PHYSICOCHEMICAL AND MINERALOGICAL PROPERTIES OF CLAYS FROM FOUR SITES IN SENEGAL FOR THEIR USE IN THE PRODUCTION OF COMPRESSED EARTH BRICKS.

Abstract

This study aimed to characterize four types of Senegalese clay (Diamniadio, Daga Kholpa, Beer, and Diender) for producing compressed earth bricks (CEB). The study methodology included geotechnical tests, chemical analyses (X-ray fluorescence), and mineralogical analyses (X ray diffraction, thermogravimetric analysis, and infrared spectroscopy).

The results show that the materials have varied grain-size distributions: clayey for Diender and Diamniadio (44.5% and 33.4%, respectively), silty for Beer (53.6%), and sandy for Daga Kholpa (64.9%). The high plasticity indices of Diamniadio (35.9%) and Diender (60.1%) indicate significant plasticity. X-ray fluorescence revealed a predominance ofSiO_2,Al_2O_3,Fe_2O_3 and CaO, whereas XRD identified quartz, kaolinite, calcite, illite, and depending on the site, montmorillonite, feldspar, dolomite, and anhydrite.

These results allow to propose different stabilization methods: the most plastic clays (Diamniadio, Diender) can be stabilized with lime and/or a lime-cement mixture, while the less plastic clays (Daga Kholpa, Beer) are better suited for cement stabilization to produce cement-stabilized soil (CEB).

Keywords:Clay's material, physicochemical characterization, mineralogical analysis, compressed earth bricks.

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Introduction:

Over the past few decades, population growth and rapid urbanization in developing countries have led to a high demand for construction materials. Given the economic and environmental limitations of conventional materials, such as cement and steel, local materials,particularly clay-based materials,are attracting growing interest in the construction industry [1-5]. In modern construction, these materials have been the subject of several studies focused on the production of fired materials, particularly roof tiles and bricks [6]. However, given the environmental and energy concerns associated with global warming, raw clay materials are becoming increasingly attractive from the perspective of sustainable construction [6]. They have long been used in construction in various forms, such as adobe, rammed earth, and cob, and more recently, compressed earth blocks. These represent promising solutions for building sustainable and affordable housing.

In Africa, particularly in Senegal, the use of clay materials is growing rapidly, especially in the production of compressed earth bricks (CEB) [7-10]. However, some of these properties remain poorly understood, limiting their widespread use [11]. Several studies conducted in similar contexts have shown that the use of local materials requires thorough characterization, including particle size, chemical, and mineralogical analyses, to assess their suitability for producing cement-based composite materials (CEBs) [6,12].

The properties of thesematerials depend heavily on their physicochemical and mineralogical compositions. The nature and proportion of clay minerals, as well as their particle size and chemical characteristics, directly influence key parameters such as plasticity, compressibility, texture, and density [6,7,13]. Furthermore, the compressibility characteristics related to the nature of clay minerals, as determined by oedometer testing, particularly the coefficient of compression, play a decisive role in these parameters.

In this context, the present study aimed to investigate the geotechnical, chemical, and mineralogical properties of clays from four sites in Senegal to assess their potential for use in the production of compressed earth bricks. The objective is to better understand the influence of intrinsic parameters, particularly the compressibility parameters of these clayson the performance of compressed earth bricks (CEB) and to contribute to the development of sustainable construction solutions adapted to local conditions.

2. Materials and Experimental Methods

2.1 Materials

The study was conducted on clay soils from four different sites located in the Dakar and Thiès regions of Senegal, namely Diamniadio, Daga Kholpa, Beer, and Diender (Figure 1), at depths ranging from 0 to 50 cm.
Diamniadio is a municipality located approximately 30 km east of Dakar, Senegal, at 14°42' N and 17°13' W. It covers an area of 20 km² and is expected to accommodate 350,000 residents by 2030–2040. The Daga Kholpa urban center, covering more than 3,800 hectares, occupies a strategic position between the municipalities of Diass and Yenne. The site straddles the regions of Dakar and Thiès (at the heart of the Dakar-Thiès-Mbour triangle), 55 km east of Dakar, 20 km southeast of the Diamniadio Urban Center, and 25 km northwest of Mbour (14° 46' 58" N and 16° 54' 06" W). Beer (14.7828° N, 16.9017° W), located in the Niayes, is a small town in the Thiès region, 70 km east of Dakar Finally, Diender is a commune located about 30 km from the city of Thiès; it is part of the Keur Moussa district and covers an area of approximately 116.1 km² at 14° 47' 00" N, 17° 03' 00" W.

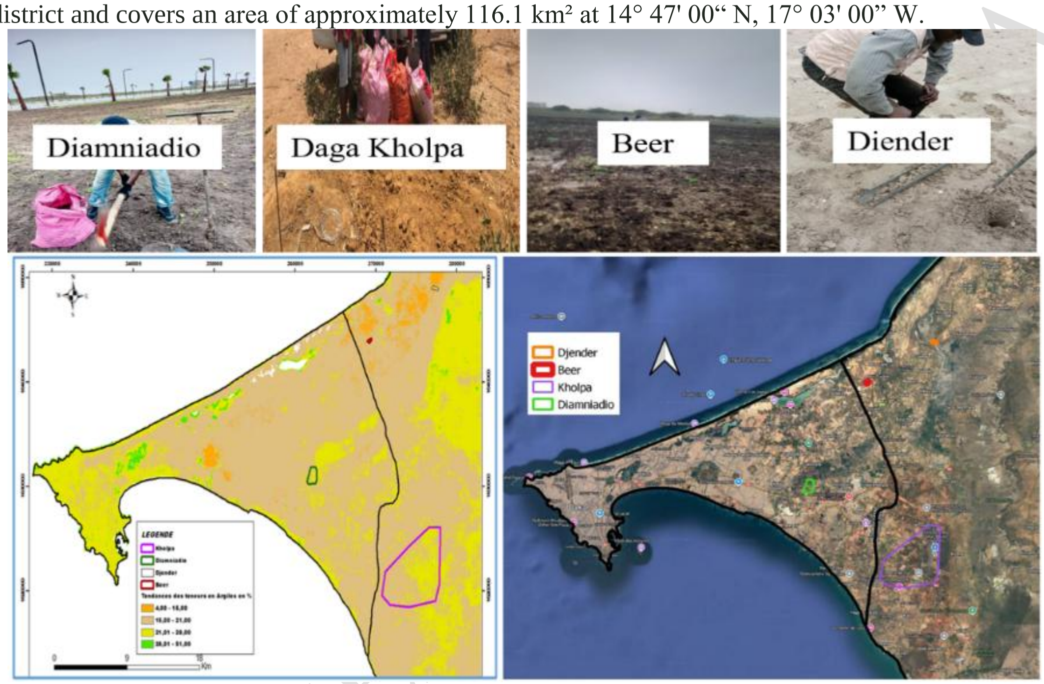


Fig.1:*Sample collection sites.*

2.2 Experimental methods

2.2.1 Geotechnical identification tests

The organic matter (OM) content of the soil was equal to the ratio of the difference between the initial mass of the sample (m) and the mass of the sample after reaction with hydrogen peroxide [14].
Particle size analysis was performed using two methods: the coarsest fraction (> 80 µm) was determined by wet sieving, and the finest fraction (< 80 µm) was determined by sedimentometry in accordance with standard NF P 94-057 [15].
The particle size distribution was determined in accordance with standard NF EN ISO 17892-4 [16].
The Atterberg limits were determined using a Casagrande apparatus in accordance with standard NF P 94-051 [17].
The quantity, activity, and swelling properties of the clay fraction contained in the material were evaluated using the methylene blue test in accordance with standard NF P 94-068[18].
The absolute and bulk densities were determined according to the standard NF P 18555 [19].
The oedometer test, which is used to determine the compressibility of a material, was conducted in accordance with standard XP P 94-090 [20].

2.2.2 Chemical and mineralogical analyses

The chemical composition was determined by extrapolation using regression lines for each element with an x-supreme8000 energy-dispersive X-ray fluorescence (XRF-ED) spectrometer. To determine the loss on ignition (LOI), the samples were calcined at 1000 °C.
Thermal Gravimetric analysis (TGA) was performed using a SETSYS Evolution SETARAM-1750 instrument. The test involved measuring the mass change of each sample heated to 1000 °C at a rate of 10°C/min in a nitrogen atmosphere with a purge flow rate of 20 ml/min.
The infrared spectra were recorded using an ALPHA II FTIR spectrometer over a range of 400–4000 cm^{-1}.
The mineralogical compositions of the samples were determined using X-ray diffraction. This technique allows for the identification of the crystalline minerals that constitute the sample. The instrument used was a BRUCKER D2 PHASER diffractometer. Determining the proportions of the minerals will be facilitated by semi-quantitative analysis of the mineral phases using the relationship proposed by Yvon et al. [21], taken over by Sore [22] and Nshimiyimana et al. [6]. Prior to testing, the samples were ground and sieved using an 80 µm sieve.

$$T(a) = \sum Mi\ Pi(a)$$

With
T(a): content (in % oxide) of a chemical element « a »
Mi: percentage (%) of mineral « i »in the sample under study that contains element «i»
Pi(a): proportion of the element « a » in the mineral « i ».

3. Results and Discussion

3.1 Geotechnical properties

3.1.1 Organic matter (OM) content

Table 1: The organic matter content of the samples.

Samples	Dry mass before testing (g)	Dry mass after testing (g)	Organic matter content (%)
Diamniadio	143.13	140.90	1.56
Daga Kholpa	172.95	172.20	0.43
Beer	158.91	150.68	5.18
Diender	172.91	169.25	2.11

Table 1 shows the organic matter content of the samples collected from the four sites. The results indicate that the samples from Diamniadio, Daga Kholpa, and Diender have organic matter contents of less than 3%. According to Bodian et al. [14], these soils are classified as mineral soils, for which the influence of organic matter on geotechnical properties is negligible. In contrast, the beer sample, with an organic matter content of 5.18%, falls into the category of mineral soils with organic matter, according to Masi et al. [23]. Thus, except for the Beer sample, the negative effects of organic matter on brick-making processes (whether stabilized or not) were negligible.

3.1.2 Particle size analysis

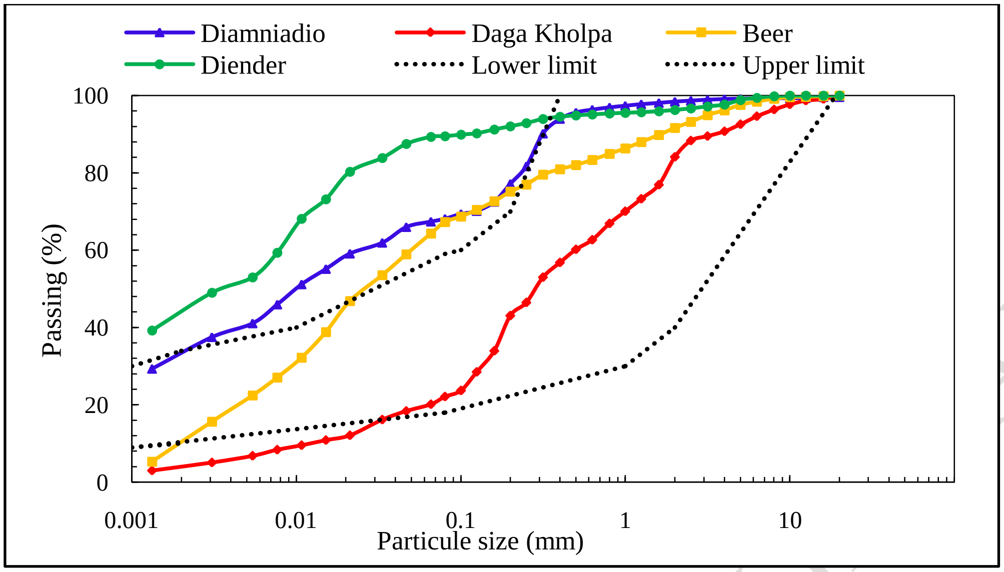


Fig.2*: Particle size distributions of the clay soils studied*

The particle size distributions of the clays are shown in Figure 2. The following information can be obtained from these curves. Variations in the shape of the curves depending on the location of each sample. The particle size distribution curves for Diamniadio and Diender do not fall perfectly within the limits recommended by CRATerre to produce stabilized bituminous concrete [5]. The Daga Kholpa and Beer curves, on the other hand, extend slightly downward in the case of Daga and toward the middle in the case of Beer. However, these limits primarily serve as guidelines and are not necessarily intended to be strictly adhered to by soil materials [5].

Table 2 explicitly illustrating the distribution of granular particles, which are subdivided into coarse particles (diameter > 2 mm), sand (diameter between 63 and 2 mm), silt (diameter between 2 and 63 µm), and clay (diameter < 2 µm). Overall, the samples from Diamniadio and Diender consisted mainly of clay, those from Beer of silt, and those from Daga Kholpa of sand.

Table 2: Particle size distribution of our samples.

Samples	Clay	Limon	Sand	Gravel	Nature
	< 2µm	2-63 µm	63-2mm	>2mm	
Diamniadio	33.4	34.1	31.1	1.4	Clay-loam
Daga Kholpa	3.7	16.1	64.9	15.3	Sandy-loam
Beer	10.4	53.6	28.2	7.8	Sandy-loam
Diender	44.5	44.9	7.1	3.5	Clay-loam

3.1.3 Atterberg Limits

Table 3: Atterberg limit for the four samples

Samples	W_L (%)	W_P (%)	I_P (%)
Diamniadio	65.3 ± 3,8	29.4 ± 1,6	35.9 ± 0,02
Daga Kholpa	24.8 ± 1	15.7 ± 0,4	9.1 ± 0,003
Beer	77.2 ± 3	64.5 ± 12	12.8 ± 0,07
Diender	92.0 ± 4,1	31.9 ± 1	60.1 ± 0,02

The results of the limits for our samples are presented in Table 3. These results clearly distinguish between the different samples. Diender (60.1 %) and Diamniadio (35.9 %) exhibited high plasticity indices, characteristic of soils ranging from highly plastic to plastic according to the geotechnical classification. In contrast, Daga-Kholpa (9.1 %) and Beer (12.8 %) were respectively classified as weakly and moderately plastic. These results are consistent with those of the particle size analysis presented in Table 2 and Figure 2. Indeed, Diender and Diamniadio, which have the highest clay content (< 2 µm) at 44.5% and 33.4 %, respectively, logically exhibit the highest PI values. Conversely, Daga Kholpa, dominated by sand (64.9 %), showed a very low IP, whereas Beer, which is predominantly loamy (53.6 %), exhibited moderate plasticity. This correlation between the clay fraction and plasticity index is commonly observed in the scientific literature [6,14, 24].

The relationship between the plasticity index (PI) and liquid limit (LL) is shown in Figure 3.

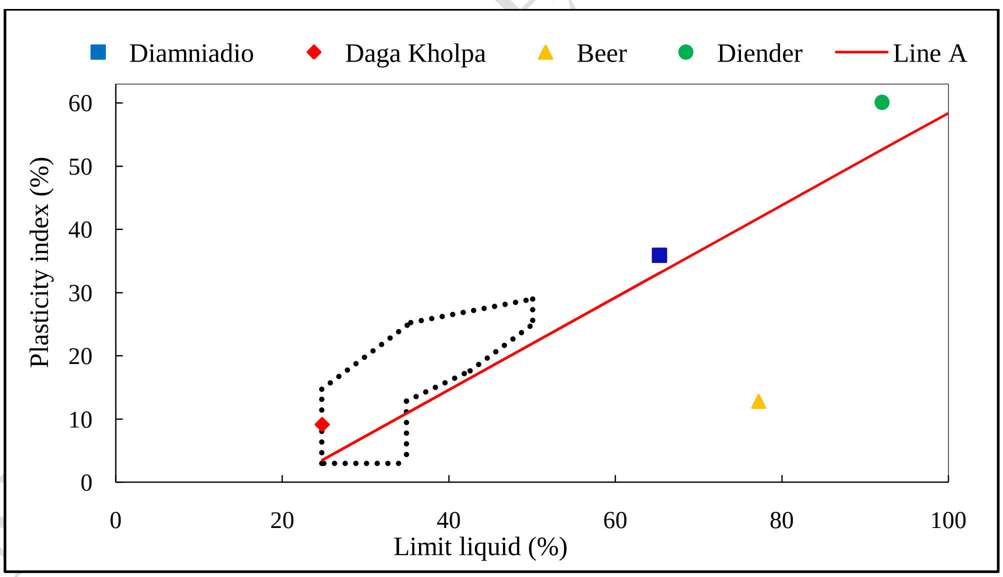


Fig.3*: Plasticity diagram for the clays studied, compared to the recommendation for CEBsaccording to XP P 13-901 [25].*

Analysis of the plasticity diagram shows that only the Daga Kholpa sample (PI = 9.1%, LL = 24.8 %) exhibited characteristics close to the range recommended for the manufacture of rammed earth bricks [25]. Therefore, it is more suitable to produce an unstabilized BTC. The other samples, particularly those from Diender and Diamniadio, which fall above Casagrande's Line A exhibit high plasticity index (60.1 % and 35.9 %) associated with high liquidity limits (92.0 % and 65.3 %), respectively, indicating a strongly clayey behavior. Therefore, these soils require stabilization treatments (addition of mineral binders) to improve their suitability for producing CEB.

3.1.4 Methylene blue value

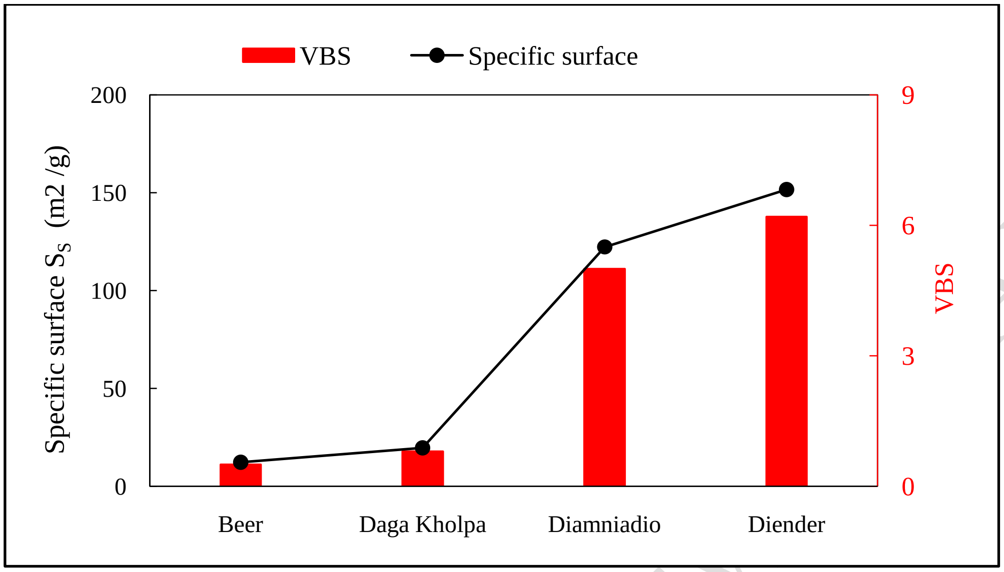


***Fig.4**: Variation in VBS and specific surface area as a function of sample location.*

The methylene blue values (VBS) and specific surface areas (S_S) of the four samples are presented in Figure 4. The results showed that the samples from Diender (VBS = 6.2 and SS = 151.70 m²/g) and Diamniadio (VBS = 5.0 and SS = 122.34 m²/g) had the highest values for these two indicators. However, Daga Kholpa and Beer exhibited significantly lower specific surface areas. These results are consistent with those of the particle size analysis (Table 2) and Atterberg limits (Table 3). Didier and Diamniadio, which have the highest clay content and IP values, exhibit the highest methylene blue consumption and largest specific surface areas. Daga and Beer, characterized by low clay content and moderate to low plasticity, showed much lower VBS and Ss values. The measured specific surface areas provide insights into the nature of the clay minerals present in the four samples. According to Santamarina et al. [26], the typical specific surface areas are approximately 10–20 m²/g for kaolinite, 80–150 m²/g for illite, and 500–800 m²/g for montmorillonite. Thus, the high values obtained for Diender (151.70 m²/g) and Diamniadio (122.23 m²/g) suggest the presence of illite or montmorillonite. In contrast, the low specific surface areas of Daga Kholpa (19.57 m²/g) and Beer (12.23 m²/g) may be characteristic of kaolinite-type clays. Taken together, these results can guide CEBproduction. The VBS is an indicator of the activity and swelling properties of the clay fraction [18]. According to CRATerre's recommendation [5] and focusing on the results in this paragraph, it can be seen that:

- Diender and Diamniadio have high VBS values, indicating an active clay fraction that requires stabilization with cement, lime, or a combination of both to control the shrinkage and swelling
- Daga Kholpa and Beer exhibited low VBS values, suggesting limited clay activity, which makes these soils suitable for use with reduced stabilizer addition or even without stabilization for non-structural applications.

3.1.5Absolute and apparent densities

Table 4: Variation in absolute and bulk densities as a function of sample location

Samples	Bulk density (ρ_{app} kg/m^3)	Absolute density (ρ_{abs} Kg/m^3)
Diamniadio	1099	2366
Daga Kholpa	1299	2604
Beer	662	1082
Diender	1024	2429

The absolute and bulk densities of the four samples are presented in Table 4. Regarding bulk density, the results show that Daga Kholpa has 1299 kg/m^3, compared to 1,099 kg/m^3 for Diamniadio, 1,024 kg/m^3 for Diender, and 662 kg/m^3 for Beer sample. This difference in bulk density may be due to the organic matter content and the mineralogical composition of each sample. The particle size distribution shown in Table 2 indicates that the Daga Kholpa sample contained 80.2 % coarse and sandy particles, compared to 32.5 %, 36 %, and 10.6 % for Diamniadio, Beer, and Diender, respectively. This indicates that the bricks produced from the Daga Kholpa sample will be denser than those produced from the other samples.

The weight of the solid grains is expressed by the absolute density. Weobserved the same trend in variation, namely that the grains from Daga Kholpa weighed more than the other grains. Wenote 2604 kg/m³ compared to 2366 kg/m³ for Diamniadio, 2429 kg/m³ for Diender, and 1082 kg/m³ for Beer.

3.1.6 Compressibility

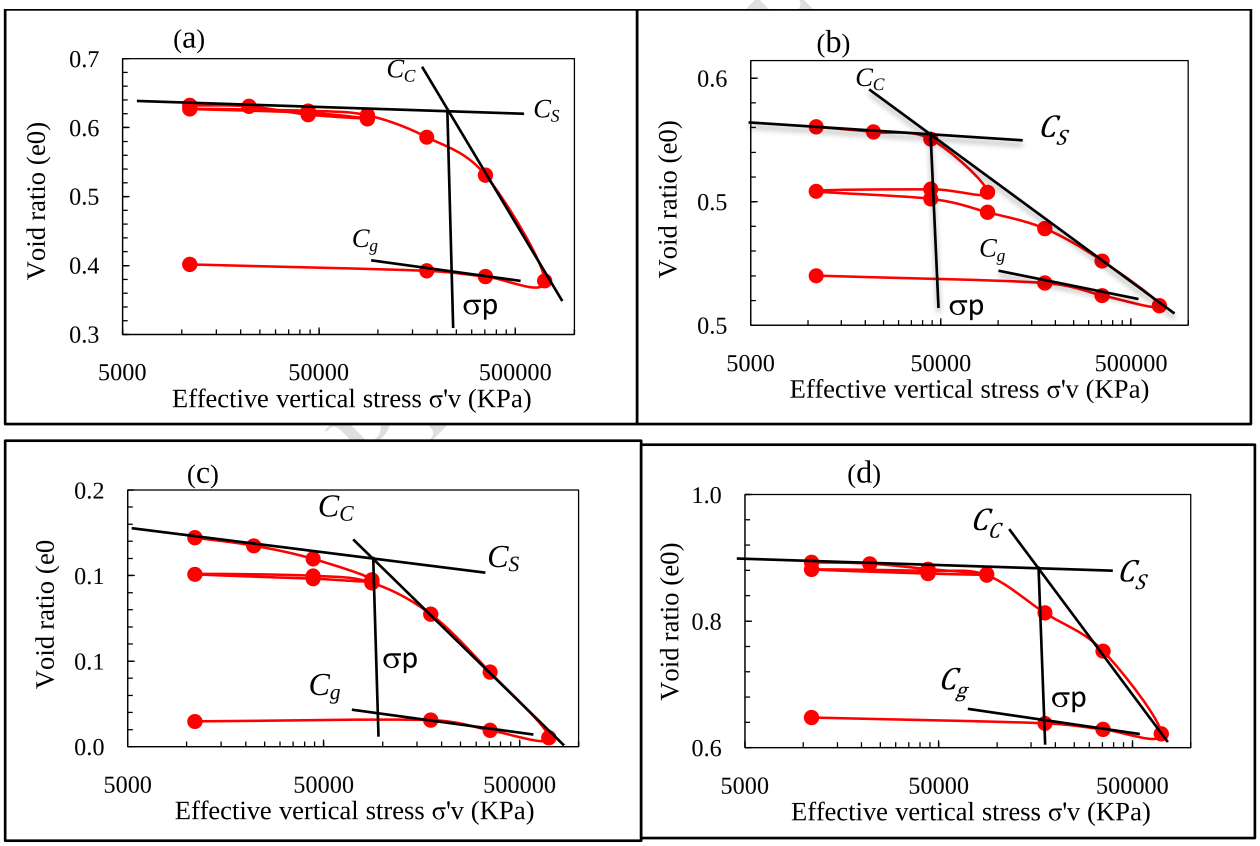


Fig.5*: Compressibility curves for the samples studied: (a) Diamniadio, (b) Daga Kholpa, (c) Beer, and (d) Diender.*

The compressibility characteristics of the four samples are illustrated by the curves in Figure 5 and are summarized in Table 5.The main determined were parameters such as the void ratio (e0), compression coefficient (Cc), decompression coefficient (Cs), consolidation coefficient (Cg), reconsolidation stress (σp), vertical stress (σv0), and oedometric modulus (Eoed) (Table 5).

Table 5: The compressibility characteristics of our four samples

Samples	COMPRESSIBILITY CHARACTERISTICS						
	e0	Cs	Cc	Cg	Eoed	σp (Pa)	σv0(Pa)
Diamniadio	0.582	0.004	0.509	0.028	6521413.2	2400000	0.870
Daga Kholpa	0.563	0.010	0.085	0.023	138838.91	50000	0.927
Beer	0.154	0.015	0.127	0.020	4493542	600000	0.697
Diender	0.893	0.006	0.437	0.033	2861218.8	1350000	0.763

These results show a notable difference between the four samples studied. Diamniadio and Diender have the highest Cc values, 0.509 and 0.437, respectively, indicating the high compressibility characteristics of plastic clay soils. In contrast, Daga Kholpa (Cc = 0.085) and Beer (Cc = 0.127) exhibited much lower compression coefficients, characteristic of sandy and silty materials with low compressibility, consistent with their low clay content (Table 2) and moderate-to-low plasticity (Table 3). The initial porosity index (e0) confirmed this distinction. Diender (0.893) and Diamniadio (0.582) had the highest values, reflecting a looser structure typical of clayey materials, whereas Beer (0.154) had a very low porosity index, characteristic of a more compact material. The oedometric modulus, which represents the stiffness of the material under load, was particularly high for Diamniadio (6.52 MPa) and Beer (4.49 MPa), indicating higher resistance to deformation under load. This is advantageous for CEB applications. According to the literature [27,28], the values of the compression coefficients (Cc) can be linked to the nature of the clay minerals present in the samples. Thus, the high Cc values obtained for Diamniadio and Diender suggest an active clay fraction, potentially composed of illite and montmorillonite in Diamniadio and illite and kaolinite in Diender. Conversely, the low Cc values for Daga Kholpa and Beer are typical of kaolinite-dominated materials.

3.2 Chemical composition

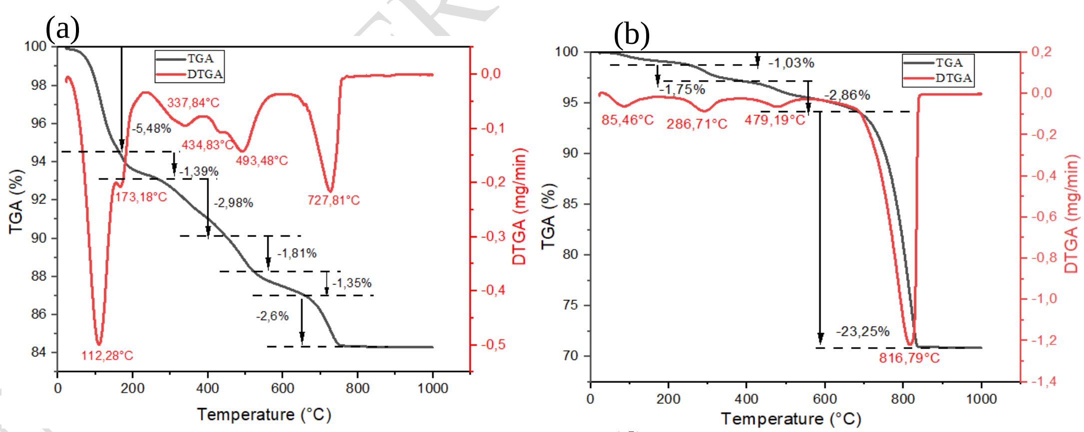
Table 6: Chemical composition of clays.

Oxides (%)	**Samples**			
	Diamniadio	**Daga Kholpa**	**Beer**	**Diender**
SiO_2	58.06	23.50	58.75	27.15
Al_2O_3	12.64	6.64	12.83	6.20
Fe_2O_3	6.79	7.78	4.4	4.86
TiO_2	0.76	0.61	0.74	0.55
CaO	6.94	36.43	0.50	23.84
MgO	2.60	0.65	0.83	6.06
SO_3	0.15	0.10	2.10	3.18
K_2O	0.42	0.31	1.21	0.77
Na_2O	0.16	0.13	0.33	2.66
PF	11.44	23.81	17.69	24.71
Total	100	100	100	100
SiO_2/ Al_2O_3	4.59	3.53	4.57	4.37
SiO_2+Al_2O_3+Fe_2O_3	77.50	37.93	76.54	38.21

The mass percentages of oxides in different clay materials are presented in Table 6. The chemical compositions of the samples, expressed as the mass percentages of their oxides, are presented in Table 6. Chemical analysis showed that the four samples were primarily composed of silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO). A note is made regarding the Diender sample; except for potassium oxide (K_2O) and titanium oxide (TiO_2), all other oxides present were significant.
The samples from Diamniadio and Beer were characterized by a high silica content (SiO_2 > 58 %) compared to the Daga Kholpa and Diender samples (23 % and 27 %, respectively). This high silica content in Diamniadio and Beer samples could indicate a high presence of quartz [14]. The sum of SiO_2, Al_2O_3, and Fe_2O_3 for the Diamniadio and Beer samples was >70 %, which is consistent with recommendations for stabilized CEBs [6,29].
The silica-alumina combination promotes the formation of calcium silicate hydrates (CSH) and calcium aluminate hydrates (CAH) during chemical stabilization with cementitious binders. The SiO_2/Al_2O_3 ratios (4.59 for Diamniadio, 3.53 for Daga Kholpa, 4.57 for Beer, and 4.37 for Diender) were similar, indicating a significant kaolinite content [14].
The high CaO content indicates the presence of either calcite ($CaCO_3$) or limestone. This means that the Daga Kholpa and Diender samples, which contain significant proportions of CaO (36.45 % and 23.84 %, respectively), with a particularly high concentration in the Daga Kholpa sample, where CaO is the main component, are rich in calcite.
The overall composition of the other oxides (TiO_2, MgO, SO_3, K_2O, and Na_2O) was 4.09 %, 1.8 %, 5.21 %, and 13.22 %, respectively, indicating that the samples were not pure clays. [30,31]. Given the MgO (2.60–6.06 %) and Na_2O (0.13–2.66 %) contents in some samples, the presence of minerals such as dolomite or feldspar can be inferred. The loss on ignition measured at 1000°C was particularly high for Diender (24.71 %) and Daga Kholpa (23.81 %). This may be related to the carbonate and/or clay mineral.
The chemical composition of the samples determined can guide the choice of stabilizer to produce stabilized clay-based concrete using these soil samples. The high proportions of silica and alumina in the Diamniadio and Beer samples suggest cement stabilization. In contrast, samples rich in carbonates (Daga Kholpa and Diender) can be stabilized with lime.

3.4 Mineralogical composition

3.3 Thermal Gravimetric Analysis (TGA)



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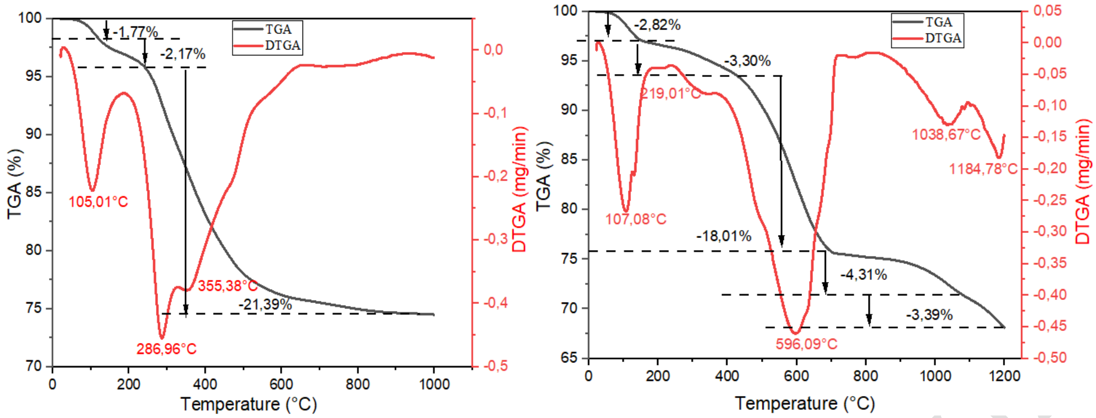

Fi***g.6:*** Thermogravimetric (TGA) and differential thermogravimetric (DTGA) curves for the clays studied: (a) Diamniadio, (b) Daga Kholpa, (c) Beer, and (d) Diender.

The TGA/DTGA curves for the samples are shown in Figure 6. The thermograms revealed several endothermic peaks, whose positions and intensities varied among the samples. This reflects the mineralogical diversity of the samples. In the DTGA curves, four significant endothermic peaks appeared for each sample, except for the beer sample.

The first peak (≈100 °C) corresponds to the removal of free water and intercellular water. The associated mass losses were 5.48 % (Diamniadio), 1.03 % (Daga Kholpa), 1.77 % (Beer), and 2.82 % (Diender). Diamniadio stands out due to its greater mass loss, indicating a higher affinity for water. This could be related to its larger specific surface area and marked plasticity.

The second peak, which appeared at a temperature of approximately 337 °C for the Diamniadio clay, 286 °C for Daga Kholpa clay, 286 °C for Beer clay, and 219 °C for Diender clay, was due to the dehydroxylation reaction of aluminum and iron hydroxides. At these temperatures, the mass losses were 2.98 %, 1.75 %, 2.17 %, and 2.55 %, respectively.

The endothermic peaks, which occur in the range of 355 °C to 596 °C for the four samples (434 °C for Diamniadio, 479 °C for Daga Kholpa, 355 °C for Beer, and 596 °C for Diender), are due to the loss reaction of kaolinite hydroxide. Within this temperature range, the Beer clay exhibited the highest mass loss (21.39 %). This may be because Beer clay contains the highest proportion of kaolinite.

Finally, the peak (> 600 °C), which is absent for Beer, low for Diamniadio (2.6 % loss), but very high for Daga Kholpa (23.25 %) and Diender (4.31 %), confirming the abundant presence of calcite and/or dolomite, suggested in XRF.

Based on these results, it can be concluded that carbonate-rich materials (Daga Kholpa and Diender) may require special attention during the drying of CEBs to prevent shrinkage-related cracking [5,32, 33].

3.4.1 X-ray diffraction (XRD)

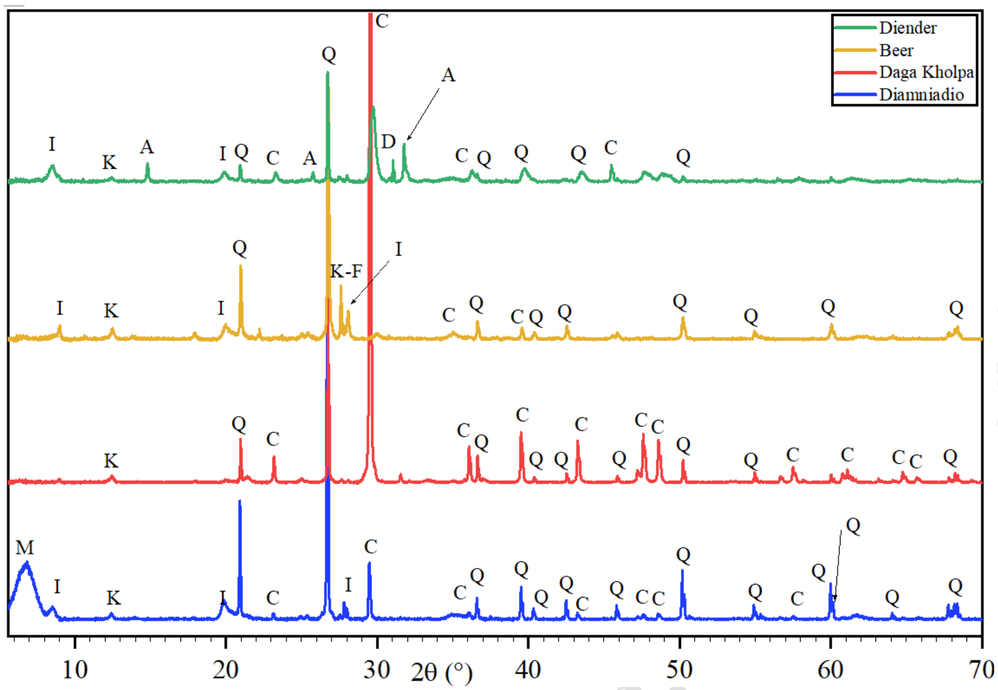

Fig.7: *X-ray diffraction patterns of the four clays studied, with C: Calcite, Q: Quartz, M: Montmorillonite, K: Kaolinite, I: Illite, A: Anhydrite, D: Dolomite, and kF: k-Feldspar.*

Table 7**:** Mineralogical composition of the four clays.

Minerals / Samples	Kaolinite (%)	Illite (%)	Montmorillonite (%)	Quartz (%)	Calcite (%)	Dolomite (%)	K-feldspath (%)	Anhydride (%)
Diamniadio	11.74	3.56	28.73	31.49	12.39	//	//	//
Daga Kholpa	16.80	//	//	15.69	65.05	//	//	//
Beer	19.17	10.25	//	40.57	0.89	//	7.16	//
Diender	9.34	6.52	//	19.86	27.42	27.88	//	5.41

The mineralogical compositions of the various samples (Figure 7) and the relative proportions of the minerals obtained through semi-quantitative analysis (Table 7) are examined.

XRD analysis revealed that quartz and kaolinite were present in all samples. However, significant differences were observed among the samples.

Diamniadio contains a mixture of quartz, kaolinite, illite, montmorillonite, and calcite; the simultaneous presence of illite and montmorillonite which explains its high plasticity (PI = 35.9 %) and high specific surface area (122.34 m^2/g).

Daga Kholpa is dominated by calcite (65.05 %) with quartz and kaolinite. This highly carbonate-rich composition is consistent with the high CaO content (36.43 %) and low plasticity.

Beer: primarily quartz, kaolinite, illite, and potassium feldspar. Its low carbonate content (0.89 %) and the presence of feldspar confirm its detritalnature, consistent with its dominant silt fraction.

Diender has a complex mineralogy combining quartz, calcite, dolomite, illite, kaolinite, and anhydrite. The presence of dolomite and anhydrite, as well as the high carbonate content (CaO = 23.84 %), explains its very high plasticity (PI = 60.1 %).

3.4.2Infrared Spectroscopy (IR)

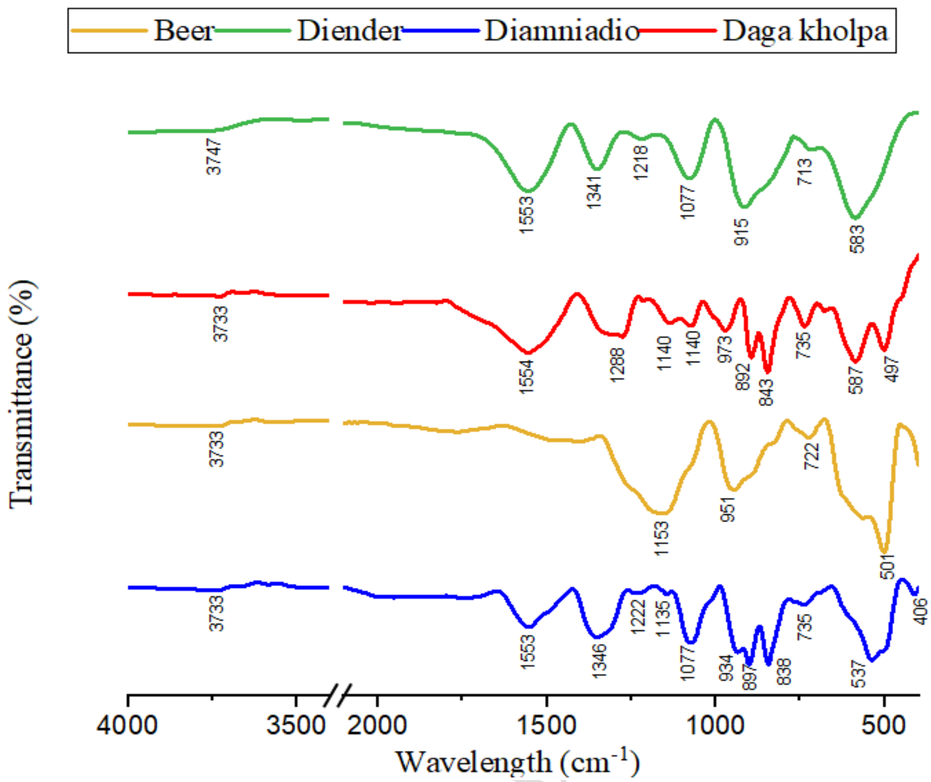

***Fig. 8**:FTIR infrared spectra of the clays studied in their raw state.*

The infrared spectra of the four clays are shown in Figure 8. Generally, the adsorption bands located around 3500 cm^{-1} correspond to the structural vibrations of hydroxyl groups characteristic of phyllosilicates [6,14]. The exact position of these bands and their intensities vary depending on the nature of the molecular bond. They appear closer for Diamniadio clay at approximately 3733 cm^{-1}, for Daga Kholpa clay at approximately 3733 cm^{-1}, for Beer clay at approximately 3733 cm^{-1}, and for Diender clay at approximately 3747 cm^{-1}. The bands appearing at approximately 1550 cm^{-1} correspond to the deformation vibrations of the OH group in the adsorbed water. For all four clays, weobserved significant absorption of radiation between 700 and 1200 cm^{-1}; this indicates the presence of Si-O and Al-O bonds, corresponding to the valence bond vibration in clays minerals.

4. Conclusion

This study examined the suitability of clay materials from four sites in Senegal, Diamniadio, Daga Kholpa, Beer, and Diender, for use as base materials in the production of compressed earth bricks (CEB). The main conclusions that can be drawn from this study are as follows:

Particle size analysis revealed a varied composition: clayey for Diender and Diamniadio (44.5 % and 33.4 %, respectively), silty for Beer (53.6 %), and sandy for Daga Kholpa (64.9 %). The Atterberg limits show that the high plasticity indices of Diamniadio (35.9 %) and Diender (60.1%) indicate marked plasticity, conferring strong cohesion, in contrast to those of Daga Kholpa and Beer (9.1 % and 12.8 %, respectively), which are classified as non-plastic and moderately plastic. X-ray fluorescence chemical analysis revealed the predominance of SiO_2, Al_2O_3, Fe_2O_3, and CaO, whereas TiO_2, MgO, SO_3, Na_2O, and K_2O were present only in small quantities. X-ray diffraction (XRD) revealed that the main constituents were quartz (31.49, 15.69, 40.57 and 19.86), calcite (12.39, 65.05, 0.89 and 27.42), kaolinite (11.74, 16.80, 19.17 and 9.34) and illite (3.56, 10.25 and 6.52) for Diamniadio, Daga Kholpa, Beer and Diender respectively. Depending on the sampling site, montmorillonite (28.73) was present at Diamniadio, K-feldspar (7.16) at Beer, and dolomite (27.88) and anhydrite (5.41) at Diender. These different results allow for the proposal of differentiated stabilization strategies: the most plastic clays (Diamniadio and Diender) can be stabilized with lime or a lime-cement mixture, while the less plastic ones (Daga Kholpa and Beer) are better stabilized with cement to produce CEB.

Funding Statement: The study was supported by the RESING project (Network for Training African Scientists in Engineering for Sustainable Industrial Development in Africa) and by Higher Polytechnic School of Cheikh Anta Diop University of Dakar- Senegal (FIRST project).

Data Availability Statement: The authors confirm that the data that supports the f indings of this study are available within the article. Raw data that support the finding of this study are available from the corresponding author, upon reasonable request.

Conflict of Interest declaration: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Contributions:Maguette Dème: drafting of the first draft, methodology, data processing, formal analysis, research, writing, and proofreading. Philbert Nshimiyimana: conceptualization, methodology, formal analysis, revision, and editing. Ndeye Awa Séne: conceptualization, formal analysis, fundraising, project management, resources, revision, and editing. Adamah Messan: conceptualization, supervision, methodology, formal analysis, revision, and editing.

Acknowledgment: We would like to extend our heartfelt thanks to the Water, Energy, Environment, and Industrial Processes (LE3PI) at the Higher Polytechnic School of Dakar, as well as the Eco-Materials and Sustainable Housing Laboratory (LEMHaD) at the International Institute for Water and Environmental Engineering (Institut 2iE) in Ouagadougou, for providing access to equipment and their support.

References

1. T. Ashour, H. Georg and W. Wu, « An experimental investigation on the use of straw–clay composite as a building material ». Construction and Building Materials, 2011, 25(3), 1414–1421.

2. A. Laborel-Préneron, J.E Aubert, C. Magniont, C. Tribout, and A. Bertron, « Plant aggregates and fibers in earth construction materials »: A review. Construction and Building Materials, 2018, 111, 719–734.

3. G. Minke. Building with Earth: Design and Technology of a Sustainable Architecture. Birkhäuser. 2012.

4. UN-Habitat. Going Green: A handbook of sustainable housing practices in developing countries. 2012.

5. H. Houben, H. Guillaud, « CRATerre: Traité de Construction en Terre: L’encyclopédie de la construction en terre », Vol. I, Editions Parathèses, Marseille, 2006.

6. P. Nshimiyimana, N. Fagel, A. Messan, D. O. Wetshondo and L. Courard, « Physico-chemical and mineralogical characterization of clay materials suitable for production of stabilized compressed earth blocks », Construction and Building Materials 241 (2020) 118097.

7. S. Bodian, M. Faye, N.A. Séne, V. Sambou, and Y. Dièye, « Physico-chemical characterization of clay raw materials from the Thicky quarry (Senegal) for the manufacture of earth bricks ». J. Sustain Const Mater Technol, Vol. 6, Issue. 3, pp. 87–94, 2021. Doi: 10.29187/jscmt.2021.64.

8. S. Bodian, M. Faye, I. Diaw, P.M. Touré, Y. Dièye and V. Sambou, « Hygroscopic characterization of earth bricks made from laterite and clay of Senegal ».Int. J. Adv. Res. 10(12), 48-62, 2022. DOI:10.21474/IJAR01/15807.

9. M. Wade, M. Thiam, M.P. Wane, and M. Ba, « Mechanical Characterization of Blocks of Compressed Earth: Comparative Study of Thicky and Sindia Laterites in the Region of Thiès, Senegal».Int. J. Curr. Res. Aca. Rev. 2024, 12(12): 62-69, Doi: https://doi.org/10.20546/ijcrar.2024.1212.008.

10. M. Séne, S. Bodian, N.A. Séne, A.O. Touré, I. Niang, A. Gaye, G. Thiam, E. Dieng, I. Diaw, A. Sakouvogui, T.N. Millomono, M. Faye and V. Sambou, « Thermomechanical Characterization of earth bricks made from excavated earth from Diamniadio in Senegal ». Open Journal of Civil Engineering, 2025, 15, 129-138. Doi: 10.4236/ojce.2025.152008 .

11. P. M. Touré, V. Sambou, M. Faye, A. Thiam, M. Adj and D. Azilinon, « Mechanical and hygrothermal properties of compressed stabilized earth bricks (CSEB) ». Journal of Building Engineering, 2017, 13, 266-271. http://dx.doi.org/10.1016/j.jobe.2017.08.012.

12.R. Abid, N. Kamoun, F. Jamoussi, H. El Feki, « Fabrication and properties of compressed earth brick from local Tunisian raw materials ». https://doi.org/10.1016/j.bsecv.2021.02.001.

13. J. T. Darman, J. H. K. Tchouata, G. F. N. Ngôn, F. Ngapgue, B. L. Ngakoupain, Y. T. Langollo, «Evaluation of lateritic soils of Mbé for use as compressed earth bricks (CEB) ». Helliyon 8 (2022) e10147. https://doi.org/10.1016/j.heliyon.2022.e10147.

14. S. Bodian, M. Faye, V. Sambou, N.A. Séne, I. Diaw et K. Faye, « Caractérisation physico-chimique des matières premières argileuses de la carrière de Thicky (Sénégal) pour la fabrication de briques en terre », J. P. Soaphys, Vol 3, N°1 (2021) C21A01.

15. NF P 94-057, «Sols: reconnaissance et essais Analyse granulométrique des sols- Méthode par sédimentation», AFNOR, Mai 1992.

16. NFENISO17892-4, « Geotechnical investigation and testing- Laboratory testing of soil- Part 4: Determination of particle size distribution », AFNOR, Saint-Denis La Plaine Cedex, 2018.

17. NF P 94-051, «Sols: reconnaissance et essais-Détermination des limites d'Atterberg-Limite de liquidité à la coupelle-Limite de plasticité au rouleau», AFNOR, Saint-Denis La Plaine Cedex, Mars 1993.

18. NF P 94-068, « Sols: Reconnaissance et essais; Mesure de la capacité d'adsorption de bleu de méthylène d'un sol ou d'un matériau rocheux», ARVOR Géotechnique, Octobre 1998.

19. A.M. Ba, S. Bodian, N.A. Séne, A.O. Touré, I. Niang, A. Gaye, G. Thiam, E. Dieng, M. Faye and V. Sambou, « Physical Characterization of Excavated Soils in Diamniadio-Senegal », Int. J. Adv. Res. 11(08), 745-750, August 2023.

20. XP P 94-090-1, « Sol: reconnaissance et essai; Essai de compressibilité sur matériaux fins quasi saturé avec chargement par paliers », AFNOR, Décembre 1997.

21. J. Yvon, O. Lietard, J.M. Cases et J.F. Delon, « Minéralogie des argiles kaoliniques des Charentes », Bull Minéralogie. 105 (1982) 431–437.

22. S.O. Sore, « Synthèse et caractérisation des liants géopolymères à base des matériaux locaux du Burkina Faso en vue d'une stabilisation des Briques en Terre Comprimées (BTC) »,Thèse de doctorat, Juillet 2017.

23. E.B. Masi, G. Bicocchi and F. Catani, « Soil organic matter relationships with the geotechnical-hydrological parameters, mineralogy and vegetation cover of hillslope deposits in Tuscany (Italy) », Bulletin of Engineering Geology and the Environment (2020) 79:4005–4020 https://doi.org/10.1007/s10064-020-01819-6.

24. H. Mahtali, « Identification du potentiel de gonflement d'un sol de la région de Souk-Ahras», Colloque International Sols Non Saturés et Environnement « UNSATlemcen09 » Tlemcen, 27 et 28 Octobre 2009.

25. XP P 13-901, Blocs de terre comprimée pour murs et cloisons, Définitions Spécifications-Méthodes d'essais-Conditions de réception, AFNor, Saint-Denis La Plaine Cedex, 2001.

26. J. Santamarina, K. Klein, Y. Wang and E. Prencke, «Specific surface: determination and relevance», Canada Geotechnique J., vol. 39, p. 233–241, 2002.

27. V. Elamathi and S. Jayalekshmi, « Effect of mineralogical composition and chemical properties on the consolidation behaviour of clay soils ». International Journal of Geotechnical Engineering, 2023, 17:7-10, 726-737, DOI: 10.1080/19386362.2023.2254135.

28. L. Ye, Y. F. Jin, Q. Y. Zhu and P. P. Sun, « Influence of Mineral Constituents on One-dimensional Compression Behaviour of Clayey Soils ». Geotechnical Engineering Journal of the SEAGS & AGSSEA Vol. 46 No.3 September 2015 ISSN 0046-5828.

29. A.L. Murmu, A. Patel, towards sustainable bricks production: An overview, Constr. Build. Mater. 165 (2018) 112–125, https://doi.org/10.1016/ j.conbuildmat.2018.01.038.

30. A. Qlihaa, S. Dhimni, F. Melrhaka, N. Hajjaji, A. Srhiri, « Physico-chemical characterization of a morrocan clay », J. Mater. Environ. Sci. 7 (5) (2016) 1741-1750 ISSN: 2028-2508 CODEN: JMESCN.

31. H. Sadki, K. Ziat, M. Saidi, « adsorption of dyes on activated local clay in aqueous solution) », Mater. Environ. Sci. 5 (S1) (2014) 2060-2065 ISSN: 2028-2508 CODEN: JMESCN MPE14.

32. B. Taallah, A. Guettala, « The mechanical and physical properties of compressed earth block stabilized with lime and filled with untreated and alkali-treated date palm fibers », J. Construction and Building Materials, 104 (2016) 52-62.

33. G. Minke, « Building with Earth: Design and Technology of a Sustainable Architecture ». Birkhäuser, 2012.