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Suitability of excavated soils for earth construction: Methodology development for earth plaster

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Abstract

The public works sector produces large quantities of excavated soil that are challenging to manage. This difficulty mainly stems from the limited availability of suitable temporary storage sites and the absence of clear guidelines for their potential reuse as construction materials. Consequently, this earth is rarely reused in construction. This paper proposes recommendations for the marketing of ready-to-use building earth developed in partnership with actors along the value chain (from excavation to commercialisation). The aim is to ensure broad applicability while requiring minimal changes to current professional practices. To comply with the circular economy approach and limit the environmental impacts, this method focuses on local reuse. According to the users, earth's specifications are drawn up to define the objectives and the corresponding physical parameters. Based on standard geotechnical report data, an innovative method for assessing earth suitability has been developed. Then, performance tests are suggested to validate this suitability and characterise the material's behaviour once implemented. Finally, experience feedback is provided to support the dissemination of the method. Although it is designed for various construction techniques, this paper presents the application of the method specifically for plastering.

Keywords: Earthen construction, Excavated soil, Suitability, Supply methodology, Plaster.

1 Introduction

Earth construction, which utilises clayey and non-humic soil, has been employed for thousands of years. Soil here is considered to be the material in its natural state, whereas earth is the extracted and processed material used as a construction material. Despite its ancestral use, it must now adapt to a modern context, facing challenges such as mass production and standardisation [1, 2]. There is currently a lack of standardisation methods for earth construction, due in particular to the significant variability of this resource's characteristics [1–3]. This lack of standards complicates the justification of service characteristics, often leading to costly testing to determine the properties of the structures. Furthermore, each project justification is carried out for a specific soil deposit. This requires some builders and manufacturers to use only particular stocks and, in some cases, to transport them over long distances. In practice, most earth materials are sourced from quarries, which offer consistent and easily characterisable supplies but are often located far from construction sites. For example, in the Auvergne-Rhône-Alpes region of France, the average distance between two quarries is 35 km, but it can reach up to 90 km [4].This affects the intrinsic low environmental impact of this building material, one of its main advantages compared to conventional construction methods such as cement [5–7]. Another potential source of earth is excavated soil. Large volumes are generated annually without being valorised. For example, in France, 150 million tonnes of uncontaminated soil are excavated each year [8]. Furthermore, these deposits have the advantage of being local and close to construction sites. Also, one of the challenges of construction waste management remains the valorisation of excavated soils.

The earth construction is still largely carried out on a small scale by skilled builders with extensive experience. With a focus on democratising earth construction, it is important to

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understand their approach to developing a tailored supply of construction earth materials.

Not all soils are suitable for earth construction, and some of them may be appropriate for only one technique [1]. It is therefore necessary to determine the suitability of each soil. This suitability must consider the implementation requirements for a technique and the performance for the intended use. Then, the suitability of a soil must be established in relation to a construction technique. There is no consensus method for assessing this suitability. Hamard et al. [9] demonstrated that soil suitability can be assessed using simple in-situ tests, such as cracking or adhesion tests. However, they emphasise that these tests must be performed on the plaster substrate. This requirement complicates the development of a soil supply chain, which cannot be adapted to each site. Rojat et al. [1] showed that an analysis combining clay activity and particle size distribution could be relevant for determining soil suitability. Finally, Hamard et al. [10] highlighted the complexity of assessing soil suitability, as it is influenced by local construction practices. These differences can lead to variations in application methods for the same construction technique. The literature lacks a simple methodological analysis of plaster suitability, similar to the approach proposed by Rojat et al. [1].

Comprehensive characterisation is a long and costly process that undermines the affordability of earth construction: it requires a huge number of tests, some of which require sophisticated technical resources. It would therefore be beneficial to propose a method for making ready-to-use earth available on the market, as is the case with concrete. This would also save builders time spent searching for earth deposits and avoid the preparation steps. Moreover, using pre-characterised earth can reassure project stakeholders and promote wider adoption of earth construction.

This study develops a methodology for commercialising excavated soil as building earth. This approach is grounded in the needs of existing stakeholders and proposes a structured framework for the sector. Two main players are involved: geotechnical offices, which can help determine soil suitability, and inert waste treatment centres, which can act as suppliers. The excavator can then excavate the soil and send it to a treatment centre, where it will be stored and prepared to make it suitable for a specific construction technique before being commercialised. This study is conducted within a French context but can be generalised to European issues. This paper presents the methodology developed for the plaster (body coat) made up of excavated soil or mixtures of excavated soil and sand. First, the stakeholders are identified, along with their needs (presented in the supplementary material). On this basis, guidelines are proposed to manage the various stages of supplying earth for construction. Secondly, the suitability is estimated through geotechnical characteristics. Finally, testing protocols are proposed to evaluate the performance in use. Finally, the feedback of all the actors is provided.

2 Convenance methodology development

A methodology to assess the suitability and characterize earth materials intended for rendering applications. It is developed in accordance with the requirements of the entire construction chain, including geotechnical offices, excavation companies, laboratories, waste treatment sites, builders, design offices, inspection agencies, structural engineers, and project managers. A summary of the discussions with these stakeholders can be found in the supplementary material. In addition, a bibliographic review was then conducted to identify the suitability characteristics, measurement methods and in-situ performances.

Discussions with local stakeholders highlighted the need for a rapid and low-cost performance-based characterisation. In the case of non-load-bearing techniques, such as plaster, compressive strength does not appear to be a relevant parameter for determining the suitability [11]. As the main function of coatings is aesthetic, the primary concern is to ensure a continuous surface. Cracks may occur during drying due to shrinkage. In the case of body coatings, slight cracking is not a problem, but it must not lead to detachment. Detachment may occur if there is a lack of cohesion between the coating and its substrate. Shrinkage, therefore, seems to be a more relevant parameter than compressive strength. Performance tests must therefore satisfy these three criteria, based on feedback from practitioners and the literature [9, 12]:

- no significant cracking;
- no detachment during drying;
- adhesion to the wall of at least 10 kPa.

Some selection criteria are intrinsic to the material itself. For body coatings, the maximum particle diameter must be below 4 mm to allow mechanical spraying without clogging the nozzles. Larger particles could be considered, but would not be suitable for builders using spray machines, which would limit their widespread use. Also, soil that could be considered polluted in accordance with the law should not be used. In France, it is necessary to comply with the decree of 12/12/2024.

3 Performance tests

To ensure the suitability of the excavated earth, performance tests must be realised. The tests presented in this paper help to evaluate how the material behaves in service, and therefore provide an innovative performance-based approach. The results also provide information to facilitate the development and acceptance of this unconventional material by the general public, particularly insurers, design offices, etc.

First of all, the earth must be tested under similar in-service conditions, which requires a material formulation study. For a plaster, the plaster is formulated by adding water until it spreads to 140 ± 5 mm using a shaking table [11, 13, 14].

Three performances are measured to characterise the plaster to comply with the specification detailed previously:

- particle size distribution [15];
- shrinkage test: measures cracking and detachment;
- adhesion test: a shear test at the interface between the support and the earth plaster.

Shrinkage and adhesion tests are typically performed on raw or stabilised earth plasters [16, 17]. However, tests are classically conducted on a material scale and not at the wall scale. To ensure performance-based evaluation, the interface between the plaster and the structure must be considered [13, 18–21]. The adhesion is generally tested using a pull-off test with normal force applied to the plaster surface. It characterises the bond between the plaster and its substrate. However, it does not measure shear strength on the wall, which represents the stress experienced by the material [9] (in addition to compressive forces).

Two tests commonly performed on-site by builders were therefore preferred. These tests are carried out by applying the material to an earthen substrate. In order to standardise the substrate, a commercial earthen panel (Plak'Argilus®) is used with the first coating layer. This coating layer is formulated with the 0/1 mm fraction of the soil in liquid form (formulated using the glove test [22]). This coating helps to limit the absorption of fine particles from the plaster [23].

The first test described is the cracking test. On this coating, 1 cm-thick plaster is applied on a 25*25 cm² surface. After 72 hours drying in an ambient condition (minimum 20°C, 50%±5 RH), the length and thickness of the cracks are measured. Any detachment is also noted [9, 24, 25]. For a plaster to be considered adequate, it must not have any cracks thicker than 5 mm. It must also not show any detachment. Figure 1 shows an example of suitable plaster with small cracks (Figure 1.A) and unsuitable plaster that detached from the wall (Figure 1.B). However, this approach does not take into account the influence of the substrate. The substrate plays a significant role in the shrinkage behaviour of the plaster through its absorption capacity and adhesion [26]. The test proposed here is therefore not an in-situ assessment but rather characterises the plaster with a standardised substrate.

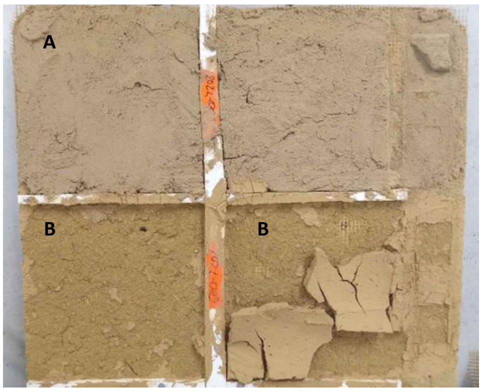

Figure 1. Shrinkage tests on earth plasters (A: suitbale; B: unsuitable).

The adhesion test consists of measuring the shear strength between the plaster and the substrate. A 5*5 cm^2 plaster and 2 cm thick is loaded through a wooden frame laid at its top (Figure 2). The load is applied using weights or by hanging a bucket filled with sand at a speed of 1 kg per 5 seconds. The shear stress at the interface with the support is then calculated using equation (1). T must be greater than 10 kPa for the earth to be considered suitable for earth plaster [9, 12]. For reference, the Argilus plaster shows only limited cracking, with a maximum crack length of 3 cm and a corresponding crack width of 1 mm. The interface shear strength determined using the protocol of this study is 59 ± 9 kPa. This soil was excluded from the study due to the presence of plant fibres.

$$T = \frac{F_s}{S} > 10\ kPa \quad (1)$$

T: shear strength (Pa), F_s: maximal shear force assimilated to the weight in the bucket (N), and S: plaster surface area (m^2).

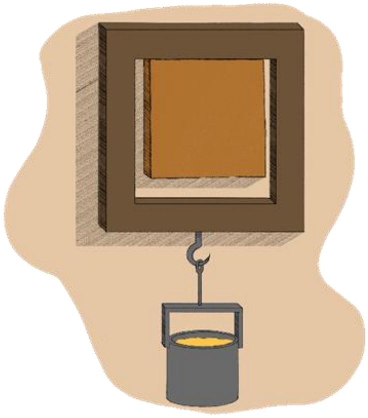

Figure 2. Adhesion test at the interface between the plaster and the support.

4 Selection criteria for a soil

The suitability of a soil for a particular technique largely depends on its intrinsic physico-chemical characteristics, determined by its composition (clay content and type, organic matter, etc.) and particle size distribution [1, 9, 27–34]. These characteristics can be assessed using a variety of techniques. To reduce testing costs, this methodology evaluates soil suitability using the results of geotechnical studies. Particle size distribution and methylene blue value (MBV) appear suitable, as they are commonly measured and involve simple tests requiring minimal equipment [28, 35–38].

To specify the acceptable ranges for these two parameters in the case of plasters, a bibliographic study was conducted [9, 18, 19, 24, 25, 34, 39–42]. These characteristics are combined with the suitability criteria presented in Section 2 to define the properties of soils suitable or unsuitable for coatings. Figure 3 shows the composition of earth-based plastering materials (clay/silt/sand) for the plasters mentioned in the literature and the soils considered in this study. This repartition is essential, yet it is currently never taken into consideration in suitability assessments [1]. An innovative representation of suitability involving three zones are proposed to take into account the mineralogy variation and adapt construction practices of earthen plaster:

- Zone 1: Good suitability of soil for plastering;
- Zone 2: A zone where the soils are sometimes suitable for plastering;
- Zone 3: No suitability of soil for plastering based on our results and the literature review.

In Zone 1, the low clay and silt contents of soils result in broad suitability for the production of earthen plasters. However, soils containing expansive clays may still be unsuitable. Consequently, it is difficult to define geotechnical characteristics that would systematically ensure the suitability of a soil for plaster applications. Zone 2 includes soils with higher proportions of clays and silts. Nevertheless, some of these soils may still be used due to a well-graded particle size distribution or the presence of low-activity clays. The transition to Zone 3 occurs when the clay and silt contents become excessively high, inevitably leading to plaster debonding and cracking.

The most suitable soils appear to be those with a high sand content and a low clay content. As clay particles adsorb water to reach the suitable consistency, a large amount of water must be added to rich clay soils. During the drying phase, the excess water evaporates and leads to shrinkage, which induces cracks [18, 19, 25, 39, 43]. However, even a small amount of clay can cause cracking if it is expansive [26, 40, 41]. The quantity of clay is therefore not sufficient to determine the suitability of the soil; the mineralogical composition of the clays must also be taken into account, but this determination remains difficult and costly.

Particle size distribution can influence shrinkage. A continuous particle size distribution could limit shrinkage by reducing voids in the material and maximising contact between grains [35, 36]. However, even if the distribution is unsatisfactory, it is possible to correct it. Indeed, skilled practitioners know how to adapt the formulation to the local soil to correct the material, for example, by adding fibres. The suitability of a plaster depends not only on the material itself, but also on the substrate.

As the precise mineralogical composition is difficult to determine, the clay activity is measured using the methylene blue value test (MBV) [44, 45]. The silt and clay proportion data are combined with the MBV results in Figure 4 to characterise excavated soil. These soils consist of both excavated materials and mixtures of excavated soil and sand. This graph is commonly employed as a soil classification method in many geotechnical studies. Figure 4 presents the currently available data, based on both the literature and tests carried out as part of this study. In the literature, MBV values are not always reported. When the MBV is unavailable, the corresponding points are positioned on the y-axis. The most suitable soils (Zone 1 described previously) appear to be those with low MBV. Indeed, soil with low MBV will be more suitable for plastering because it will require less water for application, leading to reduced cracking. However, a minimum value of MBV (clay activity) is still necessary to ensure a cohesive material. Thus, a balance must therefore be found: the clay activity should be high enough to ensure a cohesive material, but not so high that shrinkage becomes excessive. Recent findings have shown a similar trade-off for compressed earth [28, 29].

The tests carried out in this study provide new insights and establish a database of suitability characteristics for the specifications outlined in Section 2. The next step is to define acceptable zones by expanding the database. This work is planned within this project over the coming years. These results also show that analysing soil properties separately is not an optimal approach for determining suitability. A simultaneous analysis of soil characteristics is far more effective. This innovative approach is therefore the first method, to the authors' knowledge, that assesses soil suitability for plasters through the simultaneous evaluation of multiple criteria.

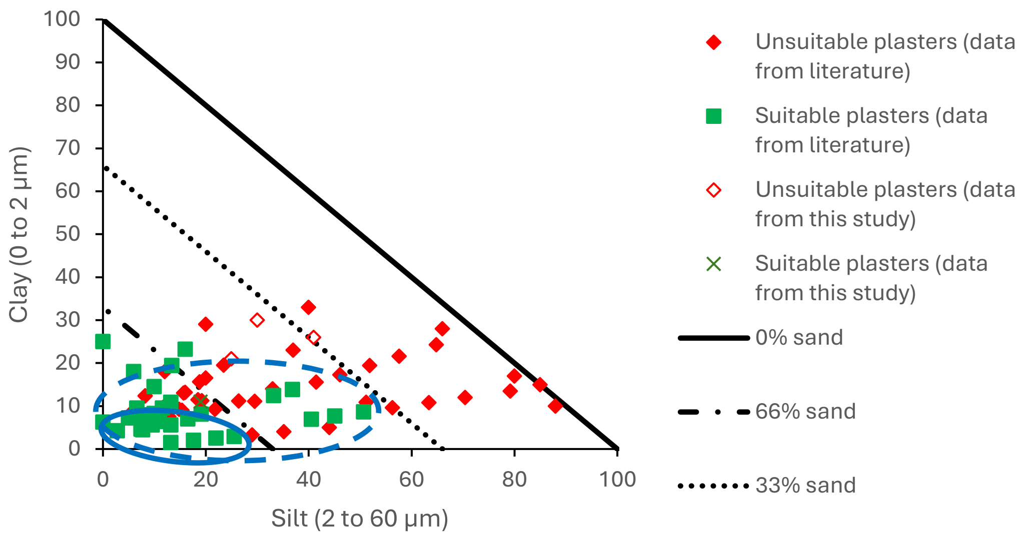

Figure 3. Particle size characteristics of the studied plastering soils [9, 18, 19, 24, 25, 34, 39–42].

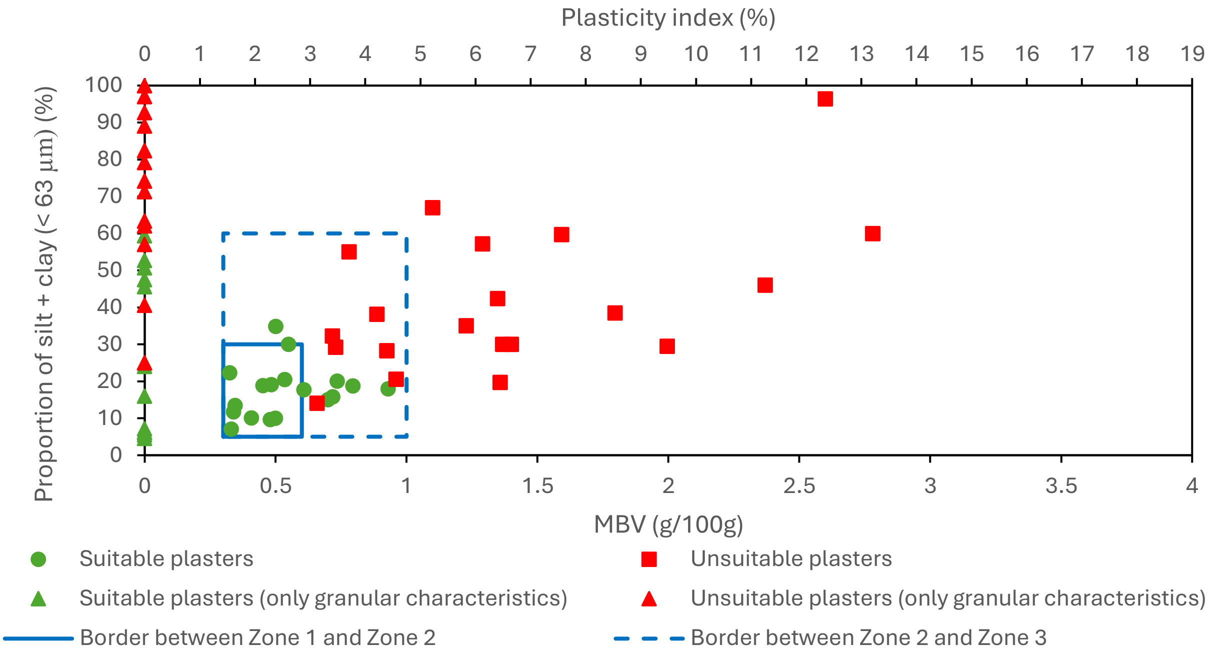

Figure 4. Characteristics of soils suitable and unsuitable for plastering [9, 18, 19, 24, 25, 34, 39–42].

5 Discussion and conclusion

To foster the democratisation of earth construction, this methodology proposes a marketing channel for excavated soils based on geotechnical studies and waste storage infrastructures. Selection relies on key parameters such as MBV and particle size distribution, enabling soils to be classified as generally suitable, sometimes suitable, or unsuitable. An innovative method for determining the suitability of soil for earthen plasters is proposed here. Performance tests provide useful but non-exhaustive information, as they depend on formulation and application methods.

Based on a literature review and tests, three suitability zones are proposed: a first zone with good suitability, a second zone where soils are sometimes suitable for plastering, and a third zone where soils appear unsuitable. This methodology allows for the consideration of variations in mineralogy and local construction practices. Soils suitable for plastering generally have a low methylene blue value (0.3–1) and a limited proportion of silt and clay (5%–60%). By relying on MBV and particle size distribution, this innovative approach provides a cost-effective way to estimate soil suitability.

The approach has generated significant interest among stakeholders in the construction sector. However, several challenges remain. The volume of earth reused in construction is small compared to excavation output. Storage centres must provide protected areas isolated from moisture and weather. Drying is often necessary to market soils, allowing builders to rehydrate them as required. Implementation also varies depending on building practices: performance tests cannot replace masons' know-how but serve to support acceptance by project stakeholders. This approach offers a promising pathway for the reuse of excavated soil, but requires a larger database of tests to better predict soil suitability.

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Authorship statement (CRediT)

Mathieu Arden: Methodology; Formal Analysis; Investigation; Data Curation; Writing – Original Draft. **Fionn McGregor:** Conceptualisation; Methodology; Writing – Review & Editing; Supervision; Project Administration; Funding Acquisition. **Céline Perlot:** Validation; Resources; Writing – Review & Editing; Supervision; Project Administration; Funding Acquisition. **Thomas Garnesson:** Conceptualisation; Resources; Supervision; Project Administration; Funding Acquisition. **Maia Louvard:**.Formal Analysis. **Maxime Deru:** Formal Analysis; Investigation; Data Curation.

References

[1] F. Rojat, E. Hamard, A. Fabbri, B. Carnus, F. McGregor, Towards an easy decision tool to assess soil suitability for earth building, Constr Build Mater (2020) 257: 119544. https://doi.org/10.1016/j.conbuildmat.2020.119544

[2] T. Vinceslas, T. Lecompte, E. Hamard, A. Hellouin de Ménibus, H. Lenormand, T. Colinart, Methods to evaluate earth slip cohesion to build with light earth, Constr Build Mater (2020) 238: 117665. https://doi.org/10.1016/j.conbuildmat.2019.117665

[3] M. Barnaure, S. Bonnet, P. Poullain, Earth buildings with local materials: Assessing the variability of properties measured using non-destructive methods, Constr Build Mater (2021) 281: 122613. https://doi.org/10.1016/j.conbuildmat.2021.122613

[4] Agence MTDA, Schéma régional des carrières de la région Auvergne Rhône Alpes (2018).

[5] L. Ben-Alon, V. Loftness, K. A. Harries, G. DiPietro, E. C. Hameen, Cradle to site life cycle assessment (LCA) of natural vs conventional building materials: A case study on cob earthen material, Build Environ (2019) 160: 106150. https://doi.org/10.1016/j.buildenv.2019.05.028

[6] E. Christoforou, A. Kylili, P. Fokaides, I. Ioannou, Cradle to site life cycle assessment (LCA) of adobe bricks, J Clean Prod (2015) 112: 443-452. https://doi.org/10.1016/j.jclepro.2015.09.016

[7] R. Mateus, S. M. Silva, P. C. P. da Silva, L. Bragança, M. G. de Almeida, P. Mendonça, Sustainability assessment of an energy efficient optimized solution, in: Proc PALENC Conf and AIVC Conf (2007): 636-640.

[8] ADEME, Déchets chiffres-clés, Édition (2020).

[9] E. Hamard, J.-C. Morel, F. Salgado, A. Marcom, N. Meunier, A procedure to assess the suitability of plaster to protect vernacular earthen architecture, J Cult Herit (2013) 14: 109-115. https://doi.org/10.1016/j.culher.2012.04.005

[10] E. Hamard, B. Lemercier, B. Cazacliu, A. Razakamanantsoa, J.-C. Morel, A new methodology to identify and quantify material resource at a large scale for earth construction - Application to cob in Brittany, Constr Build Mater (2018) 170: 485-497. https://doi.org/10.1016/j.conbuildmat.2018.03.097

[11] N. Meimaroglou, C. Mouzakis, Cation exchange capacity (CEC), texture, consistency and organic matter in soil assessment for earth construction: The case of earth mortars, Constr Build Mater (2019) 221: 27-39. https://doi.org/10.1016/j.conbuildmat.2019.06.036

[12] Réseau Ecobâtir, Enduits sur supports composés de terre crue: Règles professionnelles (2016).

[13] K. Stathopoulos, M. Apostolopoulou, A. Bakolas, Enhancement of water resistance of earthen mortars through stabilization, Constr Build Mater (2021) 289: 123180. https://doi.org/10.1016/j.conbuildmat.2021.123180

[14] AFNOR, EN 1015-3: Methods of test for mortar for masonry - Part 3: Determination of consistency of fresh mortar (by flow table) (1999).

[15] AFNOR, EN ISO 17892-4: Geotechnical investigation and testing - Laboratory testing of soil - Part 4: Determination of particle size distribution (2018).

[16] AFNOR, EN 1015-12: Methods of test for mortar for masonry - Part 12: Determination of adhesive strength of hardened rendering and plastering mortars on substrates (2016).

[17] AFNOR, EN 13872: Method of test for smoothing and/or levelling compounds - Determination of shrinkage (2004).

[18] M. Emiroğlu, A. Yalama, Y. Erdoğdu, Performance of ready-mixed clay plasters produced with different clay/sand ratios, Appl Clay Sci (2015) 115: 221-229. https://doi.org/10.1016/j.clay.2015.08.005

[19] F. Stazi, A. Nacci, F. Tittarelli, E. Pasqualini, P. Munafò, An experimental study on earth plasters for earthen building protection: The effects of different admixtures and surface treatments, J Cult Herit (2016) 17: 27-41. https://doi.org/10.1016/j.culher.2015.07.009

[20] R. Delinière, J.-E. Aubert, F. Rojat, M. Gasc-Barbier, Physical, mineralogical and mechanical characterization of ready-mixed clay plaster, Build Environ (2014) 80: 11-17. https://doi.org/10.1016/j.buildenv.2014.05.012

[21] M. I. Gomes, P. Faria, T. D. Gonçalves, Earth-based mortars for repair and protection of rammed earth walls: Stabilization with mineral binders and fibers, J Clean Prod (2018) 172: 2401-2414. https://doi.org/10.1016/j.jclepro.2017.11.170

[22] T. Vinceslas, Caractérisation d'éco-matériaux terre-chanvre en prenant en compte la variabilité des ressources disponibles localement, PhD thesis, Université de Bretagne Sud (2019).

[23] P. Faria, J. Lima, J. Nabais, V. Silva, Assessment of adhesive strength of an earth plaster on different substrates through different methods, in: Proc 5th Historic Mortars Conf (HMC) (2019): 51-64.

[24] M. Pedergnana, S. T. Elias-Ozkan, Impact of various sands and fibres on the physical and mechanical properties of earth mortars for plasters and renders, Constr Build Mater (2021) 308: 125013. https://doi.org/10.1016/j.conbuildmat.2021.125013

[25] Q. Jia, W. Chen, Y. Tong, Q. Guo, Laboratory study on shrinkage and cracking behavior of historic earthen plaster, Eng Geol (2023) 318: 107096. https://doi.org/10.1016/j.enggeo.2023.107096

[26] T. Santos, M. I. Gomes, F. Coelho, P. Faria, Eco-efficient earth plasters: Influence of clay content, sand particle size and support, J World Archit (2018) 2. https://doi.org/10.26689/jwa.v2i6.634

[27] A. Perrot, D. Rangeard, A. Levigneur, Linking rheological and geotechnical properties of kaolinite materials for earthen construction, Mater Struct (2016) 49: 4647-4655. https://doi.org/10.1617/s11527-016-0813-9

[28] D. Ardant, C. Brunaud, A. Perrot, G. Habert, Robust clay binder for earth-based concrete, Cem Concr Res (2023) 172: 107207. https://doi.org/10.1016/j.cemconres.2023.107207

[29] M. Audren, S. Guihéneuf, T. Le Borgne, D. Rangeard, A. Perrot, Strategy for the mix design of building earthen materials made of quarry by-products, Buildings (2023) 13: 2531. https://doi.org/10.3390/buildings13102531

[30] D. Ciancio, P. Jaquin, An overview of some current recommendations on the suitability of soils for rammed earth, in: Int Workshop Rammed Earth Mater Sustain Struct (2011).

[31] H. Danso, Suitability of soil for earth construction as building material, Adv Civ Eng Technol (2018) 2: 199-211. https://doi.org/10.31031/ACET.2018.02.000540

[32] Y. M. H. Mustafa, O. S. B. Al-Amoudi, M. S. Zami, M. A. Al-Osta, Assessment of the suitability of earth as a construction material from experimental and numerical perspectives: A critical review, Int J Geomech (2023) 23: 03123003. https://doi.org/10.1061/(ASCE)GM.1943-5622.0002646

[33] L. N. Reddi, A. K. Jain, H.-B. Yun, Soil materials for earth construction: Properties, classification and suitability testing, in: Modern Earth Buildings, Elsevier (2012): 155-171. https://doi.org/10.1533/9780857096166.2.155

[34] M. Lagouin, A. Laborel-Préneron, C. Magniont, S. Geoffroy, J.-E. Aubert, Effects of organic admixtures on the fresh and mechanical properties of earth-based plasters, J Build Eng (2021) 41: 102379. https://doi.org/10.1016/j.jobe.2021.102379

[35] H. A. C. K. Hettiarachchi, W. K. Mampearachchi, Validity of aggregate packing models in mixture design of interlocking concrete block pavers (ICBP), Road Mater Pavement Des (2019) 20: 462-474. https://doi.org/10.1080/14680629.2017.1393001

[36] N. Malkanthi, A. Perera, Particle packing application for improvement in the properties of compressed stabilized earth blocks with reduced clay and silt, Eng Technol Appl Sci Res (2019) 9: 4538-4542. https://doi.org/10.48084/etasr.3002

[37] E. J. Hoppe, The influence of fines on strength and drainage characteristics of aggregate bases (1996).

[38] A. Loudini, M. Ibnoussina, O. Witam, A. Limam, O. Turchanina, Valorisation of dredged marine sediments for use as road material, Case Stud Constr Mater (2020) 13: e00455. https://doi.org/10.1016/j.cscm.2020.e00455

[39] M. Lagouin, A. Laborel-Préneron, C. Magniont, J.-E. Aubert, Development of a high clay content earth plaster, IOP Conf Ser Mater Sci Eng (2019) 660: 012068. https://doi.org/10.1088/1757-899X/660/1/012068

[40] J. Lima, P. Faria, A. Santos Silva, Earth plasters: The influence of clay mineralogy in the plasters' properties, Int J Archit Herit (2020) 14: 948-963. https://doi.org/10.1080/15583058.2020.1727064

[41] T. Santos, M. I. Gomes, A. S. Silva, E. Ferraz, P. Faria, Comparison of mineralogical, mechanical and hygroscopic characteristics of earthen, gypsum and cement-based plasters, Constr Build Mater (2020) 254: 119222. https://doi.org/10.1016/j.conbuildmat.2020.119222

[42] J. Lima, P. Faria, A. Santos Silva, Earthen plasters based on illitic soils from Barrocal region of Algarve: Contributions for building performance and sustainability, Key Eng Mater (2016) 678: 64-77. https://doi.org/10.4028/www.scientific.net/KEM.678.64

[43] T. Ashour, W. Wu, An experimental study on shrinkage of earth plaster with natural fibres for straw bale buildings, Int J Sustain Eng (2010) 3: 299-304. https://doi.org/10.1080/19397038.2010.504379

[44] A. S. Nugraha, P. P. Rahardjo, B. M. Hutapea, I. A. Sadisun, Correlation between plasticity index and methylene blue value to determining soil classification, IOP Conf Ser Mater Sci Eng (2020) 852: 012012. https://doi.org/10.1088/1757-899X/852/1/012012

[45] A. Chiappone, S. Marello, C. Scavia, M. Setti, Clay mineral characterization through the methylene blue test: Comparison with other experimental techniques and applications of the method, Can Geotech J (2004) 41: 1168-1178. https://doi.org/10.1139/t04-060

Appendix

The Nexterre program aims to develop a supply chain for construction earth by leveraging a network of geotechnical engineering offices, earthmoving contractors, and waste management centres. To ensure that the proposed developments adequately address companies' needs, a dedicated "user group" was established. This group includes craftsmen, construction companies, engineering offices, and industrial stakeholders involved in the design and realisation of earthen structures. Members of the user group were consulted through individual interviews to identify their expectations regarding a future supply offer for construction earth. The present report provides a general summary of these discussions.

Formation of the user group

The companies forming the user group are mainly local businesses from the southwest of France, as this is where the activity is initially being developed. Focusing on a single geographical area was deemed necessary in order to work within a consistent constructive culture. Indeed, constructive cultures may influence both the suitability of soils and the implementation methods used for a given technique [1]. he different companies involved are listed in Table 1. All interviews and exchanges were conducted during the year 2024. In addition, some companies engage in multiple activities; in such cases, only the activity for which their expertise is sought is indicated.

Table 1. List of user group members.

Companies	Activity
A l'oeuvre	Project management assistance
De La Tête Au Toit	Group of artisans
Briques Technic Concept	Industrial company
Chapeau et Bottes	Earth construction company
Douar	Earth construction company
Etxeberri	Earth construction company
Habitat Eco Action	Group of artisans
Items	Earth construction company
Otra Construction	Earth construction company
TMH	Earth construction company
Bil Ta Garbi	Waste management centre
Goyetche	Waste management centres
CEMEX	Waste management centres
Alios	Geotechnical office
Alpes Contrôle	Control offices
	Structural office

Background of the activities conducted by the participating companies

The companies consulted are involved in a wide range of earthen construction products and components, including plasters, light earth materials for insulation, adobe, compressed earth blocks (CEB), and rammed earth. Some companies restrict their activities to the construction of non-load-bearing elements, notably because they do not hold the insurance required for structural earthworks.

The projects concerned by the implementation of earthen materials are diverse, including residential buildings, offices, and educational facilities, both new constructions and renovation works. Large-scale earthen structures are mostly found in projects led by public-sector clients. In addition, the renovation of historic or heritage buildings may also require the use of traditional earthen construction techniques.

Current supply of construction earth

Companies may use on-site soil when it is suitable for earthen construction. Otherwise, they source materials from quarries, primarily clay quarries (used for fired clay bricks), but sometimes from topsoil from sand, or gravel quarry. They also frequently rely on suppliers providing ready-to-use earth products (Brique technique concept, Argilus and Gtoupe Daniel). The use of untreated soil (excavated soil in a wet, un-screened state) requires preliminary work by the earth construction company. The extent of this work can vary significantly depending on the soil condition and the size of the project. For this reason, some companies prefer to use prepared, ready-to-use earth, especially for large-scale projects.

Companies are unwilling to disclose their suppliers, and therefore, this information is not reported here. However, other details can be provided. Soil is generally supplied in big bags or in 25 kg bags, the latter being preferred for small-scale works. When sourced from quarries, prices range from €10 to €300 per tonne (excluding VAT). The least expensive soils are waste materials or non-standardized, uncharacterized, and unpackaged topsoil from quarries. Soils priced around €90 per tonne are also quarry soils, but screened and packaged. Higher-priced soils are brickworks soils, which are dried, ground, and accompanied by a product data sheet. Prices can reach up to €600 per tonne for specific or specially formulated soils, or when packaged in 25 kg bags.

For industrial-scale production, a homogeneous soil is supplied in large quantities. Using small deposits with heterogeneous characteristics requires extensive characterisation and formulation work, which is generally not feasible. The soil used is typically sourced from quarries (clay quarry, topsoil) or originates from large-scale excavation operations.

Transport distances for soils range from 0 km, when using on-site soil, to over 50 km for soils sourced from brickworks. These price variations reflect the expected quality of the soil. Transport distance for sourcing can also be highlighted as an important factor. These characteristics are summarized in Table 2. It should be noted that these observations reflect feedback from practitioners, and exceptions may exist for specific construction sites.

Needs and expectations regarding construction earth

For the majority of respondents, the performance-based approach proposed by the Nexterre initiative appears relevant, as it ensures the compatibility of the soil with its intended application. They are particularly interested in soils whose formulation is adapted to the intended use (no additional aggregates required). A supply of pre-prepared soil with properties adapted to its intended use would allow industrial users to avoid the long-term storage burden, which requires both land and covered storage space. This approach can particularly facilitate the adoption of the material by companies with limited experience in constructing earthen structures. The performance-based method may also reduce the need for certain tests typically required by technical inspectors. This level of characterisation may be sufficient for non-load-bearing structures, but low-cost to limit the earth price.

Table 2. Expected characteristics required by earthmoving/ construction companies based on soil price and associated transport distance.

Cost (€)	Earth characteristics	Related transport distance (km)
0	Construction site earth: - Uncharacterised - Often wet - Not sieved - Unknown - Unconditioned	0
0-20	Quarry earth: - Uncharacterised - Moisture content lower than mixing requirements - Not sieved - Known - Unconditioned	< 50 (Local)
20-100	Quarry earth: - Uncharacterised - Moisture content lower than mixing requirements - Sieved - Known - Conditioned (big-bag)	< 50 (Local)
> 100	Brickworks earth: - Characterised - Dry - Sieved and crushed - Known - Conditioned (big-bag or 25 kg bag)	> 50 (Local)

The performance-based approach offers several advantages for companies. It can help reduce the number of tests required by structural or technical control offices and facilitate the implementation of the material. Testing and standardised packaging also help ensure stock homogeneity. Furthermore, these tests provide less-experienced craftsmen with pre-qualified soil and initial guidance on its use. However, the number and cost of tests should be limited to avoid significantly increasing the price of the soil. For renders, the characteristics most frequently measured are cracking and detachment. In France, these tests are standardised within professional guidelines [2]. No detachment should occur during drying. For body-plasters, minor cracks may appear, but they should not compromise the structural integrity of the wall. A crack width of up to 5 mm was considered acceptable by practitioners.

However, the following limitations were noticed:

- Construction techniques and on-site conditions may differ from those used to produce the samples submitted for performance testing. The reported performance values should therefore be regarded as achievable targets and not on-site performances. On-site testing will likely be necessary, particularly for load-bearing structures.
- For industrial-scale production, the performance achieved partially depends on the production equipment, which is often specific to the manufacturer. Consequently, the reported performance values may not correspond to those actually obtained.

To facilitate handling, the soil should be clod-broken and relatively dry to facilitate humidification. Additionally, the soil should be supplied at a moisture content equal to or lower than the moisture content for confection.

Information on the origin of the soil is interesting to stakeholders who want local materials. Transport distance can be provided in addition to the extraction site to give further context.

The earth supplier must ensure that the material offered is free from pollutants. Some soils obtained from excavation may contain chemical substances, and in such cases, it is necessary to verify that their concentrations remain below thresholds considered harmful to human health and the environment.

Soil colour is also an important characteristic, particularly for visible elements such as rammed earth, CEB, or other uncoated structures. Project owners generally prefer soils with shades ranging from white to brown, with a particular preference for lighter tones. Gray soils, sometimes observed, are associated with cement coloration, and project owners may reject their use.

Table 3. Unsuitable soil characteristics.

Silt + clay (< 63 µm) (%)	Methylene blue values	Plasticity index	Source of the data
30.0	1.40	Data unavailable	Literature
20.6	0.96	Data unavailable	Literature
20.6	0.96	Data unavailable	Literature
14.1	0.66	Data unavailable	Literature
43.0	Data unavailable	18	Literature
34.4	Data unavailable	18	Literature
28.7	Data unavailable	18	Literature
21.5	Data unavailable	18	Literature
17.2	Data unavailable	18	Literature
30.5	Data unavailable	15	Literature
24.4	Data unavailable	15	Literature
20.3	Data unavailable	15	Literature
25.0	Data unavailable	0	Literature
73.0	Data unavailable	22.4	Literature
36.5	Data unavailable	22.4	Literature
29.2	Data unavailable	22.4	Literature
98.0	Data unavailable	12.4	Literature
49.0	Data unavailable	12.4	Literature
39.2	Data unavailable	12.4	Literature
32.3	Data unavailable	12.4	Literature
94.0	Data unavailable	11.7	Literature
47.0	Data unavailable	11.7	Literature
37.6	Data unavailable	11.7	Literature
31.0	Data unavailable	11.7	Literature
60.0	Data unavailable	22.7	Literature
30.0	Data unavailable	22.7	Literature
24.0	Data unavailable	22.7	Literature
19.8	Data unavailable	22.7	Literature
49.0	Data unavailable	22.2	Literature
97.0	Data unavailable	Data unavailable	Literature
62.1	Data unavailable	Data unavailable	Literature
89.1	Data unavailable	Data unavailable	Literature
79.2	Data unavailable	Data unavailable	Literature
71.3	Data unavailable	Data unavailable	Literature
63.4	Data unavailable	Data unavailable	Literature
57.0	Data unavailable	Data unavailable	Literature
40.6	Data unavailable	Data unavailable	Literature
100.0	Data unavailable	Data unavailable	Literature
92.7	Data unavailable	Data unavailable	Literature
82.4	Data unavailable	Data unavailable	Literature
74.2	Data unavailable	Data unavailable	Literature
65.9	Data unavailable	Data unavailable	Literature
67.0	1.10	18.6	This study
46.0	2.37	15.1	This study
60.0	2.78	20.7	This study
59.7	1.59	Data unavailable	This study
96.4	2.60	Data unavailable	This study
30.0	1.37	Data unavailable	This study
38.5	1.80	Data unavailable	This study
55.0	0.78	Data unavailable	This study
19.7	1.36	Data unavailable	This study
29.5	2.00	Data unavailable	This study
38.2	0.89	Data unavailable	This study
57.2	1.29	Data unavailable	This study
28.3	0.92	Data unavailable	This study
42.4	1.35	Data unavailable	This study
29.2	0.73	Data unavailable	This study
32.2	0.72	Data unavailable	This study
35.1	1.23	Data unavailable	This study

Table 4. Suitable soil characteristics.

Silt + clay (< 63 µm) (%)	Methylene blue values	Plasticity index	Source of the data
7.1	0.33	Data unavailable	Literature
14.3	Data unavailable	18	Literature
17.4	Data unavailable	15	Literature
15.3	Data unavailable	15	Literature
12.2	Data unavailable	15	Literature
7.2	Data unavailable	Data unavailable	Literature
6.3	Data unavailable	Data unavailable	Literature
5.5	Data unavailable	Data unavailable	Literature
4.6	Data unavailable	Data unavailable	Literature
6.3	Data unavailable	Data unavailable	Literature
25.0	Data unavailable	Data unavailable	Literature
16.0	Data unavailable	Data unavailable	Literature
24.0	Data unavailable	Data unavailable	Literature
24.1	Data unavailable	22.4	Literature
21.2	Data unavailable	22.4	Literature
18.3	Data unavailable	22.4	Literature
14.6	Data unavailable	22.4	Literature
28.4	Data unavailable	12.4	Literature
24.5	Data unavailable	12.4	Literature
19.6	Data unavailable	12.4	Literature
14.7	Data unavailable	12.4	Literature
27.3	Data unavailable	11.7	Literature
23.5	Data unavailable	11.7	Literature
18.8	Data unavailable	11.7	Literature
17.4	Data unavailable	22.7	Literature
15.0	Data unavailable	22.7	Literature
12.0	Data unavailable	22.7	Literature
39.2	Data unavailable	22.2	Literature
32.8	Data unavailable	22.2	Literature
24.5	Data unavailable	22.2	Literature
16.2	Data unavailable	22.2	Literature
12.3	Data unavailable	22.2	Literature
50.7	Data unavailable	Data unavailable	Literature
45.6	Data unavailable	Data unavailable	Literature
59.3	Data unavailable	Data unavailable	Literature
52.7	Data unavailable	Data unavailable	Literature
47.5	Data unavailable	Data unavailable	Literature
30.0	0.55	8.9	Literature
9.7	0.48	Data unavailable	This study
10.0	0.50	Data unavailable	This study
15.0	0.70	Data unavailable	This study
18.8	0.80	Data unavailable	This study
22.3	0.33	Data unavailable	This study
34.9	0.50	Data unavailable	This study
18.0	0.93	Data unavailable	This study
15.8	0.72	Data unavailable	This study
19.1	0.48	Data unavailable	This study
17.7	0.61	Data unavailable	This study
11.7	0.34	Data unavailable	This study
20.5	0.53	Data unavailable	This study
13.5	0.35	Data unavailable	This study
18.8	0.45	Data unavailable	This study
10.1	0.41	Data unavailable	This study
20.1	0.74	Data unavailable	This study