TABIQUE WALLS COMPOSITE EARTH BASED MATERIAL CHARACTERIZATION IN THE ALTO DOURO WINE REGION, PORTUGAL

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ABSTRACT

The *Alto Douro Wine Region*, located in the northeast of Portugal, a UNESCO World Heritage Site, presents a relevant *tabique* building stock, a traditional vernacular building technology. A technology based on a timber framed structure filled with a composite earth-based material. Meanwhile, previous research works have revealed that, principally in rural areas, this Portuguese heritage is highly deteriorated and damaged because of the rareness of conservation and strengthening works, which is partly related to the non-engineered character of this technology and to the growing phenomenon of rural to urban migration. Those aspects associated with the lack of scientific studies related to this technology motivated the writing of this paper, whose main purpose is the physical and chemical characterization of the earth-based material applied in the *tabique* buildings of that region. Consequently, an experimental work was conducted and the results obtained allowed, among others, the proposal of a particle size distribution envelope in respect to this material. This information will provide the means to assess the suitability of a given earth-based material in regard to this technology. The knowledge from this study could be very useful for the development of future normative documents and as a reference for architects and engineers that work with earth to guide and regulate future conservation, rehabilitation or construction processes helping to preserve this fabulous legacy.

Keywords: *Alto Douro Wine Region*; *tabique*; traditional building technology; characterization tests; composite earth-based material.

REZUMAT

Regiunea viticolă Alto Douro, localizată in nord-estul Portugaliei, o regiune aflată în Patrimoniul UNESCO, prezintă o multitudine de clădiri construite prin metoda *tabique*, o tehnologie tradiţională, vernaculară, de construcţie. Această tehnologie se bazează pe o structură în cadre de lemn umplute cu un compozit având pământul ca material de bază. Între timp, cercetările anterioare au arătat faptul că, în principal în zonele rurale, această moştenire portugheză se pierde în timp datorită rarităţii lucrărilor de conservare şi consolidare, caracterului neingineresc al acestei tehnologii şi creşterii fenomenului de migraţie rurală către zonele urbane. Aceste aspecte, asociate cu lipsa studiilor ştiinţifice legate de această tehnologie, au motivat scrierea articolului de faţă, al cărui scop principal este caracterizarea fizică şi chimică a materialului pe bază de pământ folosit in construcţiile realizate din *tabique* în regiunea respectivă. Astfel, a fost realizat un studiu experimental, iar rezultatele obţinute au permis, între altele, propunerea unei înfăşurători (a unei curbe granulometrice) a distribuţiei mărimii particulelor din componenţa materialului menţionat. Această informaţie va oferi mijloacele pentru a evalua adecvarea unui material de bază de pământ, utilizat în cadrul tehnologiei respective. Cunoştinţele dobândite în urma studiului pot fi foarte utile pentru dezvoltarea de documente normative viitoare, precum şi ca referintă pentru arhitecţii şi inginerii interesaţi, pentru îndrumarea şi reglementarea viitoarelor lucrări de conservare, reabilitare şi construcţie, sprijinind ocrotirea acestei minunate moşteniri.

Cuvinte cheie: Regiunea viticolă Alto Douro; tabique; tehnici tradiţionale de construcţii; teste de caracterizare; compozite pe bază de pământ.

1. INTRODUCTION

One of the most traditional Portuguese building technologies is *tabique*, Pinto *et al.* [1] a variation of worldwide known traditional timber framed buildings with infill panels technology, [2, 3, 4]. The *Alto Douro Wine Region* (hereinafter referred to as '*Alto Douro*'), illustrated in Fig. 1, a sub-region of the *Trás-os-Montes e Alto Douro Region*, located in the northeast of Portugal, is rich in terms of *tabique* building heritage, which is an important aspect of the *Alto Douro* landscape UNESCO's World Heritage Site, [5].

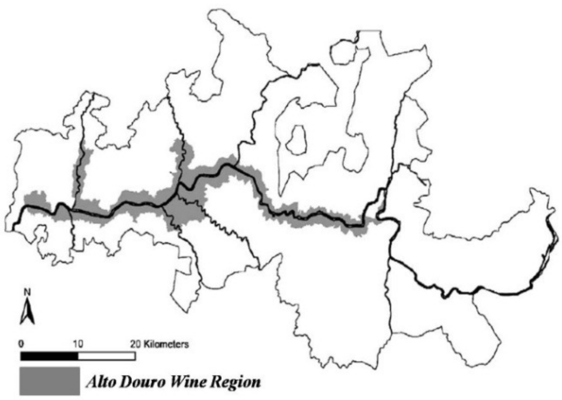


Fig. 1. *Alto Douro Wine Region*

The majority of *tabique* buildings are residential single family detached houses with two storeys, (ground and first storey). Usually, the ground floor is used as a storage room or for business and the first floor is used for housing. Those buildings have exterior stone masonry walls at the ground floor level and *tabique* exterior walls at the first floor while *tabique* partition walls can be found in any of these floor levels, Fig. 2-a). This technology applies traditional building materials as stone, wood, steel nails and a composite earth-based material (CEBM) defined as raw earth with additions of hydraulic lime, straw, dried onion foliage, wood shaving, Fig. 2-b) or corn cob.

a) Tabique building

b) CEBM

Fig. 2. *Tabique* single family detached house

This technology incorporates sustainable design principles, [6], transmits important skills and knowledge from the past to the present and is also a useful and handy reference manual for engineers and other experts, thus represents a unique building heritage.

However, this building technology has fallen into disuse over the past century, as a consequence of the arrival of modern technologies such as reinforced concrete framed structure with fired brick masonry infill and concrete slabs, a prevailing technology in Portugal and other south Mediterranean countries. Moreover, although existing *tabique* buildings are a hundred years hold, the records of conservation, strengthening or rehabilitation works are sparse. Consequently, the majority of these buildings exhibit an advanced stage of deterioration, [7], which as lead to the building collapse, demolition or replacement by reinforced concrete structure. This scenario is most probably related to the non-engineered character of this construction technology and the subsequent absence of normative documents, but also related to the massive desertification of the northeast of Portugal, as a result of littoral urbanization.

Studies regarding this technology, although initiated in 2008, [1, 7], have at this stage analysed some aspects of *tabique* buildings located in the *Trás-os-Montes e Alto Douro Region*, as materials characterization, building state of conservation, *tabique* walls typologies and building details, numerical modelling and thermal insulation, [1, 7, 8, 9, 10, 11, 12]. The present work intends to increase this knowledge and is focused on *tabique* buildings located in the *Alto Douro*. The aim of this paper is the classification and characterization of the earth-based material (EBM), defined as an earth material with the eventual addition of hydraulic lime, assessing properties, namely grain size, plasticity, organic content and chemical and mineralogical composition, in order to define the EBM suitable for this technology. For this purpose, an experimental work and its results are presented and analysed. This type of information is largely disseminated by different authors in respect to others building technologies, as rammed earth, compressed earth blocks (CEB) or adobe, [13, 14], but to our knowledge, there has been very little research about the characterization of the EBM used in *tabique* buildings or variations of it as *wattle and daub* in England or *himiş* and *bağdadi* construction in Turkey, [2]. Probably, this is due to the complexity of the analysis and because the EBM apparently do not have a load-bearing function as in the others earth-based technologies. In this context, the present work will, therefore, fill this gap.

The remainder of this paper is structured as follows: firstly, some features concerning *tabique* walls and the CEBM are referred; secondly, traditional earth-based characterization tests are reviewed; thirdly, the characterization of *tabique* EBM samples collected in the *Alto Douro* and based on grain size, plasticity and chemical and mineralogical analyses is performed; fourthly, results are presented and a particle size distribution envelope corresponding to the *tabique* EBM is proposed; finally, the main conclusions of this research work are drawn.

2. CONCEPTION OF TABIQUE WALLS

Tabique buildings are formed of granite walls, roof and floors timber structures and a timber framed structure filled with a CEBM (*tabique*) for some building components as external and partition walls, chimneys or suspended ceilings. Nevertheless, *tabique* walls are the main *tabique* building component [1, 7]. A *tabique* building wall is formed of a timber-framed structure made up of vertical boards connected by horizontal laths which are connected together with metal nails. This structure is then filled and coated with a composite earth-based material. These walls can have a major role in the overall stability of a building, [9]. The CEBM applied wrap around the timber and nail elements, filling the gap between them, protecting them from decay and contributing significantly for the durability of the construction. This material can also, to some extent, provide sound and thermal insulation as well as fire resistance, [11, 12]. Usually, a revetment is applied in the outer face of an external *tabique* wall, as metal plates, a lime render, Fig. 3-a), schist tiles, Fig. 3-b) or ceramic tiles to increase the *tabique* walls waterproofing and avoid the deterioration of the CEBM.

According to previous research works [4], the most common building materials used in this context, in the *Alto Douro*, are the *Pinus pinaster* for the timber structural elements and steel nails for their connection. According to [8], the *tabique* walls typologies of the *Alto Douro*, present an expressive amount of EBM corroborating the idea that this material as an important role in the physical and structural integrity of these buildings. It has been also reported that the actual *tabique* buildings deterioration is mostly due to the loss of the *tabique* walls original filling and protective coating, Fig. 3-a), [15].

a) Lime render b) Schist tiles

Fig. 3. *Tabique* exterior walls and revetments

In the following section, a list of test methods are presented and later used in an experimental work to access some of the main properties of the *tabique* EBM.

3. EARTH CHARACTERIZATION TESTS REVIEW

A literature review was made to access tests used for the characterization of the EBM applied in timber framed building technologies with infills. Surprisingly a lack of scientific studies was noticed, despite some studies recently initiated [1, 7], or presented by Aedo & Olmos [14] and Cyted [16] in France and South America, respectively. Currently there are several published works on earth characterization in respect to others technologies, as adobe, rammed earth and CEB, to whose standards and normative documents have been dedicated [13, 14 and 17]. For this reason, the literature review was refocused on these technologies. Grain size, plasticity, chemical and mineralogical composition of the earth are the properties mostly evaluate trough testing methods, Houben & Guillaud [18], Minke [19], Doat *et al.* [20], CRATerre-EAG & Rigassi [21], Hall & Djerbib [22], Ciancio *et al*. [17], Delgado & Guerrero [13] and Quagliarini *et al.* [23]. Some of those tests will be applied for the characterization of the *tabique* EBM.

4. EXPERIMENTAL WORK

In order to identify and characterize the EBM traditionally used in *tabique* buildings, an experimental work was carried out using material samples collected from *tabique* buildings located in the *Alto Douro*. Grain size and plasticity tests were performed at the Geotechnical and Construction Material Laboratory of the Polytechnic Institute of Coimbra, while the chemical and mineralogical tests were performed at the Microscopy Electronic Unit of the University of Trás-os-Montes e Alto Douro. In the following subsections materials, methods and results are presented and commented.

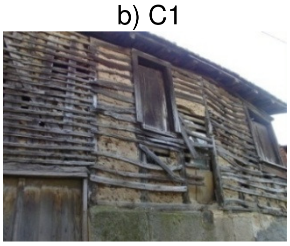
4.1. The materials

EBM samples were collected from seven *tabique* buildings designated C1, C2, C3, C4, C5, C6 e C7, located in *Lamego* municipality, [7], Fig. 4-a). Some of these buildings are illustrated in Figs. 4-b), 5-c) and 4-d).

a) The samples

b) C1

c) C5



d) C7

Fig. 4. *Tabique* buildings studied

These *tabique* buildings are rural *tabique* dwellings of two floors with exterior and partition *tabique* walls. In each building, one EBM sample, with an average weight of one kilogram, was collected and the adopted sample designation was related to the collected construction origin (C1 means that the sample was collected from construction C1). Building construction C1 is located in *Cambres* parish and the others are located in *Penajóia* parish. The sampling locations are shown in Fig. 5.

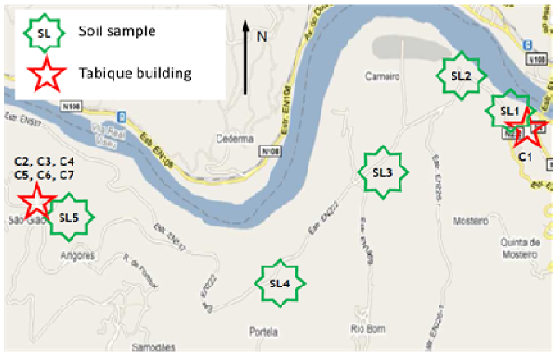


Fig. 5. Sampling locations

Additionally, we were also interested in analysing the EBM applied in different *tabique* walls of the same dwelling, in order to evaluate if this EBM has the same origin and, therefore, the same properties. For this reason, another five EBM samples were collected from the *tabique* building construction C1, from different *tabique* walls (partition and exterior wall).

Those samples were designated C1A1, C1A2, C1A3, C1A4 e C1A5 and Fig. 6-a) presents them.

a) C1A1, C1A2, C1A3, C1A4,C1A5

b) SL2 sample collecting location

Fig. 6. *Tabique* buildings EBM and soil samples

Beyond that, we were also interested in evaluating if the origin of the EBM is local, therefore five samples of earth soil were collected in the surrounding area of the dwellings and were designated SL1, SL2, SL3, SL4 e SL5. The soil samples were collected at a shallow depth of 15-30 cm. These collecting sites are located between the *Cambres* and *Penajóia* parish and Fig. 6 presents the location of the collecting sites SL1, SL2, SL3, SL4 and SL5. Sample SL2 collecting location is illustrated in Fig. 6-b). The GPS coordinates of sample C1 is N 41° 09,230' and W 7° 47,117' and the bigger distance between collecting sites is 5.5 Km, corresponding to the distance between construction C1 and construction C3.

4.2. Methods

The following tests were performed:

- Particle size distribution (PSD) laboratory test, which consisted in combined wet sieving (pebbles, gravel and sand) and sedimentation (silt and clay) analysis (using the American Standard Test Sieve Series).

- Plasticity test, consisting in the determination of the *Atterberg* limits as the liquid limit (LL), the plasticity limit (PL) and the corresponding plasticity index (PI).

- Scanning Electron Microscopy (SEM), Energy Dispersive Spectroscopy (EDS) and X-ray Diffraction (XRD) for chemical and mineralogical EBM characterization. Those tests allowed identifying the presence of clay, organic content or hydraulic binders as lime.

This information have been widely used in several research works, as in the characterization of the earth coating of *tabique* walls, [1, 7], in CEB, Cid-Falceto *et al.* [24] and in adobe and rammed earth, Delgado & Guerrero *et al.*, [13].

Some of the equipment used in SEM/EDS and XRD tests is illustrated in Fig. 7.

a) Scanning electron microscope   b) X- ray diffractometer

Fig. 7. SEM/EDS and XRD tests

4.3. Experimental results and interpretation

In the following subsections, the results obtained from each one of the tests are presented. Firstly the results regarding grain size and plasticity tests and finally those obtained from SEM/EDS and XRD tests.

4.3.1. Grain size and plasticity tests

The samples PSD curves, compiled in Fig. 8, were obtained from sieving and sedimentation analyses carried out resorting to LNEC 239 [25] and LNEC 196 [26].

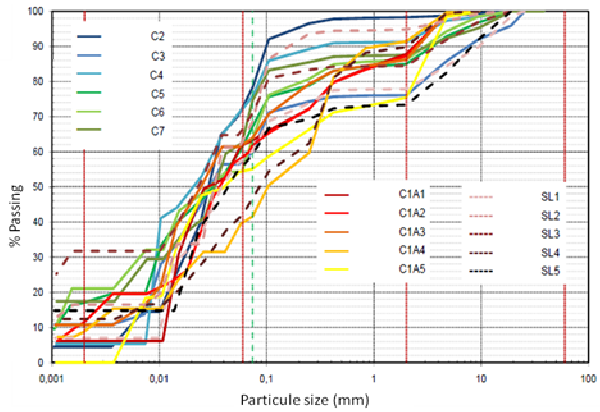


Fig. 8. Samples PSD curves

The comparison of the sixteen PSD curves shapes reflects a similar size fractions composition, indicating that the EBM follows a standard. Moreover, since the soil samples curve shapes are similar to the EBM samples suggests a local origin to those samples. The average particle size fractions of the assessed EBM samples corresponds to 14% gravel, 24% sand, 50% silt and 12% clay, while in respect to the soil sample it corresponds to 16% gravel, 27% sand, 41% silt and 16% clay.

Surprisingly, the silt content value differs significantly from the silt content of other technologies as adobe, rammed earth or CEB, which are usually lower and between 10% and 40% [13]. According to this result, this EBM is unsuitable for rammed earth, adobe or CEB, since the silt content is excessively high.

Afterwards, plasticity tests were performed for each sample resorting NP143 [27] and the obtained plastic limit (PL), liquid limit (LL) and plasticity index (PI) are presented in Table 1, as well as their classification according to the Unified Soil Classification

System (USCS). Has presented in Table 1 it was not possible to obtain the plastic limit and the plastic index for the majority of the samples due to their low clay content, excepted for sample C4. In mean terms, the liquid limit (LL) of the EBM is equal to 23,69%.

Table 1. *Plasticity results*

Sample	*Atterberg* limits (%)			USCS Classification	Sample	*Atterberg* limits (%)			USCS Classification
	LL	LP	PI			LL	LP	PI	
C1A1	25,23	--	--	ML	C5	24,16	--	--	ML
C1A2	21,18	--	--	ML	C6	26,66	--	--	ML
C1A3	22,09	--	--	ML	C7	26,83	--	--	ML
C1A4	21,65	--	--	ML	SL1	24,34	--	--	ML
C1A5	20,19	--	--	ML	SL2	24,06	--	--	ML
C2	26,42	--	--	ML	SL3	21,09	--	--	ML
C3	24,83	--	--	ML	SL4	20,15	--	--	ML
C4	21,31	20,29	1,02	ML	SL5	22,56	--	--	ML

Besides and according to the USCS these samples are classified as silt (ML). Those results confirm, as grain size tests, that all the samples have a similar composition and thus the EBM present in different *tabique* buildings and in different *tabique* walls should have the same origin, which should be local. It is interesting to note that the liquid limit means value and the USCS classification are in agreement with the recommendations proposed by Cyted [16], regarding *tabique* constructions located in South America, suggesting that EBM *tabique* buildings can follow a standard.

4.3.2. Chemical and mineralogical tests

The elementary chemical composition and proportions obtained through EDS test and relative to EBM samples are summarized in Table 2. The chemical compounds identified are sodium (Na), magnesium (Mg), aluminium (Al), Silicon (Si), chlorine (Cl), potassium (K), calcium (Ca), titanium (Ti) and iron (Fe). The EBM samples most relevant chemical compounds are silicon (Si), aluminium (Al) and iron (Fe) with the following average proportion values: 52,61% of silicon, 19,84% of aluminium and 11,58% of iron. Moreover, all the samples present approximately the same chemical composition which corroborated the idea that the EBM has a standard composition in that region. Furthermore, those results are in agreement with previous results reported by Pinto *et al.* [1], in the *Trás-os-Montes e Alto Douro Region* and relatives to other *tabique* buildings. From the results obtained, is it possible to conclude that the EBM used on the *tabique* traditional buildings of the *Alto Douro* is, basically, a natural mixture of sand and clay, since the main chemical elements detected in the samples were silicon and aluminium.

Since limestone is uncommon in these regions of Portugal, the expressive high quantity of calcium (Ca) present in sample C1, should be due to the presence of a hydraulic binder based on lime which is incorporated in the earth based material to create a filling and coating. The studies reveal that it is a common practice in *tabique* buildings presents in the *Alto Douro*. Meanwhile, the XRD test results are presented in Table 3, where the mineralogical elementary composition of the samples is identified.

These results indicate a similar mineralogical composition for each sample. Quartz is a common mineral in the region and muscovite is a clay mineral with low activity. The results also highlight an unexpected high quantity of calcite in the earth based sample C1 for reasons already reported.

Table 2. *SEM/EDS results*

Samples	Chemical compounds (%)								
	Na	Mg	Al	Si	Cl	K	Ca	Ti	Fe
C1	1,78	1,83	16,71	40,39	0,11	4,18	24,36	0,76	9,88
C2	1,80	1,78	17,68	57,62	0,60	5,61	2,47	1,16	11,28
C3	0.90	1,78	20,15	56,57	0,60	6,64	1,15	1,04	11,17
C4	0,64	2,25	22,62	49,44	0,63	6,74	1,12	2,13	14,43
C5	1,21	2,12	22,57	50,49	0	7,16	3,36	1,34	11,75
C6	0,94	1,84	20,68	54,1	0,39	7,41	0,82	1,25	12,57
C7	1,71	1,81	18,47	59,64	0,16	5,78	1,64	0,84	9,95
SL1	1,71	2,17	17,87	55,14	0,29	7,87	1,93	1,21	11,81
SL2	1,53	1,92	16,83	55,99	0,22	7,65	2,06	1,45	12,35

Finally, the surface topography of some EBM samples is illustrated in Fig. 9 through SEM micrographs taken at 500X. The images indicate that all the samples have similar surface topography and a similar texture, which confirms that EBM samples have standard properties.

Table 3. *Mineralogical elementary composition*

Sample	Calcite	Quartz	Muscovite
C1	Yes	Yes	Yes
C2, C3, C4, C5, C6, C7, SL1, SL2	No	Yes	Yes

Those results also indicate that the particles present in soil sample SL1 an SL2 are bigger than those presents in the EBM samples and with a bigger volume of voids, this could evidence that some kind of sieving and compaction process is made before the application in *tabique* elements.

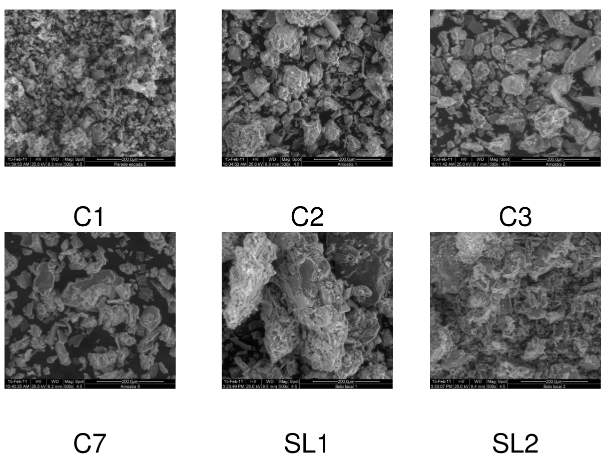


Fig. 9. EBM and soil Samples SEM micrographs

5. PROPOSAL

The literature recommends, for each earth building technology an EBM with grain size fractions located within a PSD envelope, and it is usual to found them in the literature concerning adobe, rammed earth and CEB. Therefore, in this work a PSD envelope regarding the *tabique* buildings EBM is proposed. In Fig. 10, a PSD envelope is plotted against the PSD curve samples previously studied.

Besides, in Fig. 10, a PSD envelope corresponding to the EBM recommended for a similar timber framed technology from South America and proposed by Cyted [13] is also plotted.

It is worth to mention that these two envelopes show similarities (UCSC and liquid limit similarities were already reported) suggesting that the EBM used in timber framed technologies can in some cases follow a standard.

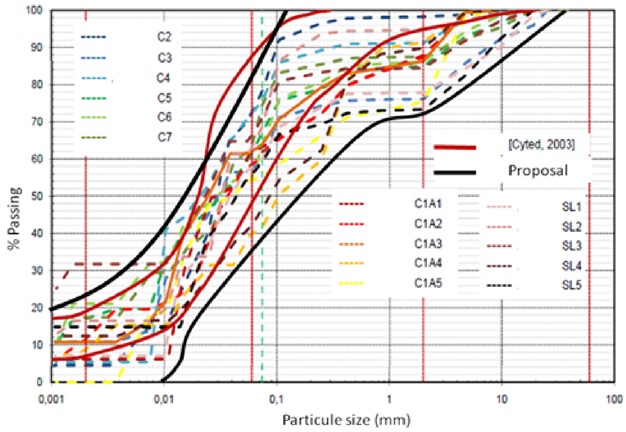


Fig. 10. Grading curves and PSD envelope

6. CONCLUSIONS

An experimental work, based on laboratory tests usually used in the characterization of earth-based samples was conducted in EBM *tabique* building samples. Those tests allowed to define the properties of the EBM used in *tabique* buildings located in the *Alto Douro*. This evaluation is a primary question because not all EBM are suitable for a given earth technologies.

It was concluded that the EBM samples PSD follows a standard and that their origin should be local. This EBM is composed of 14% of gravel, 24% sand, 50% silt and 12% clay and according to the USCS classification those samples are classified as silt (ML). These findings suggest that the EBM is unsuitable for rammed earth, adobe or CEB since the silt content are excessively high. The chemical elements presents in higher proportion are silicon (52,61%), aluminium (19,84%) and iron (11,58%). The mineralogical study shows that the EBM is made of quartz and muscovite. In some cases, calcite was present since it is a common practice in that region to use EBMs enriched with hydraulic lime. Furthermore, a PSD envelope was proposed and recommended. At our knowledge, this is the first time a PSD envelope for *tabique* buildings is proposed.

This envelope allows to evaluate the suitability of a given EBM to be used in future conservation works and in new *tabique* buildings in Lamego municipality and eventually in other places since these measures will require the application of adequate EBMs or compatible with the original ones. This information can also give guidance to the development of standards and be a requirement for the future development of numerical tools for the structural stability analysis of these *tabique* buildings.

We should be well aware that the environmental issues are gaining an increasing interest worldwide and presently, the building industry has been recalling earth-based building technologies as a modern building solution due mostly to its recognized sustainability, low environmental impact, mainly because it contains low material embodied energy, low carbon dioxide release and generate reduced waste materials, besides it as good thermal and acoustic properties and high durability.

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