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EVALUATION OF THE POSSIBILITIES OF USING CLAY SOILS FOR THE REALIZATION OF VERNACULAR CONSTRUCTIONS

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Abstract

Since time immemorial, mankind has sought solutions to the problem of creating sustainable living spaces that provide thermal comfort and good indoor air quality. One of the most prevalent techniques has been the construction of buildings from clay-based materials. Nevertheless, even at the present time, this method is still insufficiently regulated by generalised regulations. The principal issue is the diversity of raw material characteristics, which necessitates a considerable number of preliminary tests and a lengthy period of time. This paper puts forward an interdisciplinary methodology for the analysis of clayey earth, with a view to determining the potential applications of this material in the production of adobe-brick masonry elements and plastering mortars for vernacular construction. The research methodology entailed a pedological analysis of 30 clay soil samples sourced from Mârgău and Ciucea region, Cluj, followed by an evaluation of their suitability for construction applications. The experimental findings have indicated the potential for establishing limiting conditions regarding the clay, sand, and dust content of the soils, in conjunction with pH, humus, and carbonate levels.

***Key words**: vernacular constructions; clay soil; pedological analysis; adobe-brick, plaster mortar*

INTRODUCTION

The construction sector is responsible for approximately 40% of global energy consumption, 40% of raw material usage, 50% of greenhouse gas emissions, and 60% of total waste generation, with only 20-30% of this waste being recycled (Măgurean & Petran, 2023; Papadaki et al., 2022; Asif et al., 2007; Santamouris et al., 2015; Papadaki et al., 2019; Mollaei et al., 2023; Munaro et al., 2020). This issue has been widely recognised on a global level, leading to an increased focus on identifying strategies to mitigate and reduce its adverse environmental impact (Androutsopoulos et al., 2020), a significant initiative in this regard being the European Green Deal (Ak et al., 2024; Montanarella & Panagos, 2021; Kotseva-Tikova & Dvorak, 2022).

Recent studies have increasingly concentrated on formulating solutions that support sustainability objectives in the construction industry. One such approach involves the resurgence of traditional construction practices, with a focus on the development and optimisation of clay-based building techniques to preserve their benefits while mitigating their limitations.

A substantial body of documenttation on this subject is available in the scientific literature. Evidence of the growing research interest in this field is illustrated by a query of the Web of Science Core Collection using the keyword "adobe brick", which yielded 518 publications, of which 39% were classified under Construction Building Technology, 38.8% under Civil Engineering, and 25% under Materials Science Multidisciplinary.

This distribution underscores the increasing emphasis on the development of environmentally sustainnable construction materials, with a notable surge in research publications after the year 2000 (Figure 1).

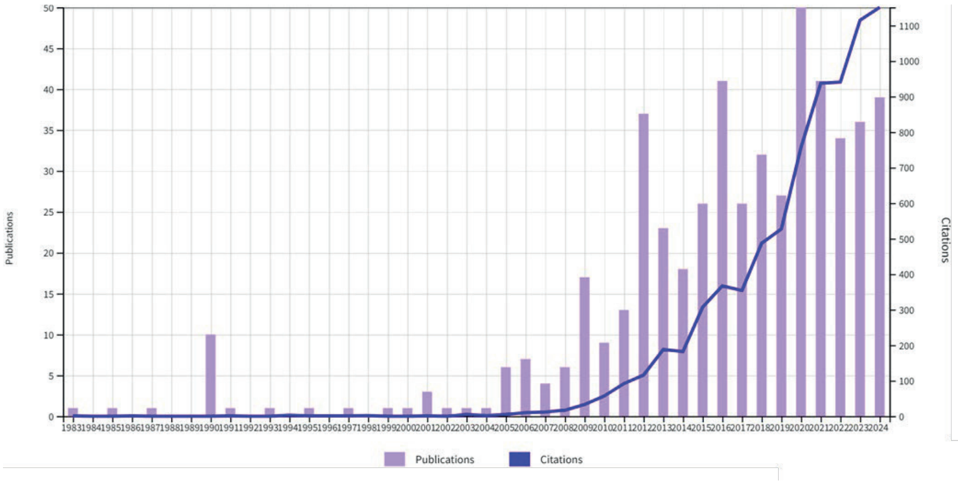


Figure 1. Evolution of publications and citations, according to WOS, of scholarly works identified using the keyword "adobe brick"

Notwithstanding the advantages inherent in unfired clay-based constructions, it is important to acknowledge their inherent limitations. Niroumand et al. (Niroumand et al., 2013) emphasise that one of the most critical drawbacks of earth-based structures is their inadequate mechanical strength, which hinders their utilisation to the same extent as conventional construction materials. However, contemporary research endeavours are actively addressing this limitation by enhancing the mechanical performance of these materials through the application of composite material principles. These advancements involve the incorporation of additive raw materials, such as lime, fly ash, bitumen, asphalt, or dispersed reinforcing fibres, to improve their structural integrity and durability.

Despite the fact that the field of earth-based construction remains a minimally regulated and standardised field, largely due to the high heterogeneity of its primary raw material, clay soil, a review of the scientific literature identifies several guiding principles that support its potential for sustainable building applications. The most notable regulatory frameworks include the German Earth Building Code, which was established in 1944 and laid the foundation for the development of DIN 18951. In addition, New Zealand has introduced relevant standards (NZS 4297:1998; NZS 4298:1998; NZS 4299:1998), and specific regulations exist in Australia, New Mexico and Zimbabwe. Furthermore, various guidelines, instructional documentation and specialised educational programmes have been developed, particularly within Europe, to promote and standardise earth-based construction practices (Pacheco-Torgal & Jalali, 2012). Therefore, given the existence of regional variations based on geographical location, several criteria have been established to determine the suitability of clay soil for the production of adobe bricks. The most fundamental requirements, irrespective of the geographical location of the experimental area, include the absence of organic matter (Pacheco-Torgal & Jalali, 2012) and the implementation of a sampling method that ensures soil collection from a minimum depth of 150 mm below the surface. This approach is designed to minimise the presence of organic residues, such as vegetal or animal matter (Giada et al., 2019). Furthermore, G. Minke advances the argument that a minimum sampling depth of 400 mm may be required to ensure the material's suitability for construction applications (Minke, 2005). From a chemical, oxide, and mineralogical composition standpoint, which are challenging to assess in the field without access to specialised laboratories, the scientific literature (Salih et al., 2020) highlights a predominance of silicon dioxide (SiO_2) in the range of 50-60%, followed by aluminium oxide (Al_2O_3) at approximately 10%. These elements contribute to the structural quality of adobe bricks. Additionally, the presence of ferric oxide

(Fe_2O_3), generally not exceeding 10%, is noted, with its hydrated form responsible for the characteristic brown-reddish soil colouration. However, ferric oxide has also been implicated in the development of efflorescence, which may have a detrimental effect on the material's durability and performance.

Limitation of the calcium oxide (CaO) concentration to a maximum of 10% is another critical aspect. When not chemically bound to SiO_2, CaO can have detrimental effects, including swelling in the presence of water and carbonation, which leads to the formation of $CaCO_3$, a compound characterised by low mechanical strength and reduced durability. In terms of granulometric composition, clay functions as the primary binding agent, while silt, sand, and aggregates act as fillers that influence the material's mechanical and structural properties. The scientific literature suggests that the aggregate fraction should not exceed 10% for particles larger than 2 mm, while the sand content should range between 40% and 80%, with particle sizes between 0.063 and 2 mm. Furthermore, the recommended silt content varies between 10% and 30%, with grain sizes between 0.002 and 0.063 mm, whereas the clay fraction typically ranges from 20% to 50% (grain sizes between 0.002-0.063 mm) (Salih et al., 2020; Giada et al.,2019). However, older references indicate that clay content should not fall below 15%, as it plays a crucial role in maintaining the structural integrity and cohesion of the material (Laaroussi et al., 2013; Boduroglu, 1989). From a mineralogical standpoint, the predominant minerals present in clay soils may be associated with a high silicon content or be characteristic of clay-rich compositions. The most commonly identified minerals include quartz, calcite, feldspars, illite, kaolinite, chlorite, smectite, and montmorillonite. The presence of calcite is often indicative of soil alkalinity (Dormohamadi & Rahimnia, 2020; Demir, 2008).

From a physico-mechanical perspective, the assurance of optimal thermal insulation and substantial thermal inertia - facilitating the accumulation of heat during warm periods and its subsequent release during colder seasons – necessitates that the bulk density of the mixture falls within the range of 1800-2000 kg/m³ (Burroughs, 2008). From a structural performance standpoint, the ASTM D1633-00 standard (New Mexico) stipulates a minimum compressive strength of 2.07 N/mm² for earthen wall materials. In a similar fashion, the Zimbabwean code for rammed earth walls establishes a minimum compressive strength of 1.5 N/mm² for single-story structures with 400 mm thick walls and 2.0 N/mm² for two-story buildings. In Australia, the relevant standard prescribes a minimum compressive strength of 1.15 N/mm², while the ASTM International E2392/E2392M-10e1-2010 standard mandates a threshold of 2.068 N/mm². Additionally, the ACI Materials Journal Committee has reported that compressive strength varies based on soil composition, with values ranging from 2.76 to 6.89 N/mm² for sandy soils and from 1.72 to 4.14 N/mm² for clay-rich soils. Moreover, the Peruvian Standard E.080 stipulates a minimum compressive strength of 1.2 N/mm² and a minimum tensile strength of 0.4 N/mm², thereby underscoring the heterogeneity of regulatory approaches to earthen construction materials (Pacheco-Torgal & Jalali, 2012; Vega et al., 2011).

During the preparation process, clay soil is typically mixed with water, thereby initiating the delamination of clay particles. Ensuring adequate plasticity and workability is crucial; however, it is important to recognize that an excessive water content increases the risk of cracking and significant axial shrinkage. Achieving crack-free final elements is imperative, and it is considered acceptable for bricks produced using soft mixture technologies to exhibit a linear shrinkage between 3% and 12%. Conversely, drier mixtures should exhibit a linear shrinkage ranging from 0.4% to 2% (Minke, 2005).

The physico-mechanical properties of clay-based materials vary significantly depending on the characteristics of the clay soil, the preparation and testing methods employed, and the type and proportion of additives incorporated. The scientific literature reports a wide range of values for these parameters, reflecting the diversity of experimental approaches1. Specifically, the compressive strength has been documented to range from 0.5 MPa to over 7 MPa (Dormohamadi & Rahimnia, 2020), while the flexural strength has been reported to vary between 0.25 MPa and 1.25

MPa (Dormohamadi & Rahimnia, 2020). Furthermore, Silveira et al. (Silveira et al., 2013) reported a tensile strength of 0.16 MPa for adobe bricks. The parameters under consideration – namely, particle size distribution, density, mixing water content, and consistency – are relatively straightforward to analyse and assess, particularly in situ, where access to a specialized laboratory for chemical and mineralogical analysis may be limited. However, for a comprehensive evaluation, it is essential to incorporate both physical and chemical testing methodologies to ensure a thorough characterization. The objective of this study was to assess, through chemical and pedological analysis, the potential suitability of clay soils from the Mârgău and Ciucea regions in Cluj County for the production of adobe masonry elements.

MATERIALS AND METHODS

The study aimed to assess the feasibility of rapidly determining the suitability of clay soils from the selected locations – Mârgău, Cluj County (46°44′35″N 22°57′51″E), and Ciucea, Cluj County (46°57′13″N 22°48′27″E) – for construction applications through chemical and pedological analysis methods was carried out by collecting soil samples at variable depths, up to a maximum of 1200 mm, using a transversal sampling method with a soil probe. The sampling process was carried out while maintaining the depth of the pedogenetic soil horizon in order to preserve the integrity of the analysed profiles. The soil sample batch was selected on the basis of pedological analysis requests submitted to OSPA (Office for Soil and Agrochemical Studies) by external clients, specifically landowners, in 2024. Each collected soil sample was assigned a unique identification code and subjected to pedological analysis under controlled laboratory conditions using standardized methods recognised in Romania. The analysis focused on key soil properties, including texture and skeletal fraction, clay content, sand content and granulometry, determined according to STAS 7184/10-79, pH value, determined according to the standardized method described in SR 7184-13:2001, humus concentration, determined according to STAS 7184/21-82, and $CaCO_3$ content determined according to the standardized method described in STAS 7184/16-80. 169 samples were collected from the Mârgău and Ciucea areas and coded as follows: M1–M114 for those collected from the Mârgău area, C1–C55 for those from the Ciucea area, and VD for the sample collected from Valea Drăganului.

In order to evaluate the potential applicability of the selected clay soils, a series of working hypotheses were formulated based on insights from the scientific literature (Figure 2). Following the pedological characterisation of the collected clay soil samples, a systematic multi-step selection process was implemented (Figure 3), wherein samples that did not meet the predefined criteria were excluded.

This methodological framework was applied to both the clay soil samples collected from the Mârgău area, Cluj County, and those from the Ciucea area, Cluj County. Subsequently, the selected soil samples were subjected to laboratory analysis in order to evaluate their physico-mechanical properties and to compare them with a reference set of indicators derived from specimens produced using clay soil collected from the Valea Drăganului area, Cluj County (46°54′10″N 22°49′53″E).

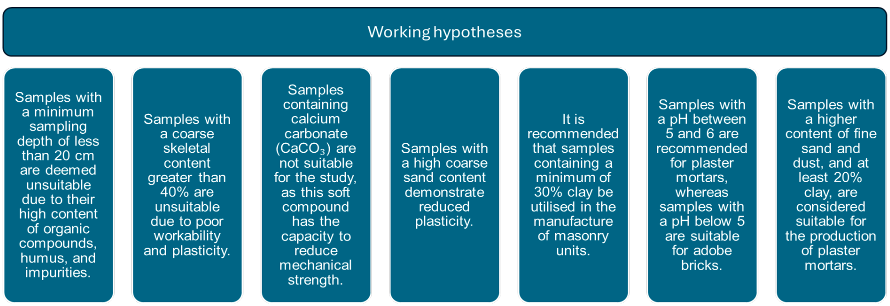


Figure 2. Working assumptions based on references found in the literature

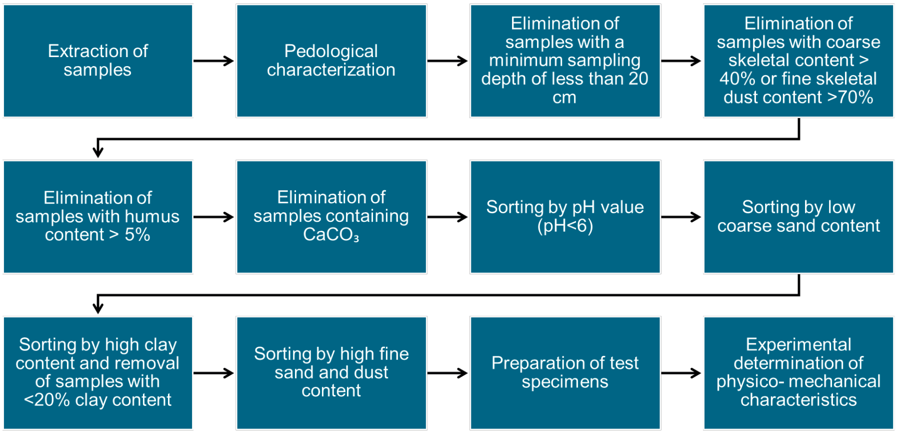


Figure 3. Clay soil sample selection scheme

The suitability of Valea Drăganului soil for adobe brick production had previously been established through experimental testing and documented findings in the scientific literature (Calatan et al., 2017; Hegy et al., 2016; Hegyi et al., 2023; Calatan et al., 2016; Călătan et al., 2020).

The present study therefore set out to validate the selection methodology applied through a comparative assessment of the soil samples.

The physico-mechanical performance of the specimens was assessed by the fabrication of prismatic specimens (40×40×160 mm) from each batch of collected and selected clay soil, as detailed below:

- the clay soil was mixed with a precise quantity of water in order to maintain consistent workability, as measured by a spread diameter of 95±5 mm;
- the freshly prepared clay-water mixture was subsequently introduced into metal moulds, with the internal dimensions of 40×40×160 mm;
- the moulded specimens were stored under controlled laboratory conditions at a temperature of 23 ± 2°C and a relative humidity of 65 ± 2% for a period of three days, after which they were demoulded for subsequent analysis;
- the clay-based specimens were then subjected to the same temperature and humidity conditions until they had attained a constant mass, which was considered an indicator of uniform drying;
- for each clay soil type selected for laboratory analysis, a set of three identical specimens was prepared to ensure the repeatability and reproducibility of the experimental results.

The physico-mechanical performance characterisation tests were conducted under controlled laboratory conditions using standardised methodologies. Thus, the analysis included the determination of apparent density in the hardened state, in accordance with EN 1015-10, and axial shrinkage, as specified by STAS 2634. Axial shrinkage represents the reduction in a material's length along its longitudinal axis during the processes of drying or curing, flexural tensile strength is defined as a material's resistance to bending stress before fracture, and compressive strength is represented as its ability to withstand axial loads without failure. Furthermore, flexural tensile strength and compressive strength were evaluated following the procedures outlined in EN 1015-11. The risk of cracking was monitored through visual examination throughout the conditioning and drying process in order to assess the material's structural integrity.

The experimental results were analysed comparatively, in relation to existing data reported in the scientific literature, as well as to the findings obtained for clay soil samples collected from the Valea Drăganului area (VD).

RESULTS AND DISCUSSIONS

In the course of the study, 114 soil samples were collected in the Mârgău area. Following the application of the sampling depth criteria, 52 samples were excluded. A similar process was followed in the Ciucea area, where 18 out of 55 samples were excluded after meeting the same selection criteria (Figure 4).

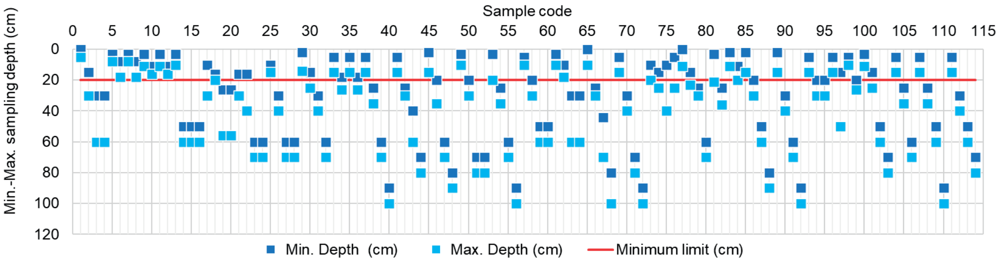
The experimental analysis of the soil texture from the predefined sampling locations revealed a wide distribution on the ternary diagram (Figure 5). As evidenced by the analysis, the soil samples from the Valea Drăganului area are classified within the L (loam) zone, having a medium-textured (M) profile.

In contrast, the soil samples collected from the Mârgău area displayed a heterogeneous distribution, with a predominant LP (loamy sand) texture, though some samples were also situated within adjacent zones, including S (sand), SS (sandy loam), SP (sandy clay loam), TP (clay loam), and AP (silty clay loam).

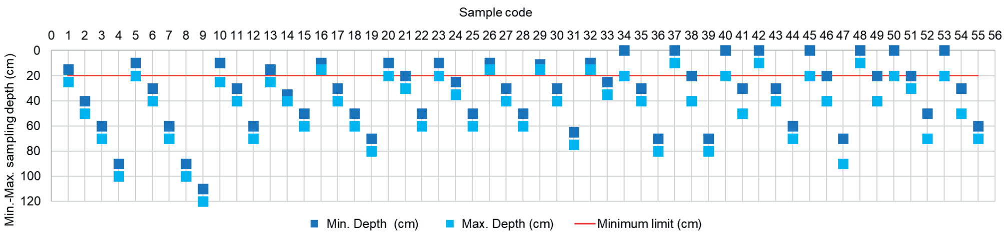
A similar distribution of soil samples was observed in the Ciucea area, with the majority of samples falling within the LP zone, and a smaller number positioned in the SS, SP, TP, and AP zones.

Following the selection process based on soil texture, an additional seven samples from the Mârgău batch were excluded due to their classification within the AP zone. Furthermore, ten additional samples were eliminated as they had a dust content exceeding 70%, coupled with a low clay content. Similarly, within the Ciucea batch, one additional sample (C9) was removed, as its fine particle composition rendered it more suitable for plaster mortar or finishing coat preparation rather than for adobe brick production.

Following the elimination of samples that did not meet the sampling depth criteria, the texture analysis of the remaining soil samples revealed the necessity for further exclusions. Specifically, additional samples (M14, M20, M52 from the Mârgău batch and C19, C43, C54 from the Ciucea batch) were excluded on the basis that their coarse skeletal content exceeded 40% (Figure 6).

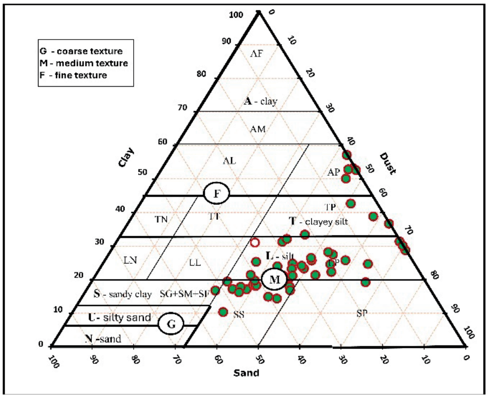


a)

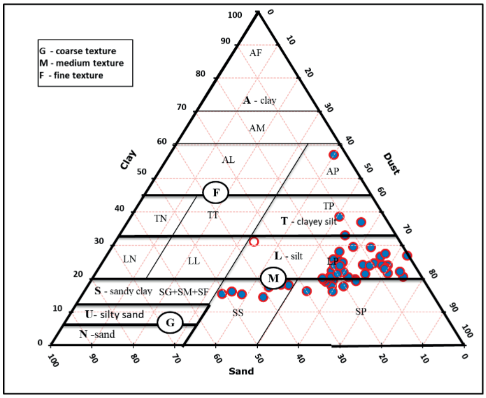


b)

Figure 4. Sampling depth for: a) samples taken from Mârgău area; b) samples taken from Ciucea area



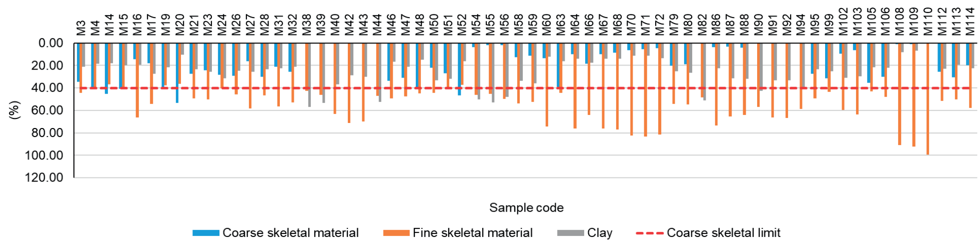
a) Texture of soil samples from Mârgău area (green) compared to soil samples from Valea Drăganului area (white)



b) Texture of the soil samples from Ciucea (blue) compared to the soil samples from Valea Drăganului (white)

Figure 5. A graphical comparison between the texture of the soils sampled for analysis and that of the soil sampled in Valea Drăganului locality

Note: Coarse Texture: N - Sand (NG - Coarse sand, NM – Medium sand, NF - Fine sand), U - Loamy sand (UG - Coarse loamy sand, UM - Medium loamy sand, UF - Fine loamy sand); Medium Texture: LN - Sandy-clayey loam, LL - Medium loam, L - Loam, LP - Silty loam, SG - Coarse sandy loam, SM - Medium sandy loam, SF - Fine sandy loam, SS - Silty sandy loam, SP - Silt; Fine Texture: AF - Fine clay, A - Clay, AM - Medium clay, AL - Loamy clay, AP = Silty clay, TN - Sandy clay, TT - Medium clayey loam, TP - Silty-clayey loam, T - Clayey loam (Ministerul Agriculturii, Academia de Științe Agricole și Silvice, ICPA, 1987)



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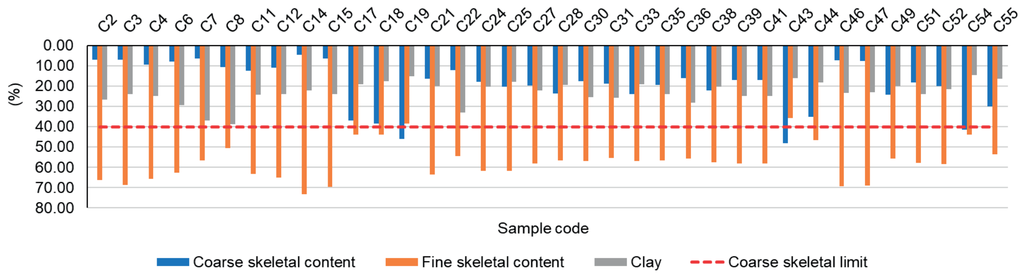

b)

Figure 6. Comparative soile texture analysis for: a) samples procured in the Mârgău area; b) samples procured in the Ciucea area

From a chemical analysis perspective, the experimental results indicated that the remaining soil samples from the Mârgău batch, after selection based on textural criteria, had a humus content ranging between 0% and 12.16% (Figure 7a). Moreover, a total of 12 samples were found to have CaCO3 concentrations ranging from 0.06% to 10.19%, which consequently prompted the exclusion of an additional 19 soil samples from the batch. Conversely, the Ciucea batch had a humus content ranging from 0% to 3.32%, with no detectable levels of $CaCO_3$ in any of the samples. Consequently, all soil samples from this batch were retained for subsequent analysis (Figure 7b).

The analysis of acidity revealed that the pH values of the Mârgău soil samples ranged between 4.12 and 6.73 (Figure 8a), while those of the Ciucea soil samples varied from 3.75 to 5.50 (Figure 8b). Following the analysis, the distribution of pH values exhibited by the clay soils under consideration enabled the grouping of the samples into three categories.:

I. soil samples with a pH greater than 6 – excluded at this stage of the analysis;

II. soil samples with a pH ranging between 5 and 6 – deemed suitable for use in plaster mortar production but not recommended for adobe brick manufacturing;

III. soil samples with a pH of 5 or lower – identified as being appropriate for adobe brick production.

Following this analysis, the Mârgău batch was reduced to 25 soil samples with a pH below 6, of which six samples had a pH ranging from 4.12 to 4.99 (≤5).

A similar reduction process was applied to the Ciucea batch, which was reduced to 21 soil samples, all with a pH between 3.75 and 4.99 (≤5).

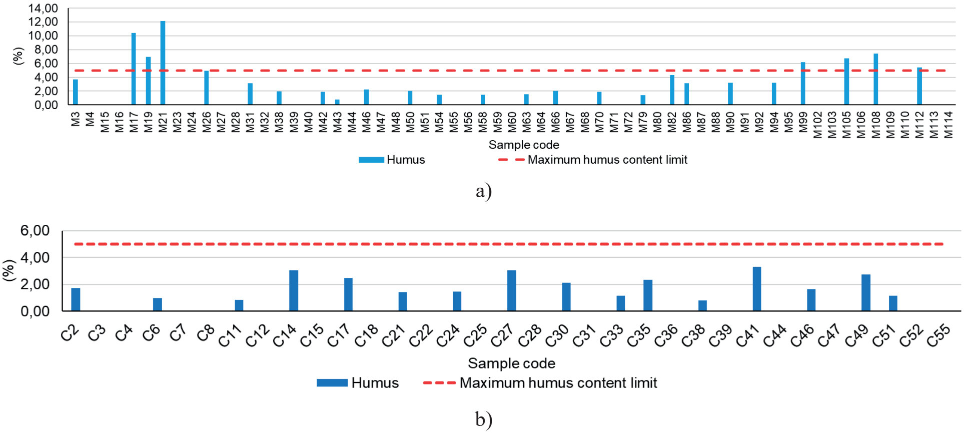

Figure 7. Comparative humus content analysis for: a) samples procured in the Mârgău area;
b) samples procured in the Ciucea area

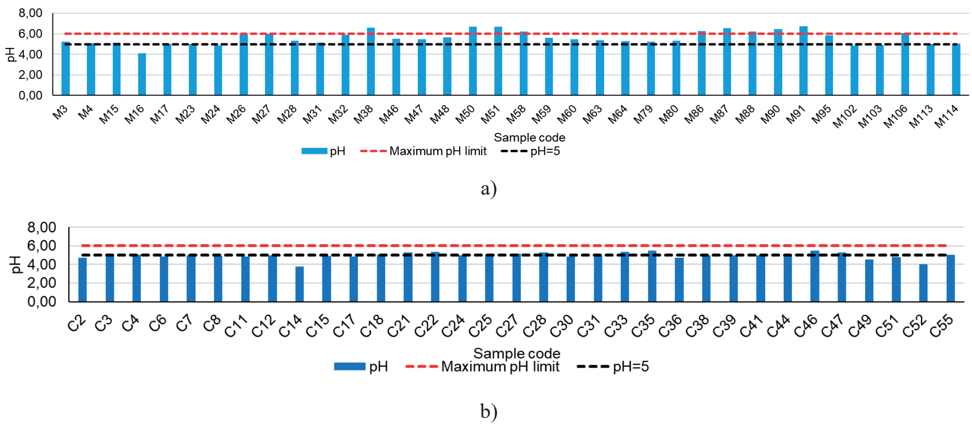

Figure 8. Comparative pH valuea analysis for: a) samples procured in the Mârgău area;
b) samples procured in the Ciucea area

A subsequent evaluation of the clay content and its proportional relationship to sand and silt, conducted as part of the selective elimination process, revealed that an additional nine samples from the Mârgău batch did not meet the established criteria. These samples (M16, M113, M4, M15, M64, M43, M60, M46, and M48) had clay content values ranging from 12.32% to 19.75%, rendering them unsuitable under the predetermined selection parameters.

A similar analysis of the Ciucea batch indicated that two of the remaining 21 samples had a clay content below 20% (C17: 19.05% and C44: 18.30%). As a result, these samples were excluded from further evaluation.

Following the selection process, 16 samples remained from the Mârgău batch. Of these, two samples (M24: 31.27% clay content, pH 4.87; M102: 30.8% clay content, pH 4.88) had a clay content exceeding 30% and a pH below 5, making them suitable for adobe brick production. The remaining 14 samples had clay contents ranging from 20 to 30%, with fine sand content exceeding 40%, making them more appropriate for plaster mortar and finishing coat applications (Figure 9a). Of particular note were samples M102 and M103, which had a coarse sand content below 10% (9.48% and 6.58%, respectively). Of additional significance is the observation that sample M102, in addition to having a pH below 5, also had a clay content in excess of 30%, thus rendering it suitable for utilisation in adobe brick production. Similarly, sample M103 had a clay content close to 30% (29.70%) and a pH below 5, which also suggested its suitability for adobe brick manufacturing.

Of the 19 remaining samples from the Ciucea batch, two samples (C8: 38.7% clay content; C7: 37.05% clay content) had a clay content of at least 30%, rendering them suitable for adobe brick production (Figure 9). Among the remaining 17 samples, which contained 20–30% clay, all had a fine sand content exceeding 50%, suggesting their compatibility for use in plaster mortar and finishing coat production (Figure 10). However, particular attention is drawn to samples C2, C3, C6, C7, C14, and C15, which were characterized by a coarse sand content ranging from 4.51% to 7.86%, with sample C14 having the lowest coarse sand content at 4.51%. Moreover, sample C7 is noteworthy for its low coarse sand content (6.44%), high fine sand content (56.51%), and clay content exceeding 30% (37.05%). These characteristics suggest that this clay soil has the potential to be utilised for the manufacturing of adobe bricks and plaster mortar.

Following the stepwise selection process, the soil samples selected for further investigation and physico-mechanical performance analysis were as follows: from the Mârgău batch: M24 (31.27% clay, 28.51% coarse sand), M102 (30.8% clay, 9.48% coarse sand), and M103 (29.7% clay, 6.58% coarse sand) and from the Ciucea batch: C7 (37.05% clay, 6.44% coarse sand) and C8 (38.7% clay, 10.82% coarse sand). The selection of these samples was based on their compositional properties, ensuring their suitability for subsequent experimental analyses. In consideration of the findings presented, and given the number of soil samples collected from a minimum depth of 20 cm at each location (62 samples from the Mârgău batch and 37 samples from the Ciucea batch), as well as the fact that, following the selection process, it was found that only three samples from Mârgău and two samples from Ciucea met the predefined criteria for adobe brick production. This indicates that the Ciucea area exhibits slightly greater potential than the Mârgău area in terms of identifying clay soils with properties that are compatible with the intended application. A subsequent investigation into the properties of the sample batch, with a focus on its compatibility with plaster mortars, fine plasters, and finishing coats, revealed that the 15 selected samples from the Ciucea batch exhibited higher compatibility with these applications when compared to the 14 samples selected from the Mârgău batch, indicating a potentially superior performance in these specific contexts.

The experimental results of the physico-mechanical tests conducted on prismatic specimens, produced by casting the selected soil samples, demonstrated that, in terms of apparent density (Figure 11), the recorded values were higher than those observed for the reference sample from Valea Drăganului.

In addition, these values correspond to the optimal range suggested in the scientific literature (1800-2000 kg/m³) to ensure adequate thermal inertia (Burroughs, 2008).

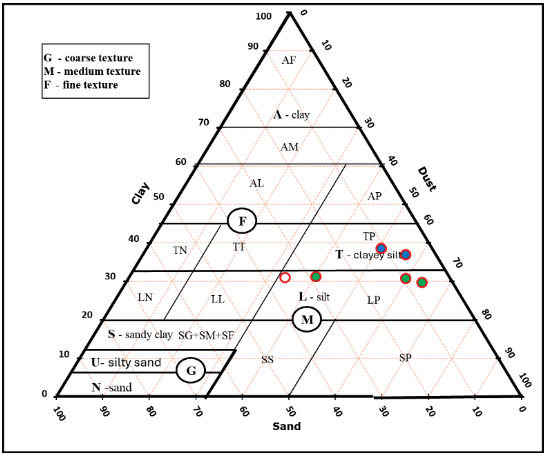

Figure 9. Humus content for: a) samples collected from Mârgău area; b) samples collected from Ciucea area

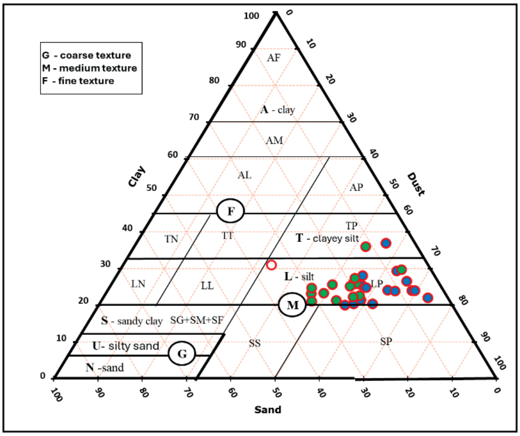

Figure 10. Texture of the soils sampled for analysis, selected for the realization of mortars for plastering, tinctures or plasters, Mârgău (green), Ciucea (blue), compared with the texture of the soil sampled in Valea Drăganului

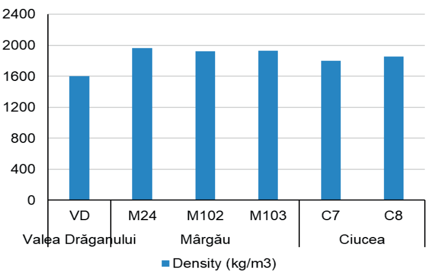

Figure 11. Graphical representation of the apparent density for a reference sample from Valea Drăganului, compared to samples M24, M102, and M103 (from Mârgău), and samples C7 and C 8 (from Ciucea)

With regard to axial shrinkage, the selected clay soil samples exhibited values within the recommended range of 3-12%, as documented in the scientific literature (Minke, 2005) (Figure 12). However, it was observed that sample M102 exceeded the upper limit of this range by 15%, suggesting an increased susceptibility to cracking during the drying process. In order to mitigate this risk, the scientific literature indicates that various additive materials, such as bone glue, salt (NaCl), or vegetable oils, may be employed to improve the material's dimensional stability.

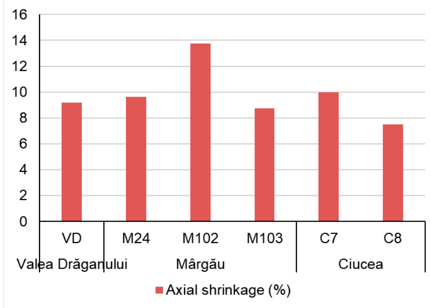

Figure 12. Graphical representation of the axial shrinkage for a reference sample from Valea Drăganului, compared to samples M24, M102, and M103 (from Mârgău), and samples C7 and C 8 (from Ciucea)

The analysis of mechanical strength under compressive and flexural tensile stresses indicates that the performance of the selected clay soil samples is comparable in magnitude to that of the reference sample from Valea Drăganului (Figure 13). Considering the previous experimental studies conducted on clay soil from Valea Drăganului (Calatan et al., 2017; Hegyi et al., 2016; Hegyi et al., 2023; Calatan et al., 2016; Călătan et al., 2020), it can be inferred that the selected clay soils from the Mârgău and Ciurila batches could also be effectively utilised for a variety of applications. These include the development of fiber-reinforced compositions incorporating dispersed vegetable fibers, as well as compositions intended for the production of construction elements, plaster mortars, and masonry mortars. Furthermore, these materials may serve as a base for incorporating performance-enhancing additives or for the integration of waste-derived raw materials, thereby contributing to the exploration of novel recycling strategies.

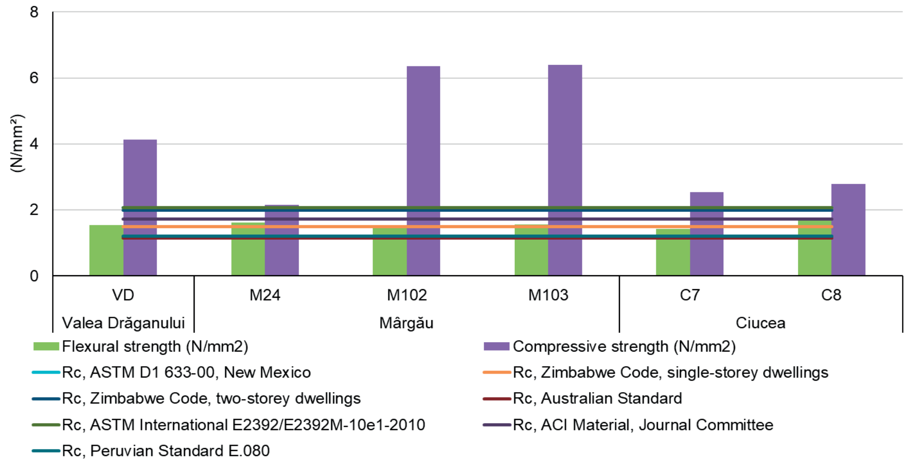

Figure 13. Analysis of flexural strength and compressive strength for a reference sample from Valea Drăganului, samples M24, M102, and M103 (from Mârgău), and samples C7 and C8 (from Ciucea), compared to relevant standards from New Mexico (ASTM D1 633-00, blue), Zimbabwe (dark blue - two stories' dwellings and orange - one story dwellings), ASTM International E2392/E2392M-10e-1-2010 (dark green), ACI Material (purple), and the Peruvian E.080 Standard (turquoise)

Furthermore, a comparison of the mechanical strength indicators with the minimum thresholds established by international standards, including ASTM D1633-00 (New Mexico), the Zimbabwean Code for Rammed Earth Walls, ASTM International E2392/E2392M-10e1-2010, and Peruvian Standard E.080, indicates that the selected and analysed samples satisfy the requirements for use in the construction of residential building walls. The findings of this study suggest that the materials can be effectively utilised in various construction techniques, facilitating the development of both single-story and multi-story structures.

CONCLUSIONS

The objective of this study was to assess the viability of utilising chemical and pedological analysis techniques to determine the prospective

suitability of clay soils from the Mârgău and Ciucea regions in Cluj County for the fabrication of adobe brick masonry components. The experimental research programme was conducted on two distinct batches of soil samples: one collected from the Mârgău area and the other from the Ciucea area, both of which are located in Cluj County. The study was designed to encompass two primary phases:
I. Selection of clay soil samples, conducted in accordance with a set of predefined criteria, which were established in alignment with the specifications outlined in the scientific literature.
II. Validation of the clay soil selection methodology is based on physico-mechanical indicators obtained through experimental testing, with a comparative analysis against references from the scientific literature. The characteristics of a clay soil sample from Valea Drăganului are also presented, and this sample had previously been investigated in a comprehensive experimental research programme.
The selection process involved the reduction of the initial 62 soil samples from the Mârgău batch and 37 soil samples from the Ciucea batch, all collected from a minimum depth of 20 cm at each location, to a final selection of three soil samples from the Mârgău batch (M24, M102, M103) and two soil samples from the Ciucea batch (C7, C8).
The validation phase, which was conducted via experimental testing, established that the selected clay soil samples had an apparent density ranging from 1798 to 1965 kg/m^3, thereby satisfying the critical mass criterion necessary to ensure optimal thermal inertia. The axial shrinkage values generally fell within the recommended range of 3-12%, with the exception of sample M102, which exceeded the upper limit by 15%, indicating a heightened risk of cracking during the drying process. The mechanical strength assessments yielded values that exceeded the minimum thresholds stipulated by international standards and were comparable in magnitude to those of the reference sample from Valea Drăganului, with compressive strength ranging from 2.54 to 6.39 N/mm² and flexural tensile strength between 1.43 and 1.69 N/mm².

In conclusion, the proposed methodology for assessing the suitability of clay soils for adobe brick production demonstrates promising potential benefits. While further refinement of the experimental protocol is necessary to fully validate the soil selection approach, it is anticipated that by integrating current knowledge in the field with rapidly obtainable data through fundamental laboratory testing in soil pedology or cost-effective on-site evaluations, the following advantages can be realised:
- enhanced comprehension of a soil horizon's capacity for a specific application;
- reduced evaluation times in comparison to conventional methodologies. In the case of conventional methods, clay soil undergoes processing, adobe bricks are fabricated, and a prolonged conditioning period is required (achieving constant mass necessitates several days under controlled temperature and humidity conditions) before being tested using physico-mechanical methods;
- the mitigation of risk associated with the selection of soil with unsuitable properties for the intended application, with a consequent minimisation of resource inefficiencies and the reduction of material and time wastage.

REFERENCES

Ak, Ş., Aytekin, O., Kuşan, H., & Zorluer, İ. (2024). Environmental sustainability of building materials in Turkey: Reference information recommendations for European Green Deal declarations. *Buildings, 14*(4), 889.

Androutsopoulos, A., Geissler, S., Charalambides, A. G., Escudero, C. J., Kyriacou, O., & Petran, H. (2020). Mapping the deep renovation possibilities of European buildings. *IOP Conference Series: Earth and Environmental Science, 410*(1), 012056. IOP Publishing.

Asif, M., Muneer, T., & Kelley, R. (2007). Life cycle assessment: A case study of a dwelling home in Scotland. *Building and Environment, 42*(3), 1391–1394.

Boduroglu, M. H. (1989). Rural buildings in Turkey that have suffered damages in recent earthquakes: Their main causes. *Bulletin of the International Institute of Seismology and Earthquake Engineering, 23*, 359–380.

Burroughs, S. (2008). Soil property criteria for rammed earth stabilization. *Journal of Materials in Civil Engineering, 20*(3), 264–273.

Călătan, G., Hegyi, A., Dico, C., & Mircea, C. (2016). Determining the optimum addition of vegetable materials in adobe bricks. *Procedia Technology, 22*, 259–265.

Călătan, G., Hegyi, A., Dico, C., & Mircea, C. (2017). Experimental research on the recyclability of the clay material used in the fabrication of adobe bricks type masonry units. *Procedia Engineering, 181*, 363–369.

Călătan, G., Hegyi, A., Grebenişan, E., & Mircea, A. C. (2020, December). Possibilities of recovery of industrial waste and by-products in adobe-brick-type masonry elements. *Proceedings, 63*(1), 1.

Demir, I. (2008). Effect of organic residues addition on the technological properties of clay bricks. *Waste Management, 28*(3), 622–627.

Dormohamadi, M., & Rahimnia, R. (2020). Combined effect of compaction and clay content on the mechanical properties of adobe brick. *Case Studies in Construction Materials, 13*, e00402.

Giada, G., Caponetto, R., & Nocera, F. (2019). Hygrothermal properties of raw earth materials: A literature review. *Sustainability, 11*(19), 5342.

Hegyi, A., Dico, C., & Călătan, G. (2016). Construction sustainability with adobe bricks type elements. *Urbanism. Arhitectura. Constructii, 7*(2), 147–156.

Hegyi, A., Petcu, C., Ciobanu, A. A., Călătan, G., & Bradu, A. (2023). Development of clay-composite plasters integrating industrial waste. *Materials, 16*(14), 4903.

Laaroussi, N., Cherki, A., Garoum, M., Khabbazi, A., & Feiz, A. (2013). Thermal properties of a sample prepared using mixtures of clay bricks. *Energy Procedia, 42*, 337–345.

Măgurean, A. M., & Petran, H. A. (2023). Analysis of measured CO2 levels through long-term monitoring in renovated multifamily buildings: A common case. *Buildings, 13*(8), 2113.

Ministerul Agriculturii, Academia de Ştiinţe Agricole şi Silvice, & ICPA (1987). *Metodologia elaborării studiilor pedologice. Partea I, II, III.* Bucureşti.

Minke, G. (2005). *Building with earth: Design and technology of a sustainable architecture.* Basel: Birkhäuser.

Mollaei, A., Bachmann, C., & Haas, C. (2023). Assessing the impact of policy tools on building material recovery. *Resources, Conservation and Recycling, 198*, 107188.

Montanarella, L., & Panagos, P. (2021). The relevance of sustainable soil management within the European Green Deal. *Land Use Policy, 100*, 104950.

Munaro, M. R., Tavares, S. F., & Bragança, L. (2020). Towards circular and more sustainable buildings: A systematic literature review on the circular economy in the built environment. *Journal of Cleaner Production, 260*, 121134.

Niroumand, H., Zain, M. F. M., & Jamil, M. (2013). A guideline for assessing critical parameters on earth architecture and earth buildings as sustainable architecture in various countries. *Renewable and Sustainable Energy Reviews, 28*, 130–165.

Standards New Zealand. (1998a). *NZS 4297: Engineering design and earth buildings.* Wellington, NZ: Standards New Zealand.

Standards New Zealand. (1998b). *NZS 4298: Materials and workmanship for earth buildings.* Wellington, NZ: Standards New Zealand.

Standards New Zealand. (1998c). *NZS 4299: Earth buildings not requiring specific design.* Wellington, NZ: Standards New Zealand.

Pacheco-Torgal, F., & Jalali, S. (2012). Earth construction: Lessons from the past for future eco-efficient construction. *Construction and Building Materials, 29*, 512–519.

Papadaki, D., Foteinis, S., Binas, V., Assimakopoulos, M. N., Tsoutsos, T., & Kiriakidis, G. (2019). A life cycle assessment of PCM and VIP in warm Mediterranean climates and their introduction as a strategy to promote energy savings and mitigate carbon emissions. *AIMS Materials Science, 6*(6), 944–959.

Papadaki, D., Nikolaou, D. A., & Assimakopoulos, M. N. (2022). Circular environmental impact of recycled building materials and residential renewable energy. *Sustainability, 14*(7), 4039.

Salih, M. M., Osofero, A. I., & Imbabi, M. S. (2020). Critical review of recent development in fiber reinforced adobe bricks for sustainable construction. *Frontiers of Structural and Civil Engineering, 14*, 839–854.

Santamouris, M., Cartalis, C., Synnefa, A., & Kolokotsa, D. (2015). On the impact of urban heat island and global warming on the power demand and electricity consumption of buildings - A review. *Energy and Buildings, 98*, 119–124.

Silveira, D., Varum, H., & Costa, A. (2013). Influence of the testing procedures in the mechanical characterization of adobe bricks. *Construction and Building Materials, 40*, 719–728.

Vega, P., Juan-Valdés, A., Ignacio Guerra, M., Morán, J., Aguado, P., & Llamas, B. (2011). Mechanical characterization of traditional adobes from the north of Spain. *Construction and Building Materials, 25*(7), 3020–3023.