Research Article

Journal of Earth & Environment Science

Evaluating Sustainable Techniques for Earthen Wall Construction-A Qualitative Study

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Citation: Kathambi E, Nille-Hauf K, Fitik B, Schänzlin J (2024) Evaluating Sustainable Techniques for Earthen Wall Construction-A Qualitative Study. J Earth Envi Sci: JEES-132.

Received Date: November 04, 2024; **Accepted Date:** November 14, 2024; **Published Date:** November 20, 2024

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Abstract
This study examines the sustainable construction techniques for earthen walls, with a specific emphasis on alternatives to conventional stabilization methods that have been proven to have significant environmental impacts. Despite the accessibility, cost, and thermal efficiency advantages provided by earthen construction materials, their use is frequently restricted by challenges related to weather resistance and durability, especially with respect to rainfall exposure conditions. This study, therefore, examines and makes recommendations on alternative approaches to the construction of unstabilized earthen walls, such as compressed earth blocks (CEBs), by leveraging natural fibres reinforcements and high compressive strength, optimizing soil mixture proportions and strategic improvements to architecture like extended roof overhangs and environmentally conscious cladding or plastering. Additionally, to increase load- bearing capacity and durability against adverse environmental conditions, structural strengthening with timber elements within walls is recommended. These methods offer an environmentally friendly alternative to building earthen buildings that are durable and retain structural integrity without using high-carbon materials. The findings also confirm ongoing innovation efforts in earthen construction, which are meant to improve sustainability, and lower carbon footprints, with their potential to address housing challenges globally, especially in low-income areas. Further research is recommended to optimize these techniques for broader adoption.

Keywords: *Earthen construction, sustainability, adobe, compressed earth blocks.*

1. Introduction

Earth is the world's oldest construction material. Statistics show that over 1 billion people still live in buildings constructed with Earth materials, a trend that is most prominent in areas like the Middle East, North Africa, and Central Asia (See Figure 1); as a result of the relatively slower development in these regions [1,2]. However, since the development of modern materials like steel, concrete, and burnt bricks, this practice has become obsolete [3]. In recent years, earth-based masonry has gained popularity, particularly with the growing interest in sustainability and efforts to address affordable and dignified housing challenges. Bredenoord and Kulshreshtha (2023) [4] estimate that currently, approximately 8-10% of the global population live in earthen houses, which is 20-25 % for low and middle-income nations. However, despite the fact that having a decent place to live is a basic human necessity, in developing countries, almost 80% of urban dwellers still live in makeshift settlements because they cannot afford expensive building materials [5]. The relationship between affordable and sustainable building practices is also examined in a review by Silva et al. (2024) [6], with special attention to easily accessible and environmentally friendly materials like soil. Additionally, with the high prices and restricted affordability of conventional building materials, a large percentage of people in developing nations are forced to build homes out of whatever materials are available, which highlights the structural difficulties in providing suitable housing [7].

Figure 1: Earth construction distribution around the word [1].

Earth construction, therefore, has a number of benefits over conventional construction methods. Silva et al. (2024) [6] emphasize that earth-based construction materials can offer durability and thermal efficiency when managed appropriately, which makes them perfect for areas in need of affordable housing options [8]. This is especially true in areas where conventional construction materials like cement or steel are limited, making soil an attractive alternative. For instance, rammed earth and compressed stabilized earth blocks (CSEBs) have drawn interest because of their affordability and minimal environmental effects [9]. The local sourcing of earth-based materials also reduces carbon emissions and transportation expenses. Studies like one by Hall et al. (2012) [10] and [5] have demonstrated how using earth-based materials stabilized with natural stabilizers or the use of compressed earth blocks increases affordability and durability. Similarly, Silva (2015) [3] highlights the benefits of earth construction, including affordability, acoustic and thermal insulation, low impact on the environment, and ease of accessibility. Notably, the financial advantages can also be attributed to the fact that they do not require highly skilled labour. Earth construction also contributes to energy consumption reduction during and after the construction phase as the waste generated can be recycled and reused effectively, which aligns with sustainability and ecological equilibrium pursuits [1].

Even with these advantages, several limitations and concerns have frequently restricted the adoption of Earth-based construction methods. According to the study by Obonyo et al. (2010) [11] the primary concerns with the use of earth-based bricks in construction include their low strength properties and lack of durability compared to concrete and other alternative construction materials. Particularly when it comes to withstanding shear pressure or compression under immense loading, materials like mud and clay are not as naturally as strong as concrete or steel [12]. Although sustainable, earth-based materials often also face adoption resistance, especially due to consumer preferences for modern architecture's aesthetic. These materials' acceptability in urban or luxury projects is therefore limited since people typically link them with "primitive" or rural construction styles [1]. Thus, it can be challenging to incorporate earth-based materials like rammed earth or adobe into mainstream designs because of their natural appearance, which doesn't always match modern design preferences.

This study, therefore, employs a qualitative analysis to assess various techniques applicable to the earth-based construction approach, focusing on its efficiency in addressing the mechanical and durability shortcomings of traditional earthen construction materials but also promoting sustainable practices. In particular, we evaluated and made recommendations on the use of unstabilized earth technologies in moisture exposure conditions in the case of rainfall. But first, we acknowledge that the variations in earth-based material properties may be attributed to the different climate conditions, manufacturing methods and soil compositions [11]. The stabilized earth construction techniques are adequate in addressing most of the challenges and experiences in the adoption of earth architecture, but they also do have some shortcomings. Turco et al. (2021b) [13] highlights that despite recent research significantly increasing on the topic of stabilization of earth blocks with natural materials, there is a gap yet to be addressed due to the uniqueness and complex nature of these materials. We compare various earth construction technologies available based on literature and investigate alternative techniques that can be leveraged to ensure the sustainable utilization of the earth architecture without stabilizing the soil with cement and other chemical additives.

2. Traditional Earth Architecture

Throughout history, human beings have adapted and developed techniques to make shelters with the resources accessible and readily available in the surrounding natural environment. The choice of construction methods using earth-based materials has deep roots in the environmental, cultural, and historical contexts of different communities internationally. 40% of the world's population is thought to reside in earthen houses, which are among the oldest construction materials [13]. According to Binici et al. (2005) [14], "Earth is a cheap, environmentally friendly and abundantly available building material". As an integral element of their traditional building styles, various communities have practiced these construction methods for decades. The earth construction materials are developed and manufactured empirically using local constructive cultures that are often passed down from generation to generation by the builders, who are primarily peasants who use the soil for agricultural purposes [15]. Traditional earth construction mainly involves the use of naturally available materials such as stone, clay, and biomass. Some common examples include rammed earth, earth fill-in, and Adobe (mud bricks). Although traditional earth-based construction techniques have been effective for years in many settings and applications, their shortcomings over the years, such as the low compressive strength and high maintenance, often needing frequent replastering during the rainy seasons, have led to the use of stabilizers to ensure longevity [13].

1.1. Traditional Rammed Earth

The traditional rammed earth includes a composite of local soils- typically a blend of sand, gravel, silt, and clay- that undergoes compaction into soil layers to create earth walls. Clay serves as a binder and is often present in less than 30% of materials [16]. This technique has been used for thousands of years, particularly in areas and regions with limited wood resources [17].

1.2. Earthy fill-in

Earth fill-in, commonly known as wattle and daub, uses wooden frames filled with mud- filled stalks or woven sticks. In some areas, the earth fill-in method is the preferred construction method for many families, especially in low-income communities since it is relatively inexpensive, accessible and requires minimal materials and labour. After installation, mud mortar is also used to plaster the surface of the wall into a smooth finish.

1.3. Adobe or mud bricks

For the formulation of the adobe or mud bricks, the soil of no less than 15% clay is combined with fibre materials like straw, grass or rice husks to create adobe, and the mixture is then moistened with water to get the desired consistency [18]. The mud bricks are typically created by pouring the adobe mixture into moulds. The mud undergoes contraction, sometimes known as deformation, as it dries, and thus, the elasticity of the bricks is increased by the presence of the fibres [14]. In some communities where the clay is of the right consistency, the bricks are made by carving them out of earth pits. The bricks are then left to dry in the sun or are fired to harden and later used to construct walls, while timber is used for the roofs [19]. When fully dried, the bricks are normally relocated and kept under cover until needed. When the bricks are ready for usage, the same mixture is made for the mortar that will hold the bricks together and as plaster.

3. Conventional Earth-based construction

Builders are now adopting innovative approaches to develop conventional earth-based construction techniques such as the Stabilized Rammed Earth (SRE), Compressed stabilized Earth Bricks (CSEB) or Interlocking Soil Stabilized Bricks (ISSB) to address the shortcomings experienced with traditional earth materials discussed earlier. SRE combines the traditional rammed earth methods with modern stabilizers and mechanical compaction to improve the thermal efficiency, durability and structural integrity of the wall. According to studies, the load-bearing capacity of these SRE walls can be increased by meticulously optimizing the use of SRE materials, which include clay, silt, sand, gravel, and stabilizers [20,21]. To formulate the Compressed stabilized Earth Bricks (CSEB), the soil mix is stabilized with cement (5-10%) to improve the structural properties of the material. The composition of the stabilized soil block consists of 60 - 70% soil, 20 - 30% coarse sand and 8 - 10% cement. The stabilized earth bricks require substantially less energy to fabricate than conventionally fired bricks [22]. To make the bricks consistent and durable, the earth mixture is moulded and compressed manually or mechanically using a hydraulic or manual press. The bricks are then dried in a kiln or air-dried for adequate curing to acquire effective strength. The bricks are used to build walls using standard bricklaying and masonry techniques, including the use of clay mix or cement mortar. The masonry must also be done by well-trained masons who can mix the materials properly to fabricate quality bricks. An additional consideration is that waterproofing sealant must be applied to the external faces of the brick after completion of the structure and must then be reapplied every three to five years to ensure that the wall systems do not succumb to erosion. The bricks must also be built on a concrete slab or footing to lower the risks of deterioration from the rising moisture over the life of the structure. Interlocking Soil Stabilized Bricks (ISSB) are made from the same soil/cement ratio as compressed stabilised earth bricks but present an interlocking form or patterns that allow for strong, rapidly assembled systems that require little to no cement mortar, leading to cost savings [22]. Mortar may only be used for the foundation or final touches. The stabilised soil is mixed and hydraulically compressed in a mould under pressure using a moulding machine. They can also be made on-site as long as the mix ratios are monitored to maintain the quality standards. According to UN-Habitat (2020) [23], the strength of an ISSB is determined by its constituents and the water-curing process undertaken after production. Overall, the ISSB interlocking design allows for quicker and easier construction, and the mechanism ensures that the walls are straight and well-aligned, which enhances the building's structural stability.

4. Questioning Stabilization in Earthen Construction

Despite the foundation of the stabilized earth construction methods being the earth mixture, they are additionally stabilized to meet some engineering properties and structural building criteria, which is achieved by manually or mechanically compacting the mix while adding the stabilizers to improve the properties further [12]. The stabilizers are broadly categorized into organic-based (fibres and polymers) and mineral-based (lime and cement). By adding cement to the soil, earth blocks' mechanical strength and durability are increased, extending structures' lifespan and lowering the likelihood of them collapsing [24]. Similarly, a study by Turco et al. (2021b) [13] examined the properties of Compressed Earth Blocks, their economic performance and environmental impact and highlighted some advantages such as eco-friendliness, since they are unfired, enhanced strength due to compaction, recyclability, and high thermal comfort. However, this study cited some disadvantages, including vulnerability to water damage, questions about durability, and low compressive, for which they recommended chemical stabilization and mechanical reinforcements for the tensile strength, brittleness after drying and excessive shrinkage. Other advantages of using the cement stabilizer are that it allows for the smooth running of the construction process and the use of a wide range of subsoil material that would otherwise not be possible with the unstabilised earth mix [20]. The authors add that the walls built with stabilized earth material have relatively higher early load-bearing capacity, which also enhances loading through the construction stages.

Although cement is the most common stabilizer for modern earth-based constructions, it has raised sustainability concerns mainly due to its carbon footprint. While it improves the strength and durability of earthen structures, cement production alone accounts for over 7% of global greenhouse gas emissions, making it one of the major contributors to air pollution [24]. Therefore, the use of lime, gypsum, bitumen or cement to stabilize or as binders for earth blocks is still considered unsustainable from both the economic and environmental points of view [25]. This urges researchers to explore alternative methods to stabilize earth-based construction materials to promote more sustainable practices Nwankwor (2011) [26]. The cost of cement and lime in countries that do not primarily produce the products locally is extremely high, which makes accessibility even more challenging [27]. Additionally, a study by Ouedraogo et al. (2020) [28] recorded that it does not seem consistent to use more than 4% of mineral binders in earth bricks and further recommends exploring the use of low environmental impact binders such as biopolymers to stabilize earth bricks or the unstabilized earth construction materials. Furthermore, Turco et al. (2021b) [13] highlights that, as sustainability and the Circular Economy (CE) principles now overlap, it is both necessary and a duty to concentrate on using materials that are appropriate for fulfilling these principles. In general, these factors thus raise the critical question of how affordability, material accessibility, structural strength and durability can be balanced while preserving the core principles of sustainable construction. In this context, the practicality of using unstabilized construction methods and the opportunities they provide over conventional earth- based techniques must be examined since a notable characteristic of earthen construction materials is their environmental performance [29]. They interact with the natural environment, supporting the maintenance of the ecological balance and possess excellent biodegradability that is paramount for sustainability efforts [30].

However, despite these important properties, the structures constructed with earthen materials must be made in such a way that they are safe from exposure to moisture which is a major concern for these materials and can lead to degradation of the structure. Earth-based materials' capacity to control moisture presents both an advantage and a drawback. Although moisture can be absorbed and released by earth walls, poor moisture management can cause structural deterioration [24]. Particularly in humid climates, moisture build-up can cause rot, mould growth, and significant material deterioration. Without sophisticated engineering procedures, earthen constructions may not always adequately meet the necessary moisture control criteria, which is especially problematic in areas with high rainfall or temperature fluctuations [1]. Moreover, the durability of the earthen structures is also a fundamental concern, which manifests through reduced strength when subjected to moisture, predisposition to shrinkage cracks, susceptibility to wind erosion and flaking, and the exposure to rain (water) weathering that is observed at the base of walls. According to Windstorm and Schmidt (2013) [20], although walls built from soil mixtures without stabilizers may acquire enough compressive strength to function as supporting structural elements, they are vulnerable to erosion from water. The durability issues arise due to the susceptibility of earth materials to erosion, weathering, and general deterioration, which can substantially decrease the lifespan of earth-based structures without proper maintenance [12].

5. Alternative techniques: Compressed Earth Blocks

Compressed earth blocks (CEBs) are the most widely used unstabilized earth construction method in the world. Since CEBs consist of 60-90% sand and minimal clay content to achieve strong, stable blocks, selecting the right soil is crucial when making the CEBs mixtures [31]. CEBs are produced by providing virgin soil with the optimum amount of moisture to achieve maximum density [32]. After that, they are compressed mechanically or manually with the use of appropriate equipment. CEBs are an improvement of adobe and are a modern form of earthen technology for building [33]. Their use is well documented because they also utilize locally accessible soil fibres and require minimum water and energy; this method can, therefore, be considered eco-friendly, cost-effective, and sustainable [34,35]. Various approaches have been utilized to optimize CEBs in order to achieve acceptable structural properties [13], and considering the sustainability limitations of chemical stabilization and the structural limitations of traditional earth-based construction materials, CEBs provide a viable solution. Now the question becomes, what are the options that can be considered in achieving this? Turco et al. (2021b) [13], highlight the importance to continue developing high-performing blocks using locally sourced and easily accessible natural materials to create a new generation of sustainable building materials for both developed and developing nations. Other ways are stabilized is by using organic stabilizers that provide a more sustainable option while additionally helping to reduce the environmental impacts and simultaneously maintaining or enhancing structural properties [36,37] or by achieving high compressive strength sufficient to acquire a structural strength comparable to the stabilized bricks [36].

5.1. Natural stabilization

A viable substitute for chemical stabilizers such as cement and lime are organic or natural stabilizers, including biopolymers or natural fibres derived from plants [13]. These additives are naturally occurring organic materials and, therefore, have less of an impact on the environment and can enhance the structural qualities of CEBs. The stabilization is done to enhance CEBs' mechanical and physical characteristics, increasing their performance and durability. According to Ramdas et al. (2021) [37], natural fibres and other organic stabilizers can improve CEBs' resistance to moisture and erosion while increasing their compressive and tensile strength. For instance, organic stabilizers lessen the need for chemical treatments by improving soil compaction and water resistance [36]. Furthermore, a study by Turco et al. (2021b) [13] on optimized, CEBs recommended consideration of the use of both natural- based fibre and binders as reinforcement and stabilizers in CEB mixtures. Similarly, Bailly et al. (2024b) [24] found that if certain mass percentage thresholds are met, incorporating natural fibres and biological binders greatly improves the characteristics of soil blocks. To enable result translation, the authors also highlight that it is necessary to establish a clear relationship between the soil matrix and the binder, possibly through computational modelling, due to the unpredictability of these factors.

Natural fibres can be divided into various categories based on where they come from: plant-based (like sisal, hemp and straw, banana, coconut, etc.) and animal-based (like wool). These fibres are widely used for sustainable stabilizing initiatives in earth construction since they are affordable, easily accessible, and biodegradable. For instance, by providing reinforcement within the block structure, fibres like bananas and coconut have been shown in studies to lessen the effects of water erosion on CEBs [38]. In the same way that plant roots shield soil from erosion, the fibres form a bonding network that stabilizes the soil particles and lessens their vulnerability to water penetration and particle washing. Furthermore, in conditions of simulated rainfall, fibre-reinforced blocks exhibit noticeably lower rates of erosion than unreinforced CEBs, demonstrating the statistical significance of the durability enhancement that fibres provide [39,40]. Additionally, according to Turco et al. (2021b) [13], natural fibres can be used to reduce the shrinkage of the CEBs during the drying process. Due to their low thermal conductivity and lightweight, they are also capable of positively influencing the thermos-physical attributes of the blocks. According to Danso et al. (2017) [41], natural fibres are eco-friendly composites that can be used as a reinforcement to improve the engineering properties of various soil types (Figure 2).

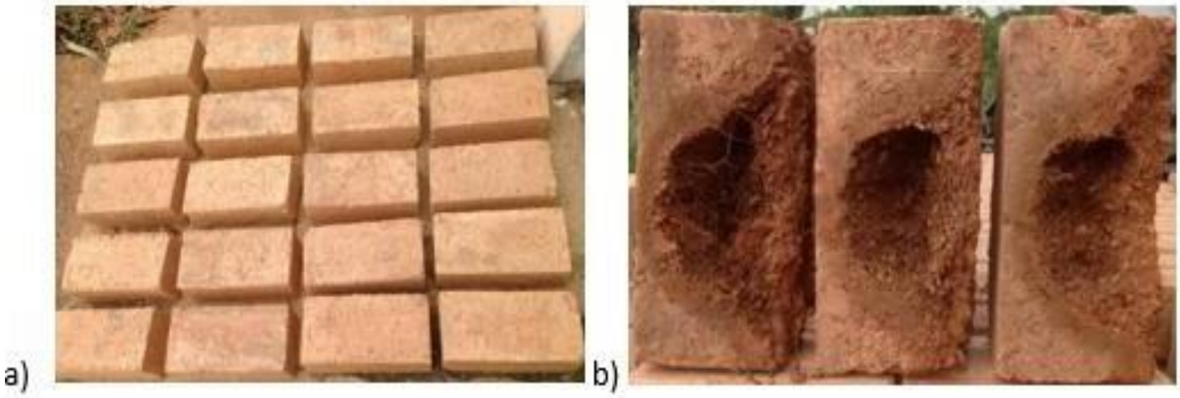

Figure 2: a) drying CEBs and b) fibre-reinforced CEBs [41]

Other advantages include their low cost and biodegradability, and they can sometimes make the blocks more ductile due to their relatively higher tensile strength [13]. Despite the benefits, natural fibres as CEB stabilizers present some challenges. For instance, using natural fibres is complicated with the addition of water in that the fibre swells during the preparation of the blocks, thus causing inadequate adhesion during the drying process and subsequent debonding [38]. A study by Turco et al. (2021b) [13] also highlights that there may be harmful overload if certain thresholds are exceeded. Similarly, Bailly et al. (2024b) [24] point out that natural fibres' ageing behaviour is still uncontrollable and that, in order to achieve optimum effectiveness, they must be uniformly distributed throughout the mix. Other studies by Namango and Starovoytova (2014) [42] and Losini et al. (2021) [43] address the vulnerability of fibre-reinforced CEBs to biological degradation. According to the results, sisal and other fibres can increase compressive and flexural strength to a certain extent, but too much fibre might cause microfractures and compromise stability. The study also points out that adding natural fibre may result in more porosity, which further reduces the density and durability of the block. Additionally, the long-term effectiveness of fibre- stabilized CEBs may be impacted by variations in fibre quality, susceptibility to microbial degradation, and incompatibility with specific soil types [44].

5.2. High compressive strength

Strength and stability are increased by densely packing soil particles, which is ensured through proper compaction techniques that also improve load-bearing capacity and reduce settling [24]. The ability of CEBs to achieve adequate structural strength by compression alone, without the use of chemical stabilizers, is one of their key advantages. A study by Raj et al. (2023) [36] discusses that the mechanical properties of CEBs are comparable to those of chemically stabilized bricks when they are sufficiently compacted; this is particularly useful when minimizing environmental impacts is the primary objective or when access to chemical stabilizers is limited. Similarly, Bredenoord and Kulshreshtha (2023) [4] study on the use of CEBS in affordable housing concluded that well-compressed CEBs, even without stabilizers, meet the structural standards in housing projects. By simply increasing the density and load-bearing capacity of CEBs, compression may help them fulfil and even surpass construction regulations for both load-bearing and non-load-bearing walls (Bailly et al., 2024b). According to Teixeira et al. (2020) [45], increasing density has a positive impact on thermal characteristics as well, which further ensures that building walls meet energy standards. Additionally, this study determined that at a compressive strength of 9MPa, CEBs had potentially little environmental impact and a strong balance between durability and thermal properties, which can improve thermal insulation by having a lower thermal conductivity than the conventional cement-based alternatives (Figure 3).

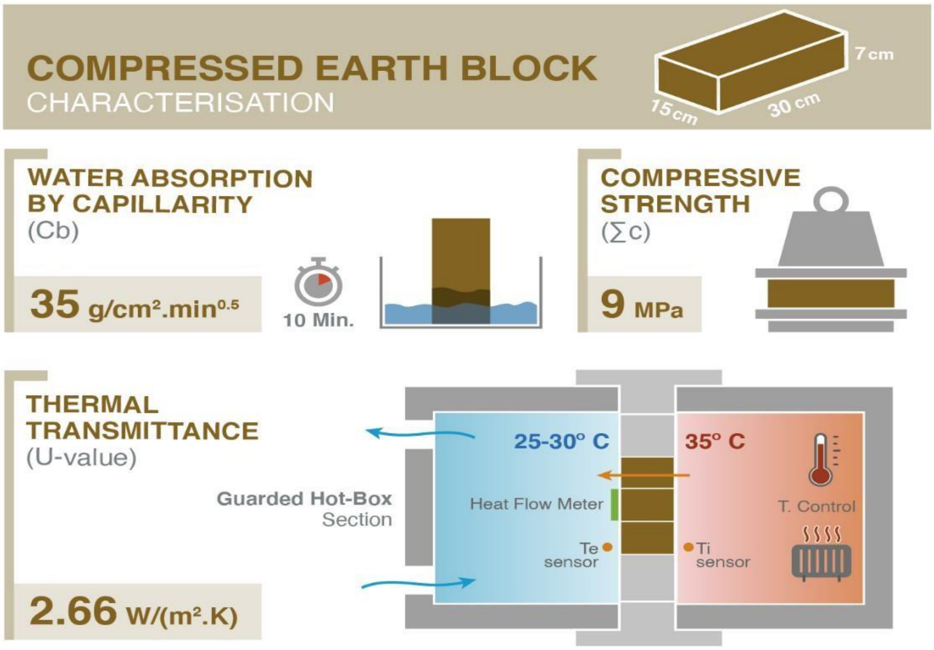

Figure 3: Compressed Earth Block Characterisation test results [45].

In this perspective, buildings constructed with CEBs, therefore, require less energy for either heating or cooling, which ultimately enhances the overall energy efficiency and long-term sustainability [37]. A study by Seco et al. (2017) [46] on the durability of unfired clay bricks, found that increasing sand content in the earth bricks significantly increased the capillarity absorbed water, which therefore provided an opposite result to the durability. Moreover, Teixeira et al. (2020) [45] found that CEBs made with soil with higher sand content experienced high capillarity. The authors recommend that the quality of the particle size distribution of the soil be well examined during CEB production to ensure low water absorption, which is a critical factor to be examined for rainfall erosion resistance after exposure conditions. A similar recommendation was made by Turco et al. (2021b) [13], who emphasized that soil selection represents the crucial variable that must be taken into account to produce high-quality CEBs. This highlights that selecting soil with higher clay content can optimize the CEBs as it acts as a binder and fills the pores within the blocks.

6. Conclusion and Recommendations

This study emphasizes the advantages and practicality of unstabilized earthen construction methods, with a special emphasis on the intrinsic benefits of unstabilized earthen materials for accessibility, affordability, and sustainability. According to the literature, earthen construction techniques offer a low-carbon footprint alternative that is consistent with sustainable practices construction. However, a major concern when it comes to the construction of unstabilized earthen walls is the effect of rainfall due to the high capillarity, which makes them highly susceptible to degradation through erosion action. This further affects the structural integrity and ultimate durability of the structure. Therefore, a few feasible measures are recommended in this study to extend the durability and robustness of unstabilized earthen walls.

Firstly, this study established that a major concern with unstabilized earthen walls is exposure to rainfall, which subsequently causes erosion. Therefore, a larger roof overhang is necessary to shield the walls from direct rainfall, which is the leading cause of degradation. Research suggests that adequate overhangs serve as efficient water- infiltration barriers, minimizing erosion and maintaining wall integrity during unfavourable weather circumstances, including exposure to wind-driven rain (WDR). For instance, a study on mid-rise structures by Chiu et al. (2015) [47] assessed both computer models and real-world data and determined that bigger overhangs greatly reduced water infiltration by sheltering walls from WDR, especially in locations with prevailing winds. According to this study, 1.2-meter overhangs improved the longevity of wall surfaces in rainy areas by lowering erosion rates and reducing wetting on facades. Another study by Ge et al. (2017) [48] examined overhangs of different widths and found that even slight increases in overhang size were associated with considerable drops in wall wetness, particularly at the top and corner locations that are usually most susceptible to rainfall. This study further provides evidence that overhangs are essential for extending the life of earthen walls exposed to rain by reducing moisture infiltration.

In tandem with this, plastering, cladding, or rendering earthen walls with sustainable materials such as natural fibre reinforcements could further protect the walls built from the CEBs against weathering, erosion, and moisture penetration [24]. Literature shows that natural fibres can be mixed with clay to create environmentally friendly coatings that offer long-lasting protective barriers, and compared to synthetic alternatives, natural plasters are easier to maintain and have a lower environmental impact because they are not only long-lasting but also replaceable [49]. Furthermore, plaster with natural fibre reinforcements, such as hemp or straw, increases the tensile strength and reduces shrinkage by creating a network which binds the soil particles and is, hence, more resilient to surface erosion and cracking. To further enhance the stability and durability of the unstabilised earthen walls, we also suggest integrating timber elements within the walls that can serve as a stabilizing framework due to their lightweight yet high-strength nature. Furthermore, research demonstrates that timber supports could assist in anchoring the walls and, therefore, increase load-bearing capacity, hence improving resistance to natural environmental forces such as wind [18]. This is especially important when it comes to load-bearing walls, which efficiently distribute structural loads to guarantee the overall stability of the structure. Premrov and Žegarac Leskovar (2023) [50] also highlight that using timber in composite wall systems can improve the resilience of the structure against external forces by effectively transferring vertical loads. Future research could investigate the effectiveness of the use of timber as reinforcement for earthen walls, especially in improving the structural behaviour or the structure.

In conclusion, the finding from this study proposes the use of sustainable, locally sourced construction materials and methods that optimize the environmental advantages of Earthen resources without compromising the integrity of the structure. This paper also highlights the complex nature of using these materials due to their variability and emphasizes the need for enhanced awareness of adequate soil selection and mixing measures to produce high-quality earthen walls. By encouraging environmentally friendly solutions that are feasible, affordable, and in alignment with international sustainability goals, the suggestions provided in this study seek to close the gap between traditional and conventional construction needs. It should, however, be noted that this paper proposes alternative earthen construction techniques but does not attempt to address all mechanical aspects such as mix design, structural behaviour and durability. Further research is required to investigate these engineering properties of the high compressive strength of earthen blocks reinforced with natural fibres and their potential to address the shortcomings associated with unstabilized earthen construction.

Acknowledgements
We would like to thank the Baden-Württemberg Ministry of Science, Research, and Arts, as well as the European Regional Development Fund (EFRE 2021-2027) for their invaluable support and funding of this research within the framework of the PAN-HAW BW research project InDeckLe. Within the research project InDeckLe, both universities, Biberach and Stuttgart, work together to design load-bearing earthen-composite slab structures, conducting mechanical experiments, but also experiments to gain knowledge about fire-resistance, acoustic behaviour and site- management and building logistics. More information can be found via https://www.linkedin.com/company/in-deck-le.

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