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# Barriers inhibiting the adoption of rammed earth construction in a developing country

Anita Odame Adade-Boateng[1*], Kofi Agyekum[1], Stephen Akunyumu[1], Frederick Wireko Manu[2] and Godsway Kobla Nunekpeku[1]

*Correspondence:
Anita Odame Adade-Boateng
anita.adade-boateng@knust.edu.gh
[1]Department of Construction Technology and Management, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana
[2]Building and Road Research Institute, Council for Scientific and Industrial Research, Kumasi, Ghana

**Abstract**
Sustainable construction practices are crucial to fostering development without depleting critical resources. This study investigates the adoption of rammed earth (RE) by specifically assessing the perceived barriers inhibiting its adoption in the Ghanaian construction industry. Primary data, sourced from literature, was used to develop a structured close-ended questionnaire administered to 114 construction professionals. Descriptive analysis, Krushal-Wallis, and Exploratory Factor Analysis were used to analyze the data. The findings indicate that while professionals possess a general understanding of sustainability, they reported being less conversant with specific sustainable practices such as RE construction. The results suggest that a strong affinity for conventional materials, the absence of dedicated local guidelines, and limited knowledge are viewed by professionals as critical sub-factors hindering widespread adoption of RE. Further analysis revealed four principal categories of barriers hindering RE's adoption: systemic barriers, technological and financial barriers, socio-cultural and user acceptance barrier, and logistical and socio-economic barriers. The factor analysis confirmed systemic barriers, such as inadequate guidelines and regulation and minimal academic coverage, as the most significant perceived impediments. Based on these perspectives, it is recommended that academic and industrial institutions create forums to promote knowledge of RE and other vernacular techniques among students and professionals respectively. The findings provide a basis for policymakers to develop frameworks to revive interest in vernacular construction. The study, therefore, contributes to the acceleration of sustainable construction practices in Ghana and the sub-Saharan region at large.

**Keywords** Rammed earth, Vernacular architecture, Earthen building, Sustainable construction, Construction professionals

## 1 Introduction

Adopting eco-friendly construction techniques and materials has become an imperative for the construction industry due to its substantial environmental impact. The industry's activities pose severe challenges in developing countries, where rapid population growth and industrialization drives extensive construction activities including territorial expansion [11]. This further leads to significant resource depletion [96]. Anecdotal evidence supported by literature reveals buildings accounts for the production of at least 37% of greenhouse gas (GHG) emissions and consumes about 36% of global energy [8, 11, 92]. This demand of materials and energy for buildings, which contributes significantly to GHG emissions, directly and indirectly drives global warming and climate change [4, 23]. The widespread adoption of cementitious materials for wall construction and demand for energy in Ghana exacerbate this issue, with cement alone responsible for about 10% of the nation's total Carbon ($CO_2$) emissions, and buildings accounting for 43% of total energy consumption in 2019 [57, 60].

In Ghana, the construction industry significantly contributes to the gross domestic product (GDP) and employs about 450,000 workers [42] [47]. Yet, literature has well-reported detrimental impacts of its activities in the landscape. Agyekum and Amudjie [9] note that the Ghanaian construction industry (GCI), like the global construction sector, extensively exploits natural resources and generates substantial environmental waste. Koranteng et al. [52] highlight challenges in delivering essential services like water and electricity to meet increasing demand. These have mounted intense pressure on the industry to explore techniques that will reduce the demand for some of these resources, while promoting their efficient usage. In recent times, Ghana has made notable sustainability progress by submitting its nationally determined contribution (NDCs) and launching a decarbonization roadmap for the built environment [60, 71]. Nonetheless, extant studies highlight the GCI's slow adoption of eco-friendly building practices [20, 21], indicating a significant gap between policy initiatives and on-site implementation.

Low carbon construction techniques, with their potential for eco-friendly environments and cost savings through economies of scale, offer the construction industry a promising alternative to conventional building practices. Using local biogenic (such as hempcrete) and geogenic materials for building represents one of such approach [57]. In the context of this study, vernacular construction encompasses the use of local techniques and available construction materials to provide building structures to meet climatic and social needs [66, 95]. It depicts the culture, social lifestyle of a locality and takes into consideration specifics of the microclimate of a particular region. Earth or soil is considered one of the vernacular materials used predominantly in the sub-Saharan African region. It encompasses adobe (or mudbrick), wattle and daub, cob, earthbags, and the like. Coupled with the need to foster sustainable buildings (i.e. low carbon buildings) at the barest minimum cost makes geogenic construction technique like the rammed earth construction an optimal choice for green buildings in Ghana [95]. Montalbano et al. [63] summarized a few relevant features of rammed earth building material that can foster circularity in the construction industry as: rammed earth is natural and does not produce waste; it can easily be recycled and reused several times. In furtherance, Nouri et al. [69] established rammed earth as a more sustainable material than fired clay brick after conducting a lifecycle assessment on the two materials based on the framework in ISO 14040:2006 standard. In the experiment, the embodied energy and carbon emission of a ton of rammed earth was found to be about 4,646 MJ and 1,245 kg $CO_2$ lesser than that of fired clay bricks respectively.

A comparative assessment on users' comfort and thermal performance of vernacular buildings in the western part of sub-Sahara Africa, recommended the adoption of rammed earth [95]. In Ghana, a few studies have focused on the broad subject of vernacular materials [11, 26, 90]. Despite the plethora of research on green construction advocating the adoption of vernacular materials as a sustainable approach to construction [8, 11], scant literature exist on the potential utilization of the rammed earth technology. Additionally, the difficulty in searching for literature pertaining to this subject area underscores the limited research in this area. Following these gaps in the literature, the overarching aim of this study is to explore the potential barriers inhibiting the use of rammed earth construction technology in Ghana. To this end, two objectives were established: (1) to assess the level of knowledge of rammed earth among construction professionals; and (2) to identify potential barriers militating against the adoption of rammed earth within the GCI.

This study contributes to the global discourse on sustainable construction by investigating and providing empirical data and insights on the level of awareness and potential barriers of rammed earth construction among construction professionals in Ghana. Accordingly, this investigation will elucidate professionals' readiness to embrace rammed earth construction, simultaneously offering actionable insights to construction professional groups and policymakers towards the advancement of rammed earth construction within the Ghanaian construction landscape. Overall, aligned with the responsibility of achieving the sustainable development goals, particularly goal 11 (sustainable cities and communities), 12 (responsible consumption and production), 13 (climate action) and 15 (life on land), this study will help foster sustainable construction practice and policies in Ghana.

## 2 Literature review

### 2.1 Vernacular architecture

Housing, as a component of the built environment, provides shelter, comfort, and healthy living spaces [24]. Beyond providing spatial cues and environmental aesthetics, housing satisfies social, cultural and emotional needs of man [40, 82]. It reflects the intricate relationship between humans and their environment, influenced mainly by ecological, political, cultural, geographical, and technological factors [13, 16]. One architectural concept that epitomise this relationship is vernacular architecture. Vernacular stems from the Latin word *vernaculus*, meaning domestic, indigenous, local and native. Glassie [43], [44] describes vernacular buildings as structures shaped by culture and context, which reflect local needs, materials and traditions. Vernacular construction extend sustainable solutions, through practices that enhances thermal and energy performances with minimal environmental implications [11]. Subsequently influencing occupants' productivity, health and satisfaction [46, 54].

Vernacular construction techniques, documented extensively in literature, vary across regions and materials. Builders utilize geogenic (soil and stone) and biogenic (fronds, wood) materials to construct cob, wattle and daub, rammed earth, compressed earth blocks, adobe, mud walls structures [31]. Local building designs often include features like facades, elongated roof eaves, pine and spruce logs as rainspout [82]. Local builders also give considerations to the building's geographical location, orientation, and shape in order to optimise indoor living conditions [40]. Vernacular buildings can incorporate passive design strategies like courtyard, earth-shelter, dome, tulou, stepwell, wind tower, roof pond and so on [13, 16, 61].

Ghana's vernacular architecture depicts the country's diverse geological, climatic, ecological and ethno-cultural landscapes. This multifaceted interplay between environmental conditions and sociocultural contexts has given rise to a number of local construction practices across the terrain. Materials such as palm frond, bamboo, coconut branches, fronds, soils, stones and timber are used for erecting timber-framed structures, pile dwellings, rammed earth, mud, cob, adobe buildings and wattle-and-daub structures [11, 35, 90]. Design considerations, including building form, orientation, and passive strategies (e.g. Courtyard design), have been incorporated in vernacular construction practices [19, 34, 35]. Principles of green buildings and climate-responsive design strategies have long been embedded in vernacular construction practices. Such that, for instance, pile dwellings – typically elevated structures constructed primarily from bamboo or timber – can provide liveable spaces above potential water level in coastal or flood-prone areas.

However, colonization, modernization, and gentrification have, marginalized these primitive practices [91]. The shift from vernacular construction began when the nation embraced colonial and colonial-modern architecture, even those buildings fashioned after the likes of those in Europe [13, 80]. Prudon and Normandin [78] maintain that convectional construction materials have dominated modern architectural practices. As a result, sustainable alternatives like rammed earth construction have been overshadowed. Rammed earth emerges as a promising alternative with superior environmental sustainability envisaged from various lenses: operational energy, embodied energy, waste management and material circularity.

### 2.2 Rammed earth construction

Rammed earth (RE) is a vernacular construction technique that entails the compaction of moist, uncemented soil within a temporary formwork to create solid, monolithic walls [29, 68]. It encompasses the use of moistened mixture of soil comprising varying proportions of clay, sand and gravel, which is compacted into rigid formworks to create structural elements, as illustrated in Fig. 1. This versatile technique allows the creating of walls and blocks using carefully selected soils through manual or mechanical ramming [63]. Nitelik Gelirli and Arpacıoğlu [68] highlight two primary types of rammed earth construction: unstabilized rammed earth (URE) and stabilized rammed earth (SRE).

URE, also called traditional rammed earth, constitutes a precisely formulated mixture of unadulterated sand, silt, water and clay as the cementitious agent [17, 63]. This method, used for millennia, is common in regions such as the Rhône-Alpes region in France and tropical areas with suitable soils [38]. In the views of Kocak and Grant [51], preferred soils for URE should have a cohesive clay content of at least 20%. In contrast, SRE incorporates additional cementitious materials, such as cement or lime, and/or other additives specifically to enhance certain properties of the resulting structure [51, 63]. Bui et al. [28] assert that the SRE exhibits superior wet strength, erosion resistance and mechanical properties when compared to URE. However, Maniatidis and Walker [58] posit that comparable performance to SRE can be achieved with URE through the implementation of appropriate design strategies and construction methodologies specifically tailored for earth buildings. This suggests that the choice between the two transcends material availability to broader design considerations and construction technique.

Several studies reveal that rammed earth construction contains lower carbon and embodied energy compared to concrete and fired clay bricks, especially when materials

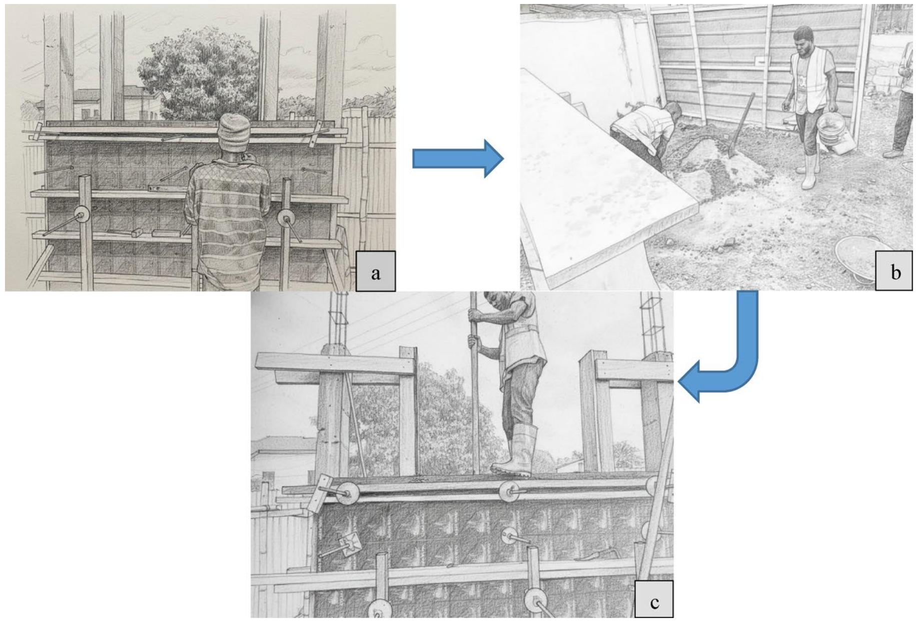


**Fig. 1** Key stages in the construction of RE wall at the Ghana Institution of Engineering, Accra in 2024. **(a) Stage 1**: On-site construction of timber formwork; **(b) Stage 2**: Preparation of stabilized soil aggregates; **(c) Stage 3**: Manual compaction of the mixture in 300 mm layers. Source: Authors (2025)

are from on-site or close by [65, 69]. Demolished concrete structures create waste management problems. However, with rammed earth, materials can be reused when the structure is demolished. This provides little to no waste to the environment [29, 63]. Other studies show that earth construction offers a cost-efficient and flexible way of construction, since materials are available and easily accessible [53, 100]. The availability of various earthen material like clay and sand for rammed earth construction play a crucial role in its usage, since this can affect the cost of transportation, environmental impact and cost of construction [11]. The flexibility of rammed earth construction is seen in its ability to be adapted in various climatic zones. The method of construction allows easy modifications in form and style during the construction process [33]. Despite its labour-intensive nature, rammed earth construction does not require relatively high level of training, thus the availability of unskilled labour suffice [41]. Darko et al. [36] posit that aside striving for energy efficiency, the indoor environment of rammed earth buildings possess quality properties due to its natural and non-toxic materials composition. This property creates healthier indoor environments and contributes immensely to occupants' health, satisfaction and productivity within the building [30, 59]. Per Strazzeri and Karrech [87], rammed earth buildings have low maintenance cost and are characterized by appreciable thermal, acoustic and fire-resistance performance. The minimal energy consumption for active cooling systems within rammed earth buildings leads to substantial cost savings for occupants. In Egypt, for example, the operational energy efficiency of rammed earth structures enables occupants to save over 50% on cooling cost compared to conventional buildings [6]. Elsewhere in Zheijang, China, studies show the average annual carbon emission of the whole life cycle of rammed earth buildings is 17.37 kg/m$^3$, which accounts for about at most 38% of that of convectional material like reinforced concrete [94, 103].

### 2.3 Barriers to rammed earth construction

Despite the historical significance and potential benefits of earthen construction in Ghana, several barriers hinder its widespread adoption within the built environment. Literature reveals these obstacles as spanning technical and technological; social and cultural; regulatory and political; economic, and environmental domains [64, 67, 98]. Table 1 contains a summary of the barriers identified in the literature search.

Technical and technological barriers inhibit the adoption and integration of innovation systems and methodologies that could otherwise promote advancements in sustainable construction [9]. A systematic review by Pelé-Peltier et al. [77] highlight challenges including the difficulty to understanding earthen material behaviour, the scalability to modern building sizes, the lack of scientific data and research investment, variability of material and quality control, and engineering related constraints. Furthermore, several authors emphasize issues related to the durability of the soil constituents under adverse environmental conditions and infestations of rodents and insects [34, 53]. While appropriate materials selection and compaction technologies can enhance the longevity RE

**Table 1** Summary of Barriers hindering the adoption of Rammed Earth Construction

| Code | Barriers | Literature Sources |
|---|---|---|
| BB1 | Limited public and industry knowledge regarding the benefits of rammed earth | [5]; [16]; [24] |
| BB2 | High-initial cost | [5]; [18]; [24] |
| BB3 | Absence of dedicated local building codes and regulation | [10]; [19]; [24] |
| BB4 | Challenges with material sourcing | [8]; [9]; [18]; [25] |
| BB5 | Inadequate support from government and industrial institutions | [2]; [15]; [18] |
| BB6 | Limited availability of skilled labour | [3]; [16]; [18]; [20]; [22] |
| BB7 | Cultural and aesthetic perceptions | [2]; [11]; [18]; [23] |
| BB8 | Engineering related challenges | [2]; [14]; [16]; [18]; [21] |
| BB9 | Strong industrial and user preferences for conventional building techniques/materials | [7]; [13]; [15]; [18] |
| BB10 | Limited research and data on performance of rammed earth building elements | [14]; [16]; [18] |
| BB11 | Climate and geographic constraints | [14]; [15]; [19] |
| BB12 | Lack of fiscal incentives | [2]; [15]; [19] |
| BB13 | Minimal academic curriculum coverage and professional training programs | [16]; [20]; [25] |
| BB14 | Unclear compliance pathways | [6]; [15] |
| BB15 | Insufficient market strategies and promotion | [16]; [18]; [19]; [22] |
| BB16 | Return on investment uncertainty | [7]; [13]; [16]; [25] |
| BB17 | Lack of research investment | [7]; [16]; [18] |
| BB18 | Complexity of modern building sizes/designs | [7]; [16]; [18]; [24] |
| BB19 | Higher cost of maintenance | [17]; [20] |
| BB20 | Difficulty in obtaining building permits, loans and insurance | [7]; [20] |
| BB21 | Unavailability of digital technologies and modern mechanization | [4]; [9]; [10] |
| BB22 | Quality control deficiencies | [9]; [22] |
| BB23 | The labour-intensive nature of rammed earth construction | [9]; [10] |
| BB24 | Competition from other Green Building Techniques and Products | [1]; [12] |

1 = Abera [1]; 2 = Acheampong et al. [3]; 3 = Addy et al. [4]; 4 = Agyekum et al. [11]; 5 = Ali et al. [15]; 6 = Ashurmamadova and Rexhepi [25]; 7 = Danso [34]; 8 = Eo et al. [39]; 9 = Gomaa et al. [45]; 10 = Kloft et al. [50]; 11 = Kulshreshtha et al. [53]; 12 = Lokko et al. [56]; 13 = Mohamed et al. [62]; 14 = Morel et al. [64]; 15 = Nikyema and Blouin [67]; 16 = Nwaki et al. [70]; 17 = Oguntona et al. [72]; 18 = Pelé-Peltier et al. [77]; 19 = Rosicki and Narloch [79]; 20 = Samarasinghe and Falk [83]; 21 = Solomon-Ayeh [85]; 22 = Strazzeri and Karrech [87]; 23 = Twumasi-Ampofo and Oppong [91]; 24 = Zami [98]; 25 = Zami and Lee [101]

*Source: Authors' construct (2025)*

structures, the limited availability and high cost of skilled professionals for post-construction maintenance, repairs and alterations present a significant operational challenges [99]. Another crucial barrier is the minimal inclusion of RE construction in academic curricula and professional development programs, which hinders widespread adoption [67]. Although some people perceive RE as low-tech construction method. This perception potentially translate to assumptions undermining its economic and technical properties. However, Strazzeri and Karrech [87] argue that, in practice, RE is relatively more expensive than other variants of earthen construction. Additionally, as noted by Agyekum et al. [11] and Zami [98], RE construction procedure requires specialized building professionals. Kulshreshtha et al. [53] emphasize that the unavailability of skilled labour can lead to inferior construction quality, which subsequently poses challenges in obtaining building permits, securing loans and insurance, while also resulting in higher maintenance cost [70].

Social and cultural barriers constitute impediments stemming from stakeholders' perceptions, scepticism and preferences that fundamentally influence acceptance or rejection of RE [77]. These inhibitors manifest through societal misconceptions and cultural resistance. According to extant literature, building with earth, as seen in RE construction, is predominantly associated with poverty and dirt [3, 85]. Another common misconception about earthen building is its perceived inferior aesthetic appearance [101]. The significant resistance to vernacular construction can also be attributed to strong industrial and user preferences for conventional building techniques and materials [77]. Clients tend to perceive conventional materials as more aesthetically appealing and synonymous with affluence. Industry players' lack understanding of rammed earth construction reinforces negative perceptions as it often leads to poor construction quality. Overall, this barrier persists in society due to the limited social awareness and knowledge of rammed earth construction's inherent benefits [98, 101].

Regulatory and political barriers represent legal and institutional frameworks that affect the viability of rammed earth construction. These barriers raise critical concerns regarding the adoption of RE construction since they encompass both government and industry's direct and indirect influence on the adoption of earthen materials [53]. This factor constitutes the absence of dedicated regulations concerning earthen materials and construction for quality assurance, unclear compliance pathways, and insufficient support from governmental and industrial institutions [70, 77, 87].

Financial barriers encompass issues relating to cost, funding, and market conditions. Strazzeri and Karrech [87] assert that RE construction can be expensive. While they did not specifically identity cost drivers, Pelé-Peltier et al. [77] revealed that materials certification requirements, fragmented construction procedures, and project size and complexity can significant influence the cost of construction. Other components include lack of fiscal incentives, uncertain return on investment, insufficient market strategies and promotion, and limited research grants and investments [34, 70, 101]. According to Acheampong et al. [3] and Zami [98], the scarcity of professionals and limited expertise in RE construction reflects prevailing market conditions.

Climate and geographic constraints constitute environmental barriers rammed earth construction adoption. Environmental factors like wind and rain significantly influences the durability of earthen buildings. Extant studies confirm that RE buildings in regions exposed to intense rainfall patterns may experience rain-driven erosion, consequently degrading the quality of building elements [28, 79]. A review by Morel et al. [64] elucidates how seasonal changes induce water molecule absorption-desorption phenomena on earthen wall surfaces, consequently causing significant disparities in indoor-outdoor humidity levels that potentially impact thermal comfort.

## 3 Research method

### 3.1 Approach/strategy

A quantitative approach, particularly a structured survey instrument (i.e. questionnaire), was employed to achieve the objectives of this study. This approach is considered appropriate as it enables researchers to collect data from a relatively large sample size [93] while allowing researchers to examine social phenomena through rigorous statistical analysis, allowing for systematic hypothesis testing and validation [22]. Furthermore, it facilitates the generalization of findings regarding a phenomenon – in this case, assessing professionals' level of awareness and identifying the potential barriers hindering the adoption of rammed earth construction technology in Ghana. This methodological approach has been extensively adopted in extant studies focusing on green construction practices [3–5, 8]. The questionnaire was structured into three distinct parts. Part 1 was intended to collects respondents' demographic information. Part 2 sought to gather respondents' knowledge on rammed earth construction as a green building strategy. In this section, respondents were required to rank various statements on rammed earth construction technique based on a five-point Likert scale (where 1 = highly unware; 2 = unaware; 3 = moderately aware; 4 = aware; 5 = highly aware). Part 3 attempted to gather respondents' perceptions of barriers inhibiting the widespread adoption of rammed earth construction in Ghana. This category required respondents to indicate their level of agreement with the 22 barriers identified through an extensive literature review on a five-point Likert scale (where 1 = strongly disagree; 2 = disagree; 3 = neutral; 4 = agree; 5 = strongly agree).

### 3.2 Survey administration

Prior to the main distribution of the questionnaire, a two-step piloting procedure was conducted. This ensured the appropriateness of the research instrument and promoted consistency in its administration to targeted respondents [32]. First, the questionnaire was reviewed by two academic professors, both experts in sustainable construction practices. Based on their feedback, necessary adjustments were made to enhance clarity and reduce ambiguity. Subsequently, the second pilot stage involved 11 construction professionals, working in either a construction or a consultancy firm, who were consulted on the suitability of the instrument. Their feedback indicated the instrument was appropriate, allowing for its full administration. The unit of analysis for the study was construction professionals (Construction Managers, Engineers, Quantity Surveyors, Architects, Project Managers, Academics and Real Estate Practitioners) employed in either construction, consultancy or research organizations within the Ghanaian built environment. Previous studies [4, 11, 21, 27] within the study milieu have revealed the difficult involved in securing a suitable sample frame for construction professionals. Furthermore, the absence of a comprehensive dataset on Ghanaian professionals who specialize in earthen construction warranted the use of purposive and snowballing method (non-probability sampling techniques). Purposive sampling is used to intentionally select respondents who possess specific characteristics (e.g. knowledge on a certain issue of interest) [7]. In this study, the purposive criteria were defined by professional qualification and active involvement in the construction industry, rather than prior technical specialization in earth building. Snowballing sampling, on the other hand, allows researchers to select participants based on recommendation/referrals from initial participants [7]. The purposive technique was first employed to identify 56 known professionals and others with professional training willing to partake in the study. Subsequently, the snowballing technique enabled further referrals from these participants. To ensure that all referred participants met the inclusion criteria, the research instrument included a mandatory screening questions to verify the professional background and industry experience. Against this backdrop, a total of 114 valid responses were analyzed, out of the 150 distributed questionnaire.

### 3.3 Data analysis

Participants' responses were coded, analyzed and interpreted using Statistical Packages for Social Sciences (SPSS) software, version 27. Descriptive statistics, including frequency, mean and median, were utilized to summarize the data. The study also adopted inferential statistical techniques, such as Kruskal-Wallis and Factor Analysis, to test hypotheses and identify components within the data [76]. All results were presented in tables and figures. Prior to testing for differences in awareness among professionals, the results from both the Kolmogorov-Smirnov and Shapiro-Wilk tests showed that all the $p$-values for the nine statements were less than significant level of 0.05. Accordingly, the null hypothesis was rejected since the data was not normally distributed. Since the data does not follow a normal distribution, Kruskal-Wallis H test, a non-parametric test was deemed suitable to examine variations in respondents' level of awareness of rammed earth as a sustainable construction technique. According to Takyi-Annan and Zhang [88], Krushal-Wallis is an alternative to a one-way ANOVA, which is ideal: (1) when an investigation involving three or more independent conditions; (2) when three or more groups are to independently assess each of the conditions; (3) when data does not follow the assumptions of a parametric test. This test works by ranking the data across the groups, coupled with a test statistic based on the sum of ranks for each professional group. The results are subsequently reported with chi-square values and their respective p-values [2].

Additionally, Exploratory Factor Analysis (EFA) was adopted to examine and cluster the barriers hindering the adoption of rammed earth in Ghana under principal components. Cronbach's alpha coefficient was used to check the reliability and consistency of the instrument. The reliability of a study's instrument is described as its consistency or repeatability [76]. The values ranges from 0 to 1, where a value closer to 1 means greater internal consistency according to Wipulanusat et al. [97]. The threshold of 0.7 or greater is generally considered acceptable for demonstrating adequate reliability [89].

## 4 Data analysis and discussion

The survey conducted within Ghana's construction industry reflect the presence of professionals with diverse backgrounds as shown in Fig. 2. Of the 114 respondents, Quantity Surveyors represented the largest group at 31% ($n$ = 35), followed by Construction Managers at 21% ($n$ = 24), Engineers at 16% ($n$ = 18), and Architects at 15% ($n$ = 17).

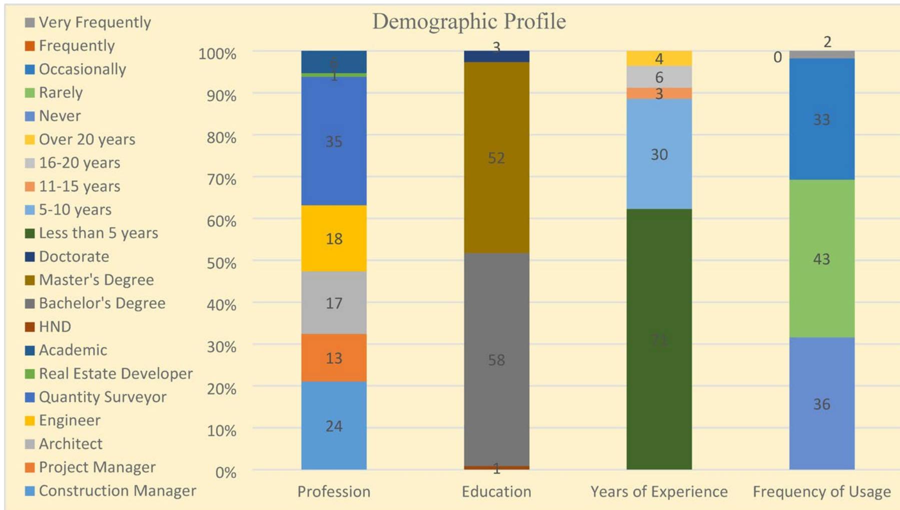


**Fig. 2** Respondents' Profile

Project Managers made up 11% ($n$ = 13), Academics 5% ($n$ = 6), and one respondent (1%) identified as a Real estate developer. 51% ($n$ = 58) of the respondents held bachelor's degrees, 52 (46%) had masters' degrees, 3 (3%) possessed doctorate degrees, and a respondent (1%) held a Higher National Diploma. Regarding professional experience, 71 (62%) respondents reported less than 5 years of work experience, 30 (26%) had 5–10 years of experience, 3 (3%) had 11–15 years of experience, 6 (5%) had 16–20 years of experience, and 4 (4%) possessed more than 20 years of experience in the built environment. This distribution indicates that the sample of the study is skewed towards the views of practicing construction professionals (architects, engineers, and quantity surveyors) in the early-to-mid stages of their careers. Pertaining to the application of RE construction techniques in Ghana, the data revealed limited engagement among professionals. A significant number 38% ($n$ = 43) indicated they '***rarely***' participated in such projects. Furthermore, 32% ($n$ = 36) stated they '***never***' utilized the RE technique, while 29% ($n$ = 33) did so '***occasionally***'. Conversely, only 2% ($n$ = 2) of professionals reported '***very frequently***' engagement with RE construction. This observation aligns with the slow uptake of sustainable practices within the industry [4, 11], and it reflects a gradual, rather than widespread, revival of this ancient building technique within the contemporary Ghanaian society.

### 4.1 Level of awareness of rammed earth as a sustainable construction material

Table 2 details the level of awareness of rammed earth construction techniques in Ghana. The research instrument used for collect data demonstrated a high degree of internal consistency, with a Cronbach's alpha of 0.862, which is above the generally accepted criteria of 0.70. As a result, the instrument was considered reliable. Per the descriptive statistics, the median score of four according to the 5-point Likert scale, for all the statements, is suggestive that construction professionals are aware of what the statements say about RE. The mean scores were subsequently used to rank the statements. Averagely, construction professionals exhibit a moderate awareness of rammed earth construction and its merits, as mean scores range from 3.24 to 3.80. Statements S1 (*Mean = 3.80, SD = 1.130*), S4 (*Mean = 3.79; SD = 1.052*) and S3 (*Mean = 3.77; SD = 1.137*)

**Table 2** Level of awareness of Rammed Earth of Professionals in Ghana

| Cronbach's alpha = 0.862 | | | | | | KW Test Statistics (df = 6) | | |
|---|---|---|---|---|---|---|---|---|
| **Code** | **Statement** | **Mean** | **Median** | **SD** | **Rank** | **Chi-square** | **Asym. Sig** | **Decision** |
| S1 | I am conversant with sustainable construction techniques | 3.80 | 4 | 1.130 | 1st | 6.858 | 0.334 | Retain |
| S2 | I consider rammed earth a sustainable construction technique | 3.65 | 4 | 1.013 | 5th | 6.523 | 0.367 | Retain |
| S3 | I am aware rammed earth construction involves compacting selected soils within a formwork to create building elements | 3.77 | 4 | 1.137 | 3rd | 14.698 | 0.023 | Reject |
| S4 | I am aware rammed earth construction requires significant skills and expertise | 3.79 | 4 | 1.052 | 2nd | 7.304 | 0.294 | Retain |
| S5 | I recognize rammed earth construction is a viable alternative to conventional techniques | 3.60 | 4 | 1.079 | 6th | 4.835 | 0.565 | Retain |
| S6 | I am knowledgeable about the different types of rammed earth construction (e.g., stabilized and unstabilized) | 3.24 | 3 | 1.170 | 9th | 5.653 | 0.463 | Retain |
| S7 | I am aware of the benefits of using rammed earth construction for the environment and building users | 3.58 | 4 | 1.088 | 7th | 12.809 | 0.046 | Reject |
| S8 | I am aware of the indoor performance characteristics of rammed earth buildings | 3.53 | 4 | 1.154 | 8th | 8.600 | 0.197 | Retain |
| S9 | I know that the materials used in rammed earth construction are abundantly available in Ghana | 3.67 | 4 | 1.180 | 4th | 7.588 | 0.270 | Retain |
| | ***Average*** | **3.23** | | | | | | |

Rankings are based on mean scores; *p*-values < 0.05 indicate statistically significant differences between groups.

Source: Field data (2025)

were highly ranked among professionals. This implies that professionals portray a relatively higher level of awareness of the concept of sustainable construction techniques, since it is a broad subject from which rammed earth construction is a part of. Meanwhile, respondents exhibit moderate awareness level of the different types of rammed earth construction (S6: *Mean = 3.24; SD = 1.170*) and its ability to enhance building performance (S8: *Mean = 3.53; SD = 1.154*).

Furthermore, Table 2 presents the test statistic and associated decisions derived from the Krushal-Wallis test for each statement. The null hypothesis ($H_o$) stated that there is no significant difference in the perceived level of awareness regarding Rammed Earth (RE) as a sustainable construction material among the various professional groups in Ghana. Conversely, the alternate hypothesis ($H_1$) posited that a significant difference exists in the perceived awareness level among at least one of these professional groups. Decisions were based on a 5% significance level: where $p$-value ≥ 0.05, the null hypothesis ($H_o$) is retained; and where $p$-value < 0.05, the $H_o$ is rejected in favor of the alternative hypothesis. With six degrees of freedom, the test results revealed two statistically significant statements (i.e. S3 and S7), since they yielded $p$-values less than 0.05. Consequently, the null hypothesis was rejected for these two statements, indicating a significant divergence in perception among the professionals investigated. Post hoc pairwise comparisons were conducted to pinpoint the specific groups between which significance differences in perception existed [12]. This involved the use of Dunn's test, a

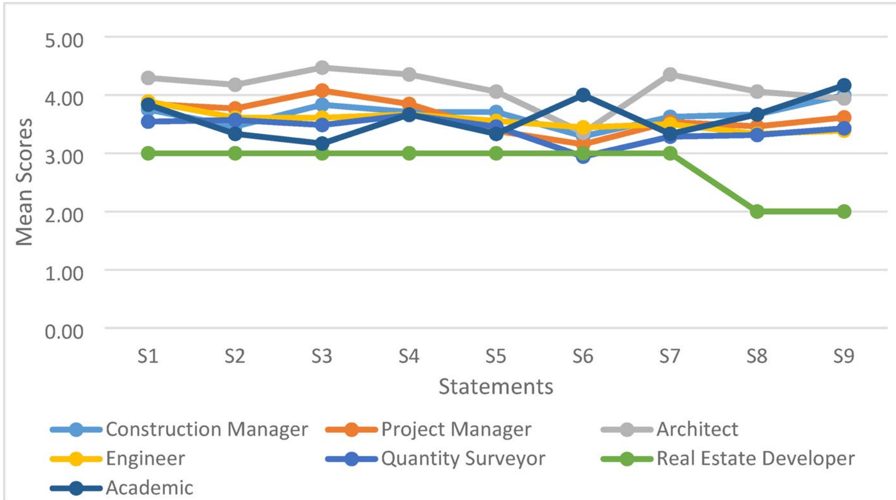


**Fig. 3** Mean Values of Responses of Construction Professionals. Source: Field data (2025)

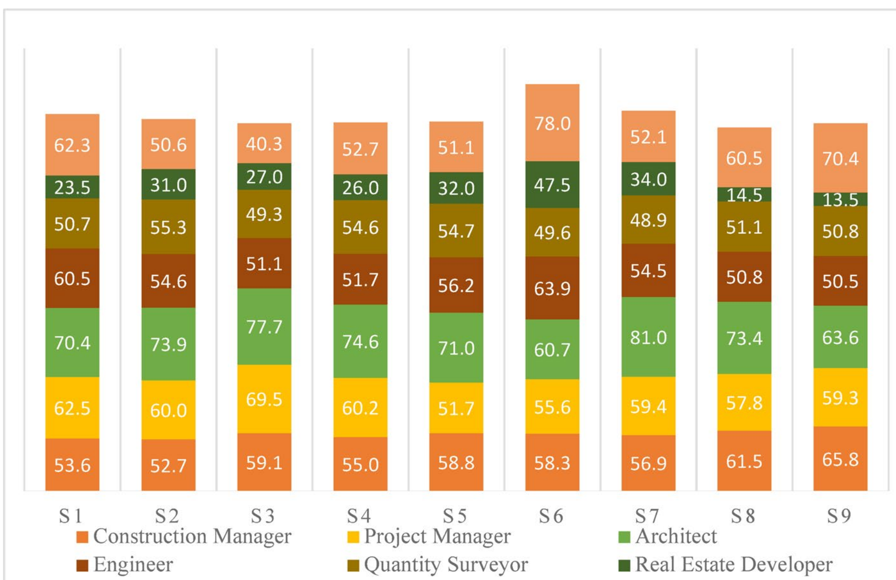


**Fig. 4** Mean ranking of Construction Professionals in Ghana. Source: Field data (2025)

non-parametric procedure for multiple comparison after a significant Krushal-Wallis analysis [102]. The Bonferroni adjustment was applied to ensure the rate of error across the tests do not exceed 0.05. The full pairwise comparison results for all 21 professional combinations across variables S3 and S7 are provided in Appendix A, Table 5. Following this, the only statistically significant difference occurred between Quantity Surveyors and Architects ($p < 0.05$). The adjusted significance was 0.049 for S2 and 0.013 for S7.

The $H_o$ of the remaining statements were retained since their $p$-values were greater than 0.05. Comparatively, the professionals in the GCI show a similar level of awareness across the most aspects of rammed earth, their knowledge on the specific construction process and the associated benefits varies significantly by professional groups.

Figures 3 and 4 illustrate the mean scores of each professional group and the sum of mean ranking, highlighting variation in the perceived awareness of rammed earth construction across the surveyed professional groups. As evinced in the line graph and bar chart, there is a notable variation in the mean scores and rankings provided by different professionals. These results suggest that the level of awareness is not uniform across the industry, likely reflecting the divergent professional backgrounds and operational contexts of the participants. For instance, the Architect group reported relatively higher mean scores (*M* = *4.50*) for most statements, with the exception of S6 (*M* = *3.50*). Conversely, the Real Estate Developer group exhibited more modest mean scores across the statements (*M* = *3.00*), and lower values recorded for S8 and S9 (*M* = *2.00*). These differences indicate that perceived awareness is shaped by professional role. The design-centric focus of architects may lead to higher reported exposure to vernacular techniques compared to the market-driven or administrative focus of real estate developers.

### 4.2 Barriers to rammed earth adoption in the Ghanaian construction industry

The 24 barriers hindering the adoption of RE construction technique in Ghana was subjected to an Exploratory Factor Analysis (EFA). This analytical tool is used to ascertain systematic co-variations from a list of variables [14]. Amos et al. [18] agree that it is not only useful as a data reducing technique, but also an effective indicator of the significance of the various subcategories of variables. It is highlighted in Osei-Kyei et al. [75] that initial tests including internal consistency, Kaiser-Meyer-Olkin (KMO) and the Bartlett's Test of Sphericity, must precede an FA, in order to ascertain the data's appropriateness for this technique. Cronbach's Alpha was used to determine the internal consistency of the dataset. A high value of 0.944 was realized, indicating a high degree of consistency among respondents as far as the barriers are concerned. The KMO statistic was 0.886, which implies dataset is adequate for the FA since it is greater than the minimum value (0.6) and close to 1.0 [84]. The Bartlett's test of sphericity yielded an approximate chi-square value of 1712.460 with 253 degree of freedom. The associated significance was minimal ($p$ = 0.000). This denotes that the population correlation matrix is not an identity matrix. Table 3 displays mean scores, standard deviations and communalities (both before and after the removal of BB1) for the identified hindrances to rammed earth construction.

As presented in Table 3, the mean score for twenty-two of the identified variables exceeded 3.50. This gives the indication that, on average, respondents agreed that these factors significantly hinder the exploitation of rammed earth construction in Ghana. In contrast, the lower mean scores recorded for BB2 and BB4 suggest that respondents perceive these barriers as less impactful. Subsequently, BB1 was removed from the factor analysis, as it yielded a communality value less than 0.5, even when approximated. Amos et al. [18] iterate variables of this nature are considered statistically independent. However, it is important to note that the high mean score for BB1 confirms its status as a significant standalone barrier, despite its statistical independence from the extracted factor structure.

The principal component analysis served as the extraction method, and Varimax was used as the rotation method. The rotation for the 23 variables resulted in a four-factor solution, with eigenvalues greater than 1.0, explaining 65.901% of the total variance. Varimax rotation was used due to its simplicity and widespread usage in orthogonal rotation [48, 49]. The 23 remaining variables in Table 4 show factor loadings are close or above 0.50, with 19 of them exceeding 0.60. The factors were categorized into four

**Table 3** Descriptive Statistics and Communalities for Barriers of Rammed Earth Construction

| Barriers | Mean | Rank | SD | Communalities | | |
|---|---|---|---|---|---|---|
| | | | | Initial | Extraction (1st ) | Extraction (2nd ) |
| Limited public and industry knowledge regarding the benefits of rammed earth (BB1) | 4.04 | 3rd | 0.990 | 1.000 | 0.437* | Deleted |
| High-initial cost (BB2) | 3.46 | 24th | 1.065 | 1.000 | 0.692 | 0.696 |
| Absence of dedicated local building codes and regulation (BB3) | 4.09 | 2nd | 0.955 | 1.000 | 0.735 | 0.738 |
| Challenges with material sourcing (BB4) | 3.48 | 23rd | 1.099 | 1.000 | 0.580 | 0.585 |
| Inadequate support from government and industrial institutions (BB5) | 3.95 | 5th | 1.088 | 1.000 | 0.746 | 0.750 |
| Limited availability of skilled labour (BB6) | 3.75 | 15th | 1.079 | 1.000 | 0.703 | 0.727 |
| Cultural and aesthetic perceptions (BB7) | 3.73 | 16th | 1.067 | 1.000 | 0.615 | 0.643 |
| Engineering related challenges (BB8) | 3.75 | 14th | 1.012 | 1.000 | 0.543 | 0.567 |
| Strong industrial and user preferences for conventional building techniques/materials (BB9) | 4.10 | 1st | 0.950 | 1.000 | 0.687 | 0.661 |
| Limited research and data on performance of rammed earth building elements (BB10) | 3.86 | 9th | 1.072 | 1.000 | 0.616 | 0.630 |
| Climate and geographic constraints (BB11) | 3.52 | 21st | 1.075 | 1.000 | 0.498 | 0.477 |
| Lack of fiscal incentives (BB12) | 3.66 | 17th | 0.958 | 1.000 | 0.559 | 0.550 |
| Minimal academic curriculum coverage and professional training programs (BB13) | 4.03 | 4th | 0.982 | 1.000 | 0.768 | 0.768 |
| Unclear compliance pathways (BB14) | 3.87 | 8th | 0.936 | 1.000 | 0.666 | 0.670 |
| Insufficient market strategies and promotion (BB15) | 3.93 | 6th | 0.966 | 1.000 | 0.795 | 0.794 |
| Return of investment uncertainty (BB16) | 3.77 | 11th | 0.960 | 1.000 | 0.702 | 0.703 |
| Lack of research investment (BB17) | 3.78 | 10th | 0.975 | 1.000 | 0.520 | 0.522 |
| Complexity of modern building sizes/designs (BB18) | 3.91 | 7th | 0.965 | 1.000 | 0.554 | 0.553 |
| Higher cost of maintenance (BB19) | 3.60 | 18th | 1.028 | 1.000 | 0.690 | 0.697 |
| Difficulty in obtaining building permits, loans and insurance (BB20) | 3.51 | 22nd | 0.998 | 1.000 | 0.735 | 0.739 |
| Unavailability of digital technologies and modern mechanization (BB21) | 3.59 | 19th | 0.948 | 1.000 | 0.678 | 0.697 |
| Quality control deficiencies (BB22) | 3.77 | 12th | 0.941 | 1.000 | 0.749 | 0.750 |
| The labour-intensive nature of rammed earth construction (BB23) | 3.75 | 13th | 0.955 | 1.000 | 0.644 | 0.648 |
| Competition from other Green Building Techniques and Products (BB24) | 3.58 | 20th | 1.055 | 1.000 | 0.591 | 0.590 |

Source: Field data (2025)

factors and were labelled with a thematic nomenclature that serves as an interpretive construct based on the logical groupings and shared characteristics of underlying variables. While these labels are informed by the literature and the thematic relationships identified in the data, they are intended to provide a conceptual framework for discussion rather than to represent definitive, immutable empirical categories. The four interpretive constructs are: (1) Systemic Barriers; (2) Technological and Financial Barriers; (3) Socio-Cultural and User Acceptance Barrier; and (4) Logistical and Socio-Economic Barrier.

## 5 Discussion

### 5.1 Knowledge of rammed earth in the Ghanaian construction industry

Generally, the concepts of sustainability and sustainable construction practices have become increasingly prevalent in the construction industry due to concerns emanating

**Table 4** Principal Factor Analysis

| Component | Code | Factor loadings (FL) | Eigenvalue | % of Variance Explained | Cumulative % of Variance Explained |
|---|---|---|---|---|---|
| Systemic Barrier | BB3 | 0.575 | 10.391 | 45.179 | 45.179 |
| | BB13 | 0.833 | | | |
| | BB14 | 0.703 | | | |
| | BB15 | 0.823 | | | |
| | BB16 | 0.681 | | | |
| | BB17 | 0.605 | | | |
| Technological and Financial Barrier | BB11 | 0.519 | 1.761 | 7.654 | 52.834 |
| | BB12 | 0.493 | | | |
| | BB19 | 0.736 | | | |
| | BB20 | 0.785 | | | |
| | BB21 | 0.761 | | | |
| | BB22 | 0.649 | | | |
| | BB24 | 0.549 | | | |
| Socio-Cultural and User Acceptance Barrier | BB7 | 0.728 | 1.683 | 7.319 | 60.152 |
| | BB8 | 0.605 | | | |
| | BB9 | 0.692 | | | |
| | BB10 | 0.646 | | | |
| | BB18 | 0.460 | | | |
| | BB23 | 0.661 | | | |
| Logistical and Socio-Economic Barrier | BB2 | 0.755 | 1.322 | 5.749 | 65.901 |
| | BB4 | 0.683 | | | |
| | BB5 | 0.720 | | | |
| | BB6 | 0.713 | | | |

Extraction Method: Principal Component Analysis; Rotation Method: Varimax with Kaiser Normalization; a rotation converged in nine iterations

from the surge in construction activities and its consequent impacts on the environment and on natural resources [21]. While literature underscores that RE construction technique offers environmental and economic appeals [11, 30], the empirical findings of this study reveal a specific pattern of awareness. The survey results in Table 2 show significant mean scores for S1 [“*I am conversant with sustainable construction techniques*,” $M$ = 3.80, $p$ = 0.334] and S4 [“*I am aware rammed earth construction requires significant skills and expertise,” Mean* = 3.79, $p$ = 0.294]. However, low mean scores were recorded for S8 [“*I am aware of the indoor performance characteristics of rammed earth buildings*,” $M$ = 3.53, $p$ = 0.197] and S6 [41, 59].

Research to understand RE properties and dedicated standards on earthen materials can affect RE’s widespread adoption and professionals’ knowledge. As noted by Addy et al. [4], a culture of non-participation and lack of enthusiasm from stakeholders in adopting eco-friendly practices can result in professionals’ disinterest, subsequently impacting their actions and willingness to engage with new subjects. This lack of engagement suggests that professionals may actively avoid information and training sessions that could expose them to such construction techniques. This challenge of expertise is not unique to Ghana, as similar professional knowledge gaps have been documented in the UK [98] and South Africa [72].

The findings also highlights a disparity in awareness across professional groups. The Kruskal-Wallis test in Table 2 showed statistically significant variations in responses to S3 [“*I am aware rammed earth construction involves compacting selected soils within a* *formwork to create building elements*," *M* = *3.77*, *p* = 0.023] and S7 ["*I am aware of the benefits of using rammed earth construction for the environment and building users*," *M* = 3.77, *p* = 0.023]. The results from the mean scores and mean rankings (Figs. 3 and 4) identify architect as the group with a significantly higher level of understanding compared to other groups. This implies that architects, who are often involved in the initial design and specification of materials, have a deeper conceptual and technical grasp of RE. This finding is consistent with global trends; for example Samarasinghe and Falk [83] reported that the knowledge of architects was critical to the development of New Zealand's own standards and guidelines. Furthermore, post hoc analysis using the Dunn-Bonferroni approach revealed that a significant divergence in perception regarding S3 and S7 exist specifically between Quantity Surveyors and Architects (see Appendix A, Table 5). This suggests that while most construction professionals in Ghana share a unified view on these variables, the cost-benefit priorities of Quantity Surveyors contrasts significantly with the design-oriented focus of Architects.

Based on these results, the overall level of awareness of RE among Ghanaian professionals can be described as 'neutral.' Neutrality in this sense refers to having moderate understanding of the properties, benefits, qualities and application of rammed earth. This explains why RE is recognized for its potential, but is less patronized. As a consequence of this level of exposure, the study suggest that professionals may be less confident recommending rammed earth as a viable option against conventional materials to potential clients. To address this, the study recommends promoting credible data and targeted training programs for professionals are essential to close this knowledge gap, foster greater confidence and enthusiasm for RE adoption. Additionally, organizing community-based forums and showcasing successful RE projects by highlighting indoor performance, energy efficiency reports, and so forth, can draw stakeholders' attention to RE.

### 5.2 Barriers of rammed earth in the Ghanaian construction industry

The factor analysis demonstrates that the barriers to the adoption of RE in Ghana can be envisaged as four principal barriers:

The first principal barrier identified is the Systemic Barrier. This factor accounted for 45.179% of the total variance with a significant eigenvalue of 10.391. This constitutes six variables namely: *Absence of dedicated local building codes and regulation*, *Minimal academic curriculum coverage and professional training programs*, *Unclear compliance pathways*, *Insufficient market strategies and promotion*, *Return of investment uncertainty*, and *Lack of research investment*. These barriers are grouped under the systemic barrier because the highlight the lack of a formal and institutional framework to bolster the adoption of RE construction. The high variance explained by this principal factor indicates that addressing the individual underlying could have a disproportionately large impact on the overall RE adoption when compared to the other principal factors.

Professionals in this study consider minimal academic curriculum coverage and professional training programs (*M* = *4.03*, *Factor Loading (FL)* = *0.833*) as the most significant systemic barrier to RE. This perception is particularly strong among the predominately early-career professionals, who have recently experienced current academic curricula and are now confronting practical challenges with without adequate knowledge on specialized construction techniques such as RE. Whether this barrier is perceived with equal intensity by senior professionals with extensive field experience cannot be determined from this sample. While previous studies have documented similar sentiments in other contexts [70, 101], this study specifically highlights that education needs to move beyond advocacy for sustainable construction practices in the construction sector. It calls for the development of modules that are tailored to practically orient students and professionals to vernacular construction techniques. This is possible if academic institutions and professional groups would adhere to approaches such as the development of special modules and program like the German's specialist for earth building program [83].

Insufficient market strategies and promotion (*M = 3.93*, *FL = 0.823*) emerged as another critical barrier to RE adoption. The high factor loading suggests that professionals perceive a lack of strategic communication within the sector as crucial. The Ghanaian construction industry requires the rollout of a comprehensive market strategy, using creative avenues to expose the public to the benefits of RE buildings. In exploring potential strategies, literature mentions creative avenues such as cultural festivities as effective platforms to showcase vernacular construction techniques while celebrating local heritage [81]. Other key barriers include Unclear compliance pathways (*M = 3.87*, *FL = 0.703*) and Return on investment (ROI) uncertainty (*M = 3.77*, *FL = 0.681*). In the absence of a structured protocol for designing, constructing, acquiring permits and insuring RE structures, professionals are likely to approach RE construction without a clear method of construction and standardized set of guidelines. This lack of uniformity can cause professionals to doubt building quality and reckon the return of investment on RE projects as unpredictable. Literature suggests that a clear and unified modality for RE construction should be established to replace reliance on segregated opinions and construction methodologies [25]. This will subsequently boost the confidence of stakeholders, especially investors, in investing in vernacular construction. Other systemic sub-factors, such as Lack of research investment (*M = 3.78*, *FL = 0.605*) and the Absence of dedicated local building codes and regulations (*M = 4.09*, *FL = 0.575*), further depict a professional environment where RE construction relies on the experience of a professionals without specialized expertise. The lack of research investment implies that little to no effort is being made to update the knowledge base of RE construction in Ghana. This creates a self-perpetuating cycle: without research, there is a lack of data on long-term performance, costs, and best practices, which, in turn, fuels the uncertainty around ROI and makes it difficult for professionals to recommend RE as a viable investment. As other stakeholders would usually approach unconventional construction techniques with high levels of uncertainty, especially when there is a lack adequate information about them [62]. Furthermore, respondents agree that the lack of a localized regulatory framework and policies to govern the use of earthen materials directly affects the quality of earthen structures. This has subsequently led to the erosion of the public's trust in earthen construction materials such as RE [70, 101].

The 2nd principal barrier is technological and financial barrier. It explains 7.654% of the total variance with an eigenvalue of 1.761. It constitutes seven variables including *Climate and geographic constraints*, *Lack of fiscal incentives*, *Higher cost of maintenance*, *Difficulty in obtaining building permits, loans and insurance*, *Unavailability of digital technologies and modern mechanization*, *Quality control deficiencies*, and *Competition from other green building techniques and products*. This finding support the reports of Danso [34], Nwaki et al. [70] and Kloft et al. [50]. Professionals consider difficulty in obtaining building permits, loans and insurance (*M = 3.51*, *FL = 0.785*) a significant challenge to the adoption of RE.

The absence of clear guidelines and quality assurance protocol, along with reluctance of financial institutions to invest in RE projects suggest that without an established protocol, the path to legal approval and financial support remains precarious. Another critical barrier is the higher cost of maintaining RE structures (*M = 3.60, FL = 0.739*). Although studies (e.g. [72]) have established the long-term financial benefits of green buildings, the perception of high maintenance costs serve as a major hindrance. Specific issues consistent with RE structures including termite attacks and weathering [70], warrant timely and costly maintenance interventions to sustain the building. The unavailability of digital technologies and modern mechanization (*M = 3.59, FL = 0.761*) for RE projects is also perceived as another barrier. According to Agyekum et al. [10], the GCI relies largely on physical force and manual work for its products. Again, the maturity level of adopting relevant technologies such as 3D printing, Building Information Modeling and robotics remain low in developing countries [5, 74], including Ghana. Even though the use of digital technologies and equipment are able to enhance project time and cost [50], the GCI faces some constraints to their adoption including the financial capacity of contractors and logistical procedures in procuring such technologies [12].

The next barrier is quality control deficiencies (*M = 3.77, FL = 0.649*). The quality of an RE structure is tied to several factors including the choice of material, expertise and tools [45]. It is also dependent on the availability of database, established guidelines and rating systems, which are lacking within the region, hence respondents' disposition towards RE adoption. Another barrier worth considering is competition from other green building techniques and products (*M = 3.58, FL = 0.549*). While a competitive market can drive down costs [1], this particular challenge for RE is nuanced. Although RE is a highly sustainable option, it faces competition from techniques and materials that are also paraded as "green" but may have relatively higher environmental impacts. This has been documented by Lokko et al. [56] and Nouri et al. [69] in their studies of embodied carbon in vernacular techniques, such as fired clay brick. Professional perceive that a crowded market of green materials can make it difficult for RE to be recognized. Climate and geographic constraints (*M = 3.52, FL = 0.519*) and the lack of fiscal incentives (*M = 3.66, FL = 0.493*) are the last factors under this principal barrier. As an earth-based material, RE structures are susceptible to distinct vulnerabilities, such as seasonal changes and heavy rainfalls. As a result, the integrity of the building elements buildings could experience rain-driven erosion, which can temper with the structural stability and aesthetics [79]. The absence of incentives from government such as tax exemptions or subsidies and grants for using RE makes it a less appealing venture. Previous research by Addy et al. [4] similarly identified the absence of government-sponsored opportunities in this context.

The 3rd third principal barrier is Socio-cultural and user acceptance barrier, and it explains 7.319% of the total variance with an eigenvalue of 1.683. It constitutes six variables including *Cultural and aesthetic perceptions*, *Engineering related challenges*, *Strong industrial and user preferences for conventional buildings techniques/materials*, *Complexity of modern building and designs*, and *Labor-intensive nature of RE construction*.

Professionals consider the cultural and aesthetic perceptions (*M = 3.73, FL = 0.728*) ascribed to RE structures as a crucial barrier. The general misconception about earthen structures is that, they are often attributed to poverty, underdevelopment and low social image [70]. And since individuals' decisions are predominantly influenced by their social environment and relationships [86], RE adoption can be directly impacted.

Twumasi-Ampofo and Oppong [91] noted that the trend of gentrification in urban centers is further complicating this challenge, consequently creating a cultural gap where many rich traditional heritages are being forgotten in the attempt to modernize communities with conventional materials. Strong industrial and user preferences for conventional building materials (*M = 4.10*, *FL = 0.692*) and limited research and data on performance of rammed earth building elements (*M = 3.86*, *FL = 0.646*) are regarded as crucial impediments to the adoption of RE. The absence of a dedicated database or readily available studies makes it rather arduous for professionals to recommend RE to potential clients and investors. Due to the absence of tangible data on long-term performance, structural integrity, and cost-effectiveness, professionals are unable to build a strong business case for using this approach; as a result, they are forced to rely on conventional materials with established performance records [77, 101]. Even though some of these materials may be less eco-friendly given Ghana's geographical and climatic context.

Furthermore, the labor-intensive nature of RE construction (*M = 3.58*, *FL = 0.661*) also hinders its widespread use. Previous research has similarly reported that many professionals still rely on conventional ramming techniques and wooden formworks, which contribute to the labor-intensive nature of RE projects [45]. The labor-intensive nature of the construction can be fueled by the lack of exposure to state-of-the-art ramming equipment and high cost. Professionals would therefore opt for familiar techniques that have predictable labor budgets, even if they are less sustainable in the long term. Engineering-related challenges (*M = 3.75*, *FL = 0.605*) pertaining to the durability of material, proper soil selection, the appropriate mixture of additives, and meeting structural requirements, directly contribute to the low acceptance of RE. The absence of research and related funding further complicates this issue, as academics lack the data and findings to present to the industry [77]. Another critical hindrance to adoption is the complexity of modern buildings designs (*M = 3.91*, *FL = 0.460*). Without dedicated research to explore the characteristics of suitable soils and establish state-of-the-art methodologies, professionals cannot confidently apply traditional RE techniques in their contemporary, complex designs [77]. This disconnect between vernacular methods and modern architectural demands restricts the versatility of RE and confines its use to simpler and more conventional projects. As Zami [98] noted, people blame construction materials and technologies when buildings are poorly designed or lack aesthetic appeal. Therefore, a key strategy to revive interest in earthen construction, particularly RE, would be for scientists and industrial practitioners to collaborate on developing a prototype of an ultramodern building constructed with RE to serve as tangible proof of concept.

The last principal barrier is logistical and socio-economic barrier. This component accounts for 5.749% of the total variance explained, with an eigenvalue of 1.322. It constitutes variables that encompass both operational and market-based challenges to RE adoption: *High initial cost*, *Challenges with material sourcing*, *Inadequate support from government and industrial institutions*, and *Limited availability of skilled labor*.

The perceive cost of RE construction (*M = 3.46*, *FL = 0.755*) is considered critical to the adoption of RE construction technique. Previous studies have similarly identified the cost of constructing earthen buildings as a major contributor to its resistance [70, 98, 101]. Professionals, particularly quantity surveyors, who prioritize providing clients value for their money, would often recommend conventional materials due to the perception of RE as being more expensive, especially in the short term. The presence of a very few dedicated green financing mechanism to foster RE construction projects further reinforces this barrier [67]. As a result, financial institutions that are willing to invest or offer loans for RE projects will do so with high interest rates and unfavorable terms. Presently, Ghana is defined by post-debt restructuring recovery initiatives and a Bank of Ghana policy rate of 15% [55], in addition to a weighted average cost of capital (WACC) ranging between 20.47% and 22.87% [37]. Such financial pressures are able to compel developers to prioritize immediate, low-risk returns from conventional materials. Aside this, inadequate support from government and industrial institutions ($M = 3.95$, $FL = 0.720$) is perceived as another sub-factor affecting the use of RE. Addy et al. [4] observed that the government of Ghana has scant incentives to boost the adoption of sustainable construction practices. The presence of this hindrance suggests that policy-makers have not created an enabling environment sufficient for the adoption of vernacular construction technique such as RE in the GCI. Apart from this, professionals indicate that limited availability of skilled labor ($M = 3.75$, $FL = 0.713$) impacts the adoption of RE. Although conventional RE construction can rely on unskilled labor [87], RE is a specialized field that requires informed technical decisions regarding soil selection and a proficient workforce [83]. The number of professionals trained in this specialized field is limited, primarily because there is a lack of demand and insufficient job opportunities. Furthermore, literature observe that most Ghanaian professionals base their competitiveness on cost reduction in lieu of technology when bidding for a project [4]. This practice favors large firms, often leading to RE projects being awarded based on price rather than technology and expertise.

Challenges with material sourcing ($M = 3.48$, $FL = 0.683$) has been identified as an impediment to the adoption of RE. RE enables creative designs through the blending and staggering of specific soil materials [39]. Earthen materials in Ghana varies in nature and exist in abundance. However, Gomaa et al. [45] state that the quality and properties of these earthen materials can vary significantly based on the sourcing conditions. This explains why sourcing of materials is critical, particularly in the bid to develop quality RE structures. The findings suggest that in the face of inadequate education and research, coupled with an underdeveloped green building market, acquiring soils with desired properties can be difficult. This finding contrasts with the situation in more developed markets, where the barrier of sourcing has been largely overcome due to more established markets for earth-based products, as documented in the UK context [98].

Although the factor analysis statistically excluded "*Limited public and industry knowledge regarding the benefits of RE*" (BB1 from Table 3) due to its low communality, its high mean score ($M=4.04$) confirms it as a pervasive standalone barrier among the sampled professionals. This suggests that limited industry knowledge is not merely a subset of systemic or technological and financial barriers, but rather a foundational challenge as perceived by technical practitioners in the study. Consequently, the relevance of knowledge deficit among stakeholders cannot be downplayed. For instance, sub-factors such as the lack of building codes will likely be ineffective unless accompanied by robust educational and professional development initiatives to bridge the knowledge gap among stakeholders.

## 6 Implications

There is an apparent urgency to address sustainable housing delivery, especially given the rapid population growth and the burgeoning demand for infrastructure. The findings of this study, based on the reprted perceptions of industry professionals, suggest that despite the benefits associated with rammed earth construction, awareness remains only moderate. This perception challenges the assumption that a global body of knowledge is uniformly accessible with the local context. The data suggests that this knowledge deficit is fostered by perceived systemic factors, including a lack of research and funding, inadequate education, and institutional support. Consequently, these perceptions underscore several potential pathways for considerations. First, there appears to be a perceived need for academic research to transition from general viability studies towards the development of context-specific, data-driven evidences and standards. Furthermore, the results point toward the potential value of a collaborative framework between academia and industry to disseminate locally curated data on RE's performance. Additionally, the findings suggest the potential value of fostering international exchange programs between developed and developing economies, such as Ghana. It is considered that engaging such initiatives could facilitate the transfer of specialized technological expertise and help bridge the existing knowledge gap regarding modern, stabilized RE techniques.

Regarding policy, the identified limitations to the adoption of RE such as the absence of a dedicated local building code and fiscal incentives, suggest that interventions from government and statutory bodies could be crucial in advancing RE and other earthen-based materials and technologies. For instance, it is suggested that public perception regarding earthen-products and buildings might be influenced through targeted green subsidies, such as VAT exemptions on specialized ramming equipment for RE construction. Similarly, establishing clear pathways to obtain permits and quality control mechanisms through a National Earth Building Standard, spearheaded by the Ghana Standard Authority (GSA), is presented here as a recommendation consideration to aid foster trust in vernacular techniques. These would positively influence the perception of people and rekindle trust in vernacular construction techniques in Ghana and beyond. While these implications are discussed within the Ghanaian setting, they may offer relevant insights for other sub-Saharan African economies facing similar professional and regulatory perceptions, such as Nigeria [73] and Burkina Faso [67].

## 7 Conclusion

The transition to a green economy is an imperative to developing all aspect of the economy, while mitigating various environmental, economic and social risks. This shift is particularly salient for nations like Ghana that are highly dependent on their natural resources for economic sustenance. Environmental and social issues, such population growth and its related consequence on the climate, requires a fundamental rethinking of how to proceed into the future without depleting critical resources. This urgency has fueled several studies, especially within the built environment, focused on examining and projecting various sustainable practices, including rammed earth construction. This research investigated the awareness and perceived barriers hindering the adoption of RE construction within the Ghanaian built environment. Using a structured questionnaire, a survey was conducted among 114 construction professionals in Ghana. The findings reveal that while there is a broad conceptual appreciation for sustainability, reported awareness of professionals regarding specific sustainable practices such RE construction remains moderate. Notably, the results suggest that Architects, Project managers and Construction managers perceive themselves to have a higher level of exposure compared to other professional groups in the study. This reflects how professional roles may influence the perception of vernacular technologies.

The factor analysis (EFA) identified four interpretive construct that represent the principal perceived barriers to RE adoption in Ghana: (1) Systemic; (2) Technological and Financial; (3) Socio-Cultural and User Acceptance; and (4) Logistical and Socio-Economic barriers. Among these, the absence of dedicated local building codes and regulation, quality control deficiencies, strong industrial and user preferences for conventional buildings techniques/materials, and inadequate support from government and industrial institutions emerged as highly ranked sub-factors. Critically, the diagnostic findings suggest that the high cost of capital in Ghana (i.e. WACC of 20.47% to 22.87%) serves as a significant underlying economic pressure that discourages professionals from moving beyond conventional construction techniques.

Based on these informed considerations, the study proffers several pathways for stakeholders. Professional bodies in the country, such as the Ghana Institute of Architect (GIA) and the Ghana Institution of Engineering (GhIE), could consider incorporating RE construction and other sustainable vernacular techniques into their Continuous Professional Development (CPD) frameworks where professionals will be introduced to soil stabilization, cost-estimation, structural performance, and so forth. Doing this is necessary to foster professional confidence and bridge the identified knowledge deficit among professionals. Similarly, the results point towards the potential utility of a National Earth Building Standard, spearheaded by the Ghana Standards Authority (GSA), to establish the quality assurance benchmarks that professionals, financiers and regulators currently lack. Theoretically, the findings of the study contribute a foundational understanding of the professional landscape of a typical developing country like Ghana. By providing a diagnostic baseline of current perceptions and reported impediments, the research offers a framework for future studies to explore the integration of sustainable materials like RE. In light of these perceived results, it is suggested for consideration that educational institutions such as universities, Technical Vocational Education and Training (TVET) institutions and specialized training centers introduce or tailor curricula to include RE and other earthen construction techniques. It is anticipated that such educational interventions could facilitate the dissemination of technical information within the industry.

Granting the goal of this exploratory study was attained, several limitations must be acknowledged. First, the use of a quantitative research design limited the respondents' ability to fully express their views in regards to the study's objectives. Future research could benefit from employing qualitative or mixed research approaches to gain deeper insights into practitioners' opinions and measure the utility of rammed earth construction in Ghana. The second limitation was the potential bias consistent with the non-probability sampling techniques employed in the study. It was noted that the opinions of certain professional groups (i.e. real estate developers) were less represented given the sample recorded. Additionally, the findings in this study predominately reflected the perspectives of technical and managerial professionals in the construction sector's supply chain. This implies that the generalizability of findings is limited to underrepresented groups, particularly developers. Meanwhile, the views of other stakeholders such as financiers and regulators remain a subject for future investigation. Future research should also employ targeted sampling strategies to capture the perspectives of these underrepresented groups, particularly developers, financiers, and regulators, to provide a more comprehensive understanding of RE adoption barriers across the entire decision-making ecosystem. Additionally, larger sample sizes would improve the generalizability of findings across different professional contexts. An intriguing direction for future studies is suggested, as omnibus policies may not sufficiently address the unique factors and barriers associated with the adoption of sustainable construction materials like the rammed earth.

## Appendix A

See Table 5 here

**Table 5** Pairwise Comparison (Dunn-Bonferroni) Test for Statements 3 and 7

| Code | Group-Group Comparison | Test Statistic | Sig. | Adj. Sig.[a] |
|---|---|---|---|---|
| **S3** | Real Estate Developer-Academic/ Researcher | -13.333 | 0.696 | 1.000 |
| | Real Estate Developer-Quantity Surveyor | 22.271 | 0.487 | 1.000 |
| | Real Estate Developer-Engineer | 24.056 | 0.459 | 1.000 |
| | Real Estate Developer-Construction Manager | 32.083 | 0.320 | 1.000 |
| | Real Estate Developer-Project Manager | 42.500 | 0.195 | 1.000 |
| | Real Estate Developer-Architect | 50.706 | 0.119 | 1.000 |
| | Academic/ Researcher-Quantity Surveyor | 8.938 | 0.522 | 1.000 |
| | Academic/ Researcher-Engineer | 10.722 | 0.472 | 1.000 |
| | Academic/ Researcher-Construction Manager | 18.750 | 0.194 | 1.000 |
| | Academic/ Researcher-Project Manager | 29.167 | 0.062 | 1.000 |
| | Academic/ Researcher-Architect | 37.373 | 0.013 | 0.269 |
| | Quantity Surveyor-Engineer | 1.784 | 0.846 | 1.000 |
| | Quantity Surveyor-Construction Manager | 9.812 | 0.242 | 1.000 |
| | Quantity Surveyor-Project Manager | 20.229 | 0.049 | 1.000 |
| | **Quantity Surveyor-Architect*** | **28.434** | **0.002** | **0.049*** |
| | Engineer-Construction Manager | 8.028 | 0.415 | 1.000 |
| | Engineer-Project Manager | 18.444 | 0.109 | 1.000 |
| | Engineer-Architect | 26.650 | 0.013 | 0.266 |
| | Construction Manager-Project Manager | -10.417 | 0.339 | 1.000 |
| | Construction Manager-Architect | -18.623 | 0.063 | 1.000 |
| | Project Manager-Architect | -8.206 | 0.481 | 1.000 |
| **S7** | Real Estate Developer-Quantity Surveyor | 14.929 | 0.643 | 1.000 |
| | Real Estate Developer-Academic/ Researcher | -18.083 | 0.598 | 1.000 |
| | Real Estate Developer-Engineer | 20.472 | 0.530 | 1.000 |
| | Real Estate Developer-Construction Manager | 22.938 | 0.479 | 1.000 |
| | Real Estate Developer-Project Manager | 25.385 | 0.441 | 1.000 |
| | Real Estate Developer-Architect | 47.000 | 0.150 | 1.000 |
| | Quantity Surveyor-Academic/ Researcher | -3.155 | 0.822 | 1.000 |
| | Quantity Surveyor-Engineer | 5.544 | 0.547 | 1.000 |
| | Quantity Surveyor-Construction Manager | 8.009 | 0.341 | 1.000 |
| | Quantity Surveyor-Project Manager | 10.456 | 0.311 | 1.000 |
| | **Quantity Surveyor-Architect*** | **32.071** | **0.001** | **0.013*** |
| | Academic/ Researcher-Engineer | 2.389 | 0.873 | 1.000 |
| | Academic/ Researcher-Construction Manager | 4.854 | 0.738 | 1.000 |
| | Academic/ Researcher-Project Manager | 7.301 | 0.641 | 1.000 |
| | Academic/ Researcher-Architect | 28.917 | 0.055 | 1.000 |
| | Engineer-Construction Manager | 2.465 | 0.803 | 1.000 |
| | Engineer-Project Manager | 4.912 | 0.671 | 1.000 |
| | Engineer-Architect | 26.528 | 0.013 | 0.283 |
| | Construction Manager-Project Manager | -2.447 | 0.823 | 1.000 |
| | Construction Manager-Architect | -24.063 | 0.017 | 0.353 |
| | Project Manager-Architect | -21.615 | 0.065 | 1.000 |

a. Significance values have been adjusted by the Bonferroni correction for multiple tests

* Significant differences in the perceived significance level of awareness of RE of professionals in Ghana

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**Author contributions**
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**Data availability**
Data collected during this study, analyzed and reported in the current study, will be available from the corresponding author upon reasonable request.

## Declarations

**Ethics approval and consent to participate**
The study was approved by the Human and Social Science Research Ethics Committee (HuSSREC) of the Kwame Nkrumah University of Science and Technology, Kumasi, Ghana in accordance with the Declaration of Helsinki and institutional guidelines. Written informed consent to participate in this study was obtained from all participants during the survey. The written consent to participate ensured that all respondents were aware of the study's objectives and their right to withdraw at any time.

**Consent for publication**
Written informed consent to publish anonymized data was obtained from all participants. No participant under the age of 18 was included in this study; hence, there was no need for such consent to be sought as such.

**Competing interests**
The authors declare no competing interests.

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