Critical Study of Stabilized Earth Technologies for Contemporary Architecture in Chhattisgarh

Krishna Goyal[1], Khushboo Sahu[2]
[1]*Student, Amity School of Architecture and Planning, Amity University Chhattisgarh*
[2]*Assistant Professor, Amity School of Architecture and Planning, Amity University Chhattisgarh*
doi.org/10.64643/IJIRTV12I6-187554-459

***Abstract*— A comprehensive literature-based critical study of stabilized earth technologies with a specific focus on their applicability to contemporary architecture in Chhattisgarh. The review synthesizes technical performance (mechanical and thermal), environmental impacts, standardisation and policy frameworks, and socio-economic considerations associated with Compressed Stabilized Earth Blocks (CSEB), stabilized rammed earth, and other stabilization techniques (lime, fly ash, cement). The methodology is strictly secondary systematic review and comparative analysis of peer-reviewed studies, standards, government and institutional reports, and credible technical manuals. Key findings indicate that CSEB and lime/fly ash stabilisation offer viable, lower-carbon alternatives to conventional fired clay bricks for low-rise residential construction in the regional climate of Chhattisgarh. Nevertheless, regulatory gaps, perceptional barriers, and skills shortages pose significant constraints to widespread adoption. The paper concludes with recommendations for policy, design guidance, and future research priorities tailored to Chhattisgarh.**

***Index Terms*— Stabilized Earth, CSEB, Lime Stabilization, Fly Ash, Chhattisgarh, Thermal Performance, Sustainable Construction**

I. INTRODUCTION

Chhattisgarh lies in central India and falls within predominantly hot-humid and composite climatic conditions, which makes thermal comfort and material responsiveness an important factor in building construction (BMTPC, n.d.) With ongoing urban development and increased demand for low- and middle-income housing under national schemes, conventional materials such as burnt clay bricks and cement-based systems continue to be widely used (mohua.gov.in, 2021). However, studies show that brick-firing processes demand significant energy, contribute to topsoil removal, and release considerable emissions, raising concerns over long-term environmental sustainability (Bureau of Energy Efficiency, 2017) (Suresh R, 2016)

In response, stabilised earth construction has gained attention for its low embodied energy, ability to use local soil, and potential to improve thermal comfort while reducing reliance on high-energy materials (Auroville Earth Institute, 2011). Research also indicates that stabilisation using lime and cement can improve compressive strength and long-term performance, making systems such as CSEB and stabilised rammed earth suitable for contemporary applications when executed correctly (Nagaraj, 2016). Although durability-related hesitations and limited technical awareness still affect adoption, existing studies highlight that stabilised earth can meet structural and environmental expectations if implemented with proper material testing and detailing (Medvey & Dobszay, G., 2020)

Based on this background, the paper applies a literature-based review to assess the relevance and feasibility of stabilised earth construction for modern architectural practice in Chhattisgarh, considering both performance evidence and contextual requirements.

II. RATIONALE FOR A LITERATURE BASED STUDY

The decision to pursue a literature-only methodology is rooted in three pragmatic considerations:

- A mature body of empirical and field-tested research exists internationally and within India—encompassing laboratory characterisation, thermal modelling, and life-cycle assessments that can be synthesised for regional recommendations;

- Standards, codes and institutional reports (e.g., BIS standards, BMTPC compendia, and Auroville Earth Institute manuals) provide prescriptive and performance data sufficient to map regional applicability;
- The objective is evaluative and comparative—centred on policy, design guidance, and theoretical adaptation rather than novel material invention making literature review academically rigorous and defensible for submission and publication.

III. LITERATURE STUDY

3.1 *Historical and Institutional Background*

Modern concepts of compressed stabilised earth blocks (CSEB) build on traditional earthen construction methods but incorporate technical refinements such as mechanical compression and stabiliser additives (cement, lime) typically in the range of 4 – 10 % by weight of soil. For instance, according to Auroville Earth Institute, a mixture of about 5 % cement stabiliser with site-prepared soil yields CSEBs with significantly reduced embodied. (Auroville Earth Institute, 2011) AVEI has also developed training programmes, block-making equipment, design manuals and dissemination efforts. These institutional frameworks have helped define best-practice protocols for CSEB production, quality control, masonry detailing and capacity-building in India and abroad.

3.2 *Standards and Government Guidance*

Regulatory and guideline frameworks support stabilised earth technologies. (The Indian Standard IS: 1725, 1982) provides foundational requirements for soil-based masonry units, including stabilised earth blocks. Among its stipulations are minimum permissible stabiliser percentages, dimensional tolerances, compressive strength requirements and water-absorption limits. Beyond statutory standards, government-sponsored bodies such as Building Materials & Technology Promotion Council (BMTPC) publish compendia and technology-guides on low-carbon construction, including stabilised earth systems, thereby bridging research and practice.

3.3 *Material Stabilisation: Cement, Lime, Fly Ash*

Literature shows key trade-offs among stabiliser types. Cement stabilisation typically yields high early compressive strength, enabling thinner walls or faster construction, yet carries a higher embodied-CO_2 footprint. For example, AVEI reports that a CSEB produced with ~5 % cement can require only about one-tenth of the energy of a conventional country-fired brick. In contrast, lime (and class-F fly ash) can promote pozzolanic reactions, deliver long-term strength gains, improve durability and reduce CO_2 emissions when properly proportioned and cured. Soil-cement block studies indicate that a combination of 4 % cement + 4 % lime achieved higher 28-day strength than 8 % cement alone in one trial. (Raseena.N.P, 2018) Thus, judicious stabiliser selection is central to balancing performance, durability and sustainability.

3.4 *Mechanical and Thermal Performance*

Experimental studies emphasise that CSEB systems, when correctly designed, achieve sufficient compressive strength for low-rise load-bearing walls and offer thermal mass benefits favourable in climates with diurnal swings (such as central India). For example, manual production tests following IS 1725 procedures demonstrated that curing times, stabiliser proportion and soil type significantly influence strength outcomes. (The Indian Standard IS: 1725, 1982) AVEI's design guidelines recommend key parameters (e.g., wet crushing strength ≥ 25 kg/cm² for hollow interlocking CSEB under wet conditions) and address detailing for moisture protection, structural stability and thermal performance. (Auroville Earth Institute, 2011) The thermal mass of thick earthen walls can attenuate indoor temperature peaks, which holds particular relevance for regional climates like that of Chhattisgarh.

3.5 *Environmental and Life-Cycle Considerations*

Life-Cycle Assessment (LCA) comparisons of stabilised earth systems with conventional fired clay brick masonry consistently show lower embodied energy and greenhouse-gas emissions for the earth-based options — although the exact benefit depends heavily on stabiliser type, transport distances, production methods and curing regime. AVEI reports data indicating that the embodied energy of a CSEB can be around 572 MJ/m³ versus 6,122 MJ/m³ for a country-fired brick. (Auroville Earth Institute, 2011) These large differentials underscore the potential of stabilised earth technologies for low-carbon construction if implemented with appropriate quality control and local sourcing.

IV. CASE STUDIES

4.1 *Auroville Earth Institute (Tamil Nadu, India)*

The Auroville Earth Institute (AVEI) has pioneered modern stabilised earth technologies including Compressed Stabilised Earth Blocks (CSEB) by combining soil with ~5 % cement, manual or mechanical compression, and training programmes. AVEI reports that their CSEB production uses significantly less energy (up to ~10.7 times less) than conventional country-fired bricks. (Curry Stone Foundation, 2018) AVEI has also developed on-site block presses, design guidelines, and has built projects (such as the "Vikas" community) demonstrating large scale use of CSEB in a real residential setting. (Kaur, 2019)

4.2 *Hunnarshala Foundation (Bhuj, Gujarat, India)*

Following the 2001 Gujarat earthquake, Hunnarshala engaged in large-scale application of earth-based technologies (including CSEB and rammed earth) for post-disaster rehabilitation, community housing and artisan training. They used local soils, fewer stabilisers, and trained communities in production of stabilised earth units. (The Better India, 2019) For instance, the foundation reports reaching thousands of houses built with earth-based techniques in Kutch and beyond.

4.3 *Development Alternatives (Various states, India – eco-housing/technology adoption)*

Development Alternatives (DA) has published guides and undertaken projects for Stabilised Compressed Earth Blocks (SCEB / CSEB) as "eco-friendly multi-hazard resistant construction technologies." For example, their Production and Construction Guide for SCEB outlines production infrastructure, specifications, applicability to rural/low-income housing under Himalayan/mountainous contexts. (Development Alternatives)

V. FINDINGS (SYNTHESIS FOR LITERATURE)

5.1 *Technical Viability*

Studies consistently show that CSEB and stabilised rammed earth can achieve compressive strengths suitable for low-rise load-bearing construction when soil grading, stabiliser percentage and curing are appropriately controlled. Cement-stabilised mixes in the range of 4–8 % OPC have shown early strength gains suitable for masonry, while lime or fly-ash based blends require longer curing but can reach comparable strengths due to pozzolanic reactions. Nagaraj et al. (2014) demonstrated that a combined 4 % cement + 4 % lime mix produced higher long-term strength than cement-only mixes. Experimental data further confirm typical strength ranges of approximately 3.5–5 MPa for well-compacted CSEB with ~8 % cement stabilisation, adequate for structural walling in single and double-storey buildings.

5.2 *Thermal and Indoor Comfort Benefits*

Evidence indicates that earthen wall systems provide effective thermal mass, delaying and reducing indoor temperature peaks, making them suitable for climates with diurnal variations such as central India. Comparative monitoring shows that houses built with earthen envelopes maintain narrower indoor temperature ranges than fired-brick masonry, due to higher heat capacity and slower heat transfer. This aligns with adaptive thermal comfort models that favour high-thermal-mass envelopes in composite and hot-humid climates.

5.3 *Environmental Performance*

Life Cycle Assessment (LCA) comparisons between stabilised earth blocks and fired-clay bricks generally report lower embodied energy and greenhouse-gas emissions for stabilised earth, mainly due to elimination of kiln-firing and reduced transport when soil is sourced locally. Interlocking or compressed earth blocks also show reduced global warming potential compared to brick-based construction, especially when cement content is optimised and partially substituted with lime or fly ash. Fired-brick systems typically exhibit much higher embodied energy, reported in the range of 4.9–7.8 GJ/m³, reinforcing the advantage of earth-based walling where feasible.

5.4 *Socio-Economic and Institutional Barriers*

Despite technical and environmental advantages, adoption barriers remain predominantly socio-economic and regulatory rather than performance-based. These include limited trained labour, persistent perceptions of earthen materials as “poor-quality”, and lack of dedicated codes in local bye-laws. Research also documents declining use of earth-based systems in some regions due to aspirations for “modern” materials and limited demonstration-based awareness. Literature indicates that successful implementation requires integrated support including training, demonstration buildings, and enabling policy rather than material-only advocacy.

VI. DISCUSSION

6.1 *Applicability to Chhattisgarh*

Given the hot-humid to composite climate of Chhattisgarh and its need for sustainable low-rise housing, stabilised earth systems (such as a low-cement or lime/fly ash blend) present a strongly relevant alternative. Commentary on earth block systems highlights that when locally characterised soils are used with modest stabiliser proportions and proper compaction/curing, the embodied energy and CO_2 footprint drop significantly compared to fired clay bricks or concrete masonry. (Yask Kulshreshtha, et al., 2020) Thermal-mass advantages of earthen walls specifically their capacity to moderate indoor temperatures and buffer peak heat flux—apply well in contexts with large diurnal swings such as central India. For example, a study of rammed earth walls reports reduced cooling loads by 20-52 % through thermal mass effects. (Uma, 2024) (Pragya Gupta, Dana Cupkova, Lola Ben-Alon, & Erica Hameen, 2020) Furthermore, the use of local soils and onsite or near-site production supports regional labour, reduces transport energy, and aligns with the state’s employment and material-localisation goals. In short, for Chhattisgarh’s building scenario rural and peri-urban low-cost housing, community buildings, moderate rise residential stabilised earth technology offers a plausible path that simultaneously addresses thermal comfort, embodied-carbon reduction and local empowerment.

6.2 *Design and Policy Recommendations*

To translate this technical potential into actual practice in Chhattisgarh, several design and policy measures must be put in place:

Policy Framework:

- The state government should incorporate stabilised earth specifications into building bye-laws and housing scheme tenders, thereby recognising technologies such as CSEB and rammed earth as eligible. Such regulatory endorsement is often cited as a key adoption enabler. (Yask Kulshreshtha, et al., 2020)
- Launch pilot housing projects under state rural/urban housing schemes (e.g., low-income housing) that demonstrably use stabilised earth wall systems, to generate visibility, performance data and confidence.
- Establish training programmes for local masons, block-manufacturing operators and site supervisors on production, curing, quality-control and detailing for stabilised earth systems. Publications emphasise that workforce skill and awareness are major adoption barriers. (Swati Sinha & Jayaraman Sethuraman Sudarsan , 2025; Placeholder1)

Design & Implementation Guidance:

- Standardise mix-design documentation for local soils: e.g., identify soil classification, optimal stabiliser percentages (cement, lime, fly ash), required compaction pressure, moisture content, curing regime. Use documented guides such as the “SCEB Production and Construction Guide” as reference. (Zeenat Niazi, Pankaj Khanna, Suhani Gupta, & Rashi S, 2020)
- Ensure strict quality control during block production—compaction, curing, dry/wet strength testing—so that masonry units meet structural, durability and durability performance expectations.
- Pay special attention to moisture-protection detailing: provide elevated plinths, roof overhangs, damp-proof courses, and avoid direct soil contact. Such detailing is critical for performance in climates with rainfall and humid conditions.

- Integrate passive cooling strategies with the stabilised earth wall system: use shading, cross ventilation, thermal mass exposed internally, and roof insulation so that the thermal benefits of the walls are fully realised. Empirical studies in earth-based construction underscore that the material's thermal mass advantage is realised only when combined with appropriate architectural and climate-responsive design.

By aligning policy, production, design and training, Chhattisgarh can convert the technical promise of stabilised earth systems into viable mainstream application—thus advancing low-carbon, climate-responsive, regionally grounded construction in a cost-effective way.

VII. CONCLUSION

This literature-based study finds that stabilised earth construction—particularly CSEB and lime/fly-ash blended systems—presents a technically viable and environmentally favourable walling alternative for low-rise buildings in Chhattisgarh. Experimental evidence confirms that well-designed stabilised earth mixes can achieve compressive strengths suitable for structural masonry when soil selection, stabiliser percentage and curing are properly controlled (Nagaraj, 2016). In addition, thermal-mass studies show that earthen envelopes can moderate indoor temperatures and reduce cooling demand, offering strong relevance to the state's hot-humid to composite climatic profile. Life-cycle comparisons further indicate reductions in embodied energy and greenhouse-gas emissions relative to fired clay brick systems when stabiliser content is optimised and materials are locally sourced.

While technical and environmental performance is well supported, adoption remains limited by perception bias, limited training availability and insufficient regulatory inclusion (Yask Kulshreshtha, et al., 2020). Therefore, policy integration, demonstration projects, skilled workforce development and awareness programmes are critical for mainstreaming. Based on current evidence, stabilised earth systems are suitable for Chhattisgarh and merit structured scale-up through coordinated technical, institutional and educational measures.

VIII. FUTURE RESEARCH SCOPE

- Regional soil characterisation studies for Chhattisgarh districts to develop standardized mix-design tables.
- Pilot demonstrative housing projects with documented performance monitoring (thermal, moisture, durability) to build local evidence.
- Detailed LCA studies specific to Chhattisgarh accounting for local transport, energy mix, and construction practices.
- Social research on perception change and market uptake strategies for earthen technologies.

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