests, which are rapidly depleting owing to short-sighted development and resource mismanagement.

e. **Reduced Carbon Emissions:** When compared to typical brick or concrete block production, the manufacturing process for CSEBs generally creates fewer carbon emissions, especially if the stabilizers employed are eco-friendly (CO2 Emissions - Our World in Data, n.d.; Macknick, 2011; Peters et al., 2012).

f. **Versatility:** CSEBs can be used to build everything from houses to schools and other structures. Notable projects utilizing Compressed Stabilized Earth Blocks (CSEBs) include a low-cost housing project in Vietnam, a post-earthquake housing project in Sri Lanka, a sustainable building project in India, and a school building project in Zimbabwe (Bredenoord & Kulshreshtha, 2023b; Happho, n.d.; Raj et al., 2023; Turco et al., 2021). It can be seen that CSEBs are adaptable to various architectural styles.

g. **Durability:** When properly manufactured and cured, CSEBs can be long-lasting and weather-resistant (Ipinge, 2012). Compressed Stabilized Earth Blocks (CSEBs) can have a durability similar to that of traditional bricks or blocks.

h. **Reduced Construction Time:** Because CSEBs are larger than regular bricks, fewer blocks are required for a given space (Turco et al., 2021b). This could result in shorter building timelines and lower labor costs.

i. **Low Maintenance:** Structures built with CSEBs often require less maintenance over time, contributing to long-term cost savings (Luna Shah Thakuri, 2020).

Limitations of CSEBS:

a. Correct identification of soil is necessary for the production of CSEB every time which is sometimes time-consuming and difficult.
b. There is a waiting period associated with this construction method of CSEB since the pressed blocks require time to dry after the first pressing procedure.
c. Insufficient stabilization of CSEB leads to poor quality, compromising structural integrity and overall effectiveness of the compressed stabilized earth blocks.
d. Excessive stabilization of CSEB driven by fear or ignorance results in an unwarranted, exaggerated outcome, potentially causing adverse and extreme repercussions.
e. Using CSEB to build long, wide, and tall structures can be difficult because of the structural complexity involved, thereby requiring precise construction techniques and expertise.
f. CSEBs are socially less acceptable.
g. Limited technical performances when contrasted with concrete, showcasing inferior capabilities in various aspects of construction.
h. When CSEBs are exposed to water for an extended length of time, they often lose strength and dimensional stability. It could sometimes end in the block's total disintegration

4. COMPARISON BETWEEN CSEBS AND FCBS

Compressed Stabilized Earth Blocks (CSEBs) and normal-fired bricks differ in several key aspects. A brief comparison of mechanical properties, environmental effects, and manufacturing costs between CSEBs and FCBs is listed in Table 2.

Table 2: Comparison between CSEB and FCB

Properties	CSEB	Fired Clay Brick
Compressive strength	3-7 MPa	10-140 Mpa
Tensile strength	0.5-1 MPa	Maximum 2.8 Mpa
Apparent bulk density	1750-2000 kg/m^3	1800-2200 kg/ m^3
Total water absorption	8-15% (Standard)	7-15% (Best quality)

Carbon emission during production	22 kg CO_2/tonne	200 kg CO_2/tonne
Manufacturing Cost	40 and 45% less than FCB	13,200 Tk/1000 unit

FCBs are well recognized for their compressive higher strength. The higher-strength bricks (like 140 Mpa) are used for high-performance construction and are very expensive. However, the typical strength of FCBs that are widely used ranges from 10 to 35 Mpa. In terms of strength, normal-fired clay bricks typically exhibit higher compressive strength due to the intense firing process. However, CSEBs can still achieve satisfactory strength levels, especially when well-stabilized. In density, fired bricks tend to be denser and more homogeneous due to the kiln firing, while CSEBs might have a slightly lower density. Regarding water absorption, CSEBs may absorb more water than fired bricks, necessitating proper waterproofing measures. In terms of cost, CSEBs are often considered more cost-effective, benefitting from the use of locally available materials and a less energy-intensive production process

5. CONCLUSION

CSEBs provide sustainable construction in Bangladesh using local, eco-friendly materials. They require less energy to manufacture than traditional bricks, offer affordable housing, and align with sustainable development goals. The blocks are often manufactured using manual or semi-automatic presses, creating employment opportunities throughout the surrounding areas. The construction of CSEB structures is also faster, contributing to quicker completion times and reduced construction-related disturbances. Moreover, CSEBs possess thermal insulation properties, which can contribute to energy efficiency in buildings. This is particularly relevant in Bangladesh's climate, where extreme temperatures are common. In contrast, it can be said that CSEBs are sustainable construction materials. However, using CSEBs in high-performance and high-cost construction is not yet possible because of their average mechanical properties. Therefore, the study encourages the use of CSEBs in low-cost house settings in Bangladesh as a step towards sustainable development.

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