Characterization of Traditional Tabique Constructions in Douro North Valley Region

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Abstract: - Generally, the traditional building techniques uses natural and local building materials such as stone, woodand earth and, are associated to building procedures that requires small amount of energy consumption and release an expressive noxious gases to atmosphere. The development of green building techniques that help the building industry contributing to a much more sustainable world may be inspired on these traditional building techniques as models. Each sector of societies including ourselves should pay a bill for environmental damaging. Each construction should have as associated environmental damaging cost and the selection process of a construction design solution should also be done in a sustainable bases in which the environmental parameters should be clearly identified and quantified. The tabique is one of the main Portuguese traditional building techniques, which is based on raw materials as earth and wood. In general, a tabique wall is formed by a simple timber structure covered by an earth based material. Earth has an important role in this system because it protects the internal timber structure as well as is a finishing. The Trás-os-Montes e Alto Douro is the northeast region of Portugal and it is very rich in terms of tabique heritage construction. Meanwhile, the existing tabique constructions show a generalized advanced stage of deterioration. This aspect associated to the fact that there is still a lack of scientific studies done in this field motivated this research work, which its main objectives are to identify the building process of tabique elements and to identify/characterize the applied materials. It is intended to stimulate and to give guidance for future rehabilitation works in this field. Taking into account that this region has a large area, it was necessary to divide this work in six stages related to the six council associations, which are Alto Tâmega; Terra Quente Transmontana; Terra Fria do Nordeste Transmontano; Vale do Douro Norte; Vale do Douro Sul and Douro Superior. This work is focused on the council association of Vale do Douro Norte (Douro North Valley), and uses twelve constructions as study cases. This research work also intends to contribute for a better sustainable world by stimulating the applications of natural building materials and the reutilization of traditional building techniques which are environmental friendly.

Key-Words: - Tabique, timber structures, raw materials, urban rehabilitation, materials characterization, traditional construction techniques, sustainability

1 Introduction

The most popular traditional Portuguese building techniques that use earth as a building material are taipa, adobe and tabique [1]. A tabique element, such as a wall, is formed by a timber structure covered by an earth-based mortar plaster layer.

This research work is focused on the study of the tabique technique in the region of Trás-os-Montes e Alto Douro. This is northeast region of Portugal, where this traditional Portuguese building technique has a significant incidence.

Taking into account that the traditional technical knowledge was loosed, on the other hand, there is still a lack of scientific studies on this subject for the aforementioned region and that traditional tabique constructions show generally an advanced stage of deterioration; this research work is completely justified, intending to guide and support future conservation and rehabilitation works.

From preliminary research works [1, 2], it was concluded that due to the diversity of tabique solutions and to the dimension of the region, it would be

convenient to divide the above region in sub-regions in order to have a handle area of work, making feasible this study highly supported on field work.

Thus, the Trás-os-Montes e Alto Douro region was divided in six sub-regions, which are Alto Tâmega, Terra Quente Transmontana, Terra Fria do Nordeste Transmontano, Vale do Douro Norte, Vale do Douro Sul and Vale do Douro Superior. The tabique constructions of the Vale do Douro Sul sub-region were already studied and reported on [3].

Meanwhile, a study of tabique constructions in the sub-region of Alto Tâmega is being developed. This research work is related to the sub-region of Douro North Valley (Vale do Douro Norte).

To achieve the objectives of this work, several technical visits to this sub-region were done in order to locate and select representative tabique constructions, to collect data of the selected buildings and the related construction details.

All the information collected was organized in appraisal forms. For each construction were extracted material samples for the experimental characterization.

It was found that the most common use of tabique technique was in interior partition walls, but can be also found in exterior façade walls. The majority of the existing tabique constructions are detached houses with two storeys and, generally, this constructions show an advanced stage of deterioration, which can dangerously progress till the total construction loss.

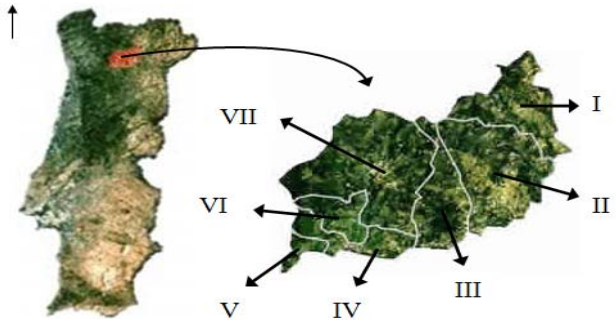
From the research done on the selected representative constructions, it was concluded that the most common materials used are the *Pinus pinaster* for the timber structural elements, earth for the mortars covering the timber structure, and steel nails for the connection between timber elements.

2 Council Association of the Douro North Valley (AMVDN)

The council association of the Douro North Valley (AMVDN) is one of the six council associations that form the Trás-os-Montes e Alto Douro region.

The seven councils of the AMVDN are Murça, Alijó, Sabrosa, Peso da Régua, Mesão Frio, Santa Marta de Penaguião and Vila Real (see Fig.1). These seven councils present all together an area of 1214 km^2 and a population of 112786 persons.

The councils which have higher population density are Mesão Frio and Peso da Régua, with more than 180 persons/km^2. In contrast, Murça is the council with lower population density, approximately 37 persons/km^2 [4].



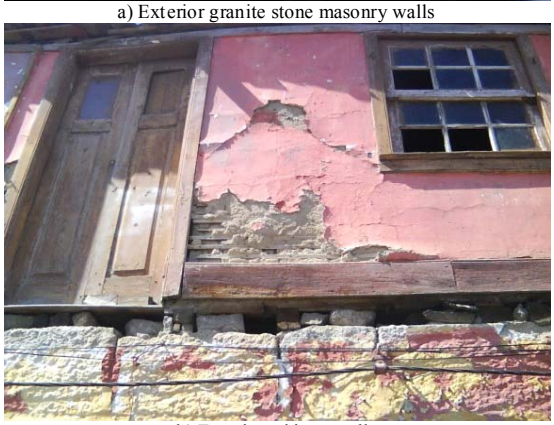
I - Murça
II - Alijó
III - Sabrosa
IV – Peso da Régua
V – Mesão Frio
VI – Santa Marta de Penaguião
VII – Vila Real

Fig.1 - Location of AMVDN in the continental Portuguese territory and its councils [4]

3 Tabique Construction

In Portugal the tabique construction is spread out along the country. However, this Portuguese traditional construction is more likely to find out in the north and, in particular, in the region under research.

a) Exterior granite stone masonry walls



b) Exterior tabique walls

Fig.2 - Two examples of typical tabique houses

The tabique construction is mainly from the Sec. XVIII and early XIX and started to be in disuse when the reinforced concrete and the ceramic bricks were introduced.

The type of tabique construction that is frequent to find is single houses of two floors in which the exteriors walls are granite stone masonries and the interior ones are tabique. At the same time, there are also cases in which the exterior walls of the upper floors are also in tabique, Fig.2.

A tabique constructive system can be found in several building components/elements as walls, verandas or even chimneys (see examples in Fig.2 and Fig.3). These last examples give indications of the capacity of tabique elements to resist even to very aggressive actions, if properly protected.

a) A tabique veranda

b) A tabique chimney

Fig.3 - Examples of tabique constructive elements (veranda and chimney)

The research work developed is mainly focused on tabique walls.

4 Research Strategy and Fieldwork

Taking into account that the area under study has an extension of 1214 km^2, it was necessary to organize and plan the field work in order to achieve efficiently the proposed first objectives without excessive time consuming tasks and as have been adopted in other similar research projects [5, 7, 8, 9, 10].

Therefore, the field work consisted on the following logic sequential tasks: (i) to visit all the seven councils areas in order to select the tabique constructions to be detailed studied and to interview retired builders; (ii) to contact the building owner of each construction and to ask for permission; (iii) to visit the constructions, making an extensive photographic report of the construction details, measuring the buildings and its constructive elements, and getting material's samples for the experimental characterization studies to be made at the laboratories.

APPRAISAL FORM	
Construction type: Detached house	
Number of floors: 2	
Owner: Dr. Afonso	
Location	
District: Vila Real	**Area:** Candedo
City: Murça	**Street:** Travessa da Laranjeira
Description/Characterization of the tabique construction element	
Conservation level: Deteriorated	
Identification: Interior wall	
Material samples: Yes	
Finishing: earth mortar and plaster	
Height (cm): 330	
Width (cm): 207	
Thickness (cm): 6.5	
Vertical timber	
Width (cm): 16.5	
Thickness (cm): 4.5	
Spacing (cm): 2.5	
Horizontal timber elements	
Width (cm): 2.5	
Thickness (cm): 1	
Spacing (cm): 2.8	

Fig.4 - Appraisal form filled for an example of a house construction of tabique in Candedo, Murça council (April 2009)

For the buildings survey, it was adopted the application form presented in Fig.4, which was very helpful in the compilation and systematization of the information needed for this research work. The application form structure and contents was detailed explained and justified in [3].

In the framework of this research project were studied twelve tabique constructions, which location is indicated in Fig.5. The selected constructions are a sampling representative of the existing tabique constructions in the AMVDN. As already stated, this type of construction is fully disseminated in the entire AMVDN region.

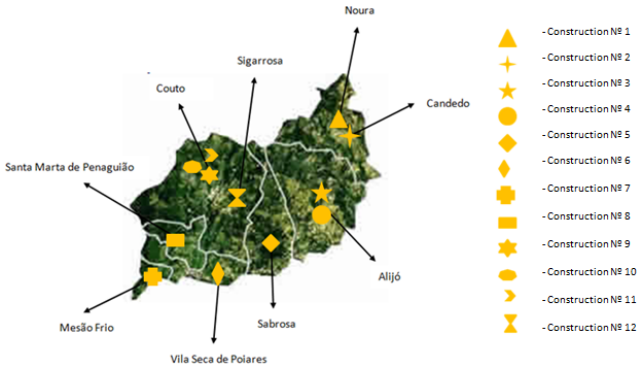


Fig.5 - Location of the twelve tabique constructions studied

For this research work, it was defined a global conservation scale to identify the deterioration stage of each tabique constructions analyzed. Fig.6 shows the proposed conservation scale.

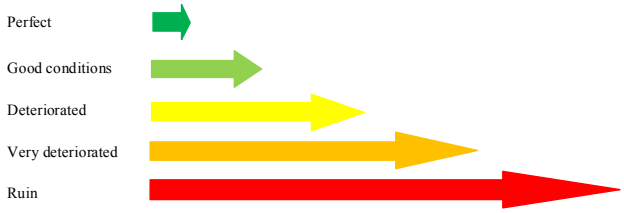


Fig.6 - Conservation scale

Fig.7 - Conservation state: Perfect

Fig.8 - Conservation state: Good conditions

Fig.9 - Conservation state: Deteriorated

Fig.10 - Conservation state: Very deteriorated

Fig.11 - Conservation state: Ruin

Fig.7 to Fig.11 exemplify, for each conservation scale level respectively, an example of the typical damage scenario.

5 Field Work Results and Analysis

Fig.12 shows the twelve constructions studied in this research work. This figure also indicates the adopted designation for each construction, which will be related to the designation used for the different material samples collected and studied.

Table 1 summarizes the principal data collected for the twelve tabique constructions studied within this research.

a) Construction Nº 1 b) Construction Nº 2 c) Construction Nº 3
d) Construction Nº 4 e) Construction Nº 5 f) Construction Nº 6
g) Construction Nº 7 h) Construction Nº 8 i) Construction Nº 9
j) Construction Nº 10 k) Construction Nº 11 l) Construction Nº 12

Fig.12 - Tabique constructions studied in the AMVDN

Table 1 - Data collected for the twelve tabique constructions studied

Construction			Tabique walls						Wooden structure elements					
									Vertical elements			Horizontal elements		
Label	and type	Nº of storeys	Location	Height (cm)	Width (cm)	Thickness (cm)	Finishing	Conservation state	Width (cm)	Thickness (cm)	Space between elements (cm)	Width (cm)	Thickness (cm)	Space between elements (cm)
Nº 1	detached house	2	exterior façade on the first storey	200	484	12	whitewash	deteriorated	14	3	1.5	3	1	4
Nº 2	detached house	2	interior wall on the first storey	130	207	6.5	whitewash	deteriorated	16.5	4.5	2.5	2.5	1	2.8
Nº 3	terraced house	3	interior wall on the first storey	330	255	10	whitewash	deteriorated	20	3	1	2.5	1	4
Nº 4	detached house	2	interior wall on the first storey	260	383	10	whitewash	deteriorated	12	4.5	2	3	1	2.5
Nº 5	detached house	2	interior wall on the first storey	290	295	8	wallpaper	good conditions	19	3	1	2	1.5	2
Nº 6	detached house	2	interior wall on the first storey	330	370	5.5	---	very deteriorated	15	4.5	1.5	2.5	1	3.5
Nº 7	detached house	2	exterior façade on the ground and first storeys	660	385	7	slate board	very deteriorated	13	5	2	4	1	2.5
Nº 8	detached house	3	interior wall on the first storey	260	270	5.5	whitewash	very deteriorated	18	2.5	5	2	1.5	3.5
Nº 9	detached house	2	exterior façade on the first storey	200	537	10	whitewash	deteriorated	21.5	3	2	2.3	1	3.5
Nº 10	detached house	2	exterior façade on the first storey	200	367	---	whitewash	deteriorated	---	---	---	3.25	2	4
Nº 11	detached house	2	exterior façade on the first storey	250	200	11	whitewash	ruin	14	2	2	2.5	1.5	3
Nº 12	detached house	2	interior wall on the first storey	222	160	9.5	whitewash	very deteriorated	18	5.5	2.5	3	1.5	3

Based on the data of Table 1, it is possible to notice that most of the tabique constructions of the AMVDN region are detached houses of two storeys where the tabique constructive elements basically appears as interior partition walls located on the first storey. However, it should be underlined a very interesting aspect observed, specifically were found frequently exterior façade tabique walls on the first storey level.

From the conservation stage observed *in-situ*, the majority of the inspected constructions were classified as "deteriorated", according to the conservation scale presented in Fig.6. Only one of the studied tabique constructions showed a good level of conservation.

Regarding to the timber structural components of the tabique construction elements, data of Table 1 shows that no uniform dimensions of the timber elements were found. However, typical dimensions details of tabique walls are presented in Fig.13 and Fig.14, for interior and exterior tabique walls, respectively.

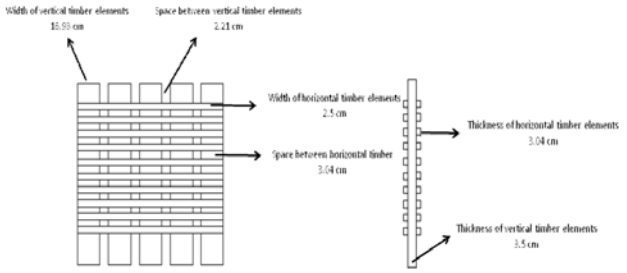


Fig.13 – Detail for the timber structure of a typical interior tabique wall

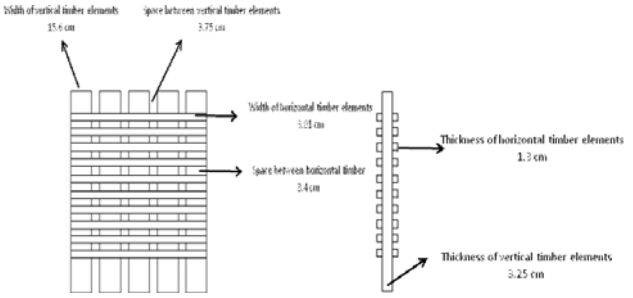


Fig.14 – Detail for the timber structure of a typical exterior tabique wall

The dimensions presented are the most common dimensions founded for each component of the inspected tabique constructions, which individual dimensions were presented in Table 1.

It is important to underline that the gap between the vertical timber elements allows for a better adherence of the earth based plaster mortar. The traditional application of the plastering mortar in this way guarantees that the timber elements are completely surrounded and covered by this earth based mortar, which creates good conditions for their natural protection. The observation of examples of tabique walls in many existing constructions proves that an adequate conservation can be assured of the timber elements by the traditional lime plasters.

6 Materials Identification and Characterization

In order to identify and characterize the materials traditionally used in the tabique constructions, an experimental campaign was developed using the materials samples collected at the studied constructions during the fieldwork.

Apart from the metal nails used to connect the timber elements, the most relevant tabique construction materials are earth and timber, natural materials.

6.1 Mortar

The timber structure of a tabique constructive element is covered on both sides by mortar, usually an earth-based material.

A granulometric analysis was done at the Material and Soil Laboratory of the University of Trás-os-Montes e Alto Douro (UTAD) of the mortar samples collected in the existing constructions under analysis (see example of a mortar sample in Fig.15), using the procedures according to the ASTM standards. Results of the granulometric analysis have shown that the soil typically used for the production of these mortars is approximately composed by 80% of sand and 20% of silt and clay and, as the results in the granulometric curves presented in Fig.16 indicate.

Fig.15 - Mortar sample for the granulometric analysis

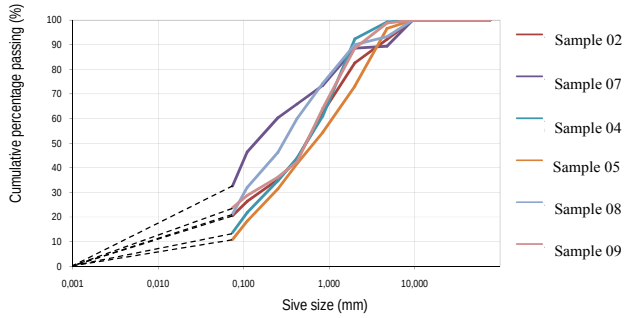


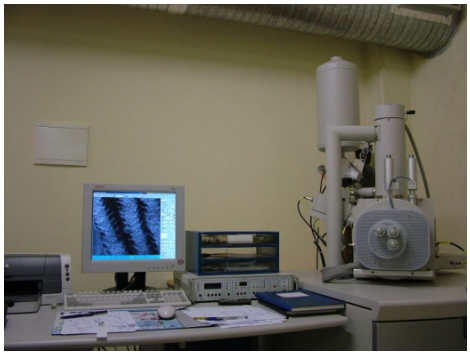
Fig.16 - Granulometric curves

In order to identify the chemical and mineralogical elementary composition of the samples mortars collected, scanning electron microscopy/energy dispersive spectroscopy (SEM/EDS) and X-ray tests were performed, in the Microscopic Electronic Unity of the UTAD (see Fig.17-a and Fig.17-b, respectively). The material samples used for this study are also shown in Fig.17-c.

Similar tests have been already done in the framework of other research projects (see [2] and [6]), to characterize the available and used materials for the local traditional constructions.

The results obtained by the SEM/EDS test are presented in Table 2 and the results of the X-ray test are shown in Fig.18.

The adopted designation for the earth-based mortar samples in Table 2 is related to the constructions from where each sample was extracted (for example, earth-based mortar sample 02 means that the sample was extracted in construction 02, Fig.12). This information also means that it was not possible to get earth-based mortar samples from all the studied constructions. It was also used a sample of clay, which was designed by *reference sample* (see Table 2, column 2), to sustain the comparative analysis.



a) SEM/EDS`s test equipment

b) X-ray test equipment

c) samples for the tests

Fig.17 - Equipment and samples used for the SEM/EDS and X-ray tests

Table 2 - Results of SEM/EDS tests

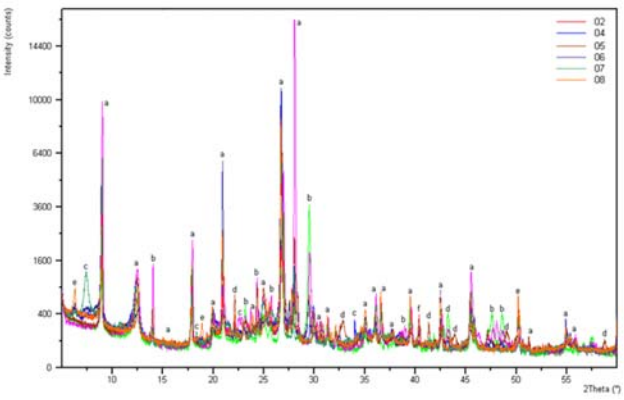
Chemical element (%)	Reference sample	Earth based mortar samples					
		02	04	05	06	07	08
Oxygen (O)	48.12	46.10	47.13	48.49	45.27	44.90	44.91
Sodium (Na)	0.62	---	0.52	1.19	0.63	---	0.88
Magnesium (Mg)	0.89	1.15	0.62	0.77	1.57	1.11	1.39
Aluminium (Al)	12.90	12.74	16.53	10.30	10.73	15.01	13.04
Silicon (Si)	29.04	28.02	26.38	17.70	26.89	25.63	27.53
Phosphorus (P)	---	---	---	0.21	0.16	---	0.26
Sulphur (S)	---	---	0.19	0.66	0.26	---	0.08
Chlorine (Cl)	---	---	0.08	0.07	0.30	0.08	0.12
Potassium (K)	---	3.08	3.09	1.47	3.06	2.95	3.86
Calcium (Ca)	---	0.28	**0.25**	**16.38**	5.03	---	1.08
Titanium (Ti)	0.38	0.48	0.46	0.20	0.51	0.82	0.24
Iron (Fe)	4.36	5.52	4.51	1.90	4.94	8.99	5.95
Copper (Cu)	---	---	0.24	0.68	0.65	0.52	0.67

The results obtained, and presented in Table 2, confirms that the earth-based mortar used on the tabique traditional constructions of AMVDN region is, basically, a natural mixture of sand and clay, since the main chemical elements detected in the samples were the Silicon and Aluminium.

It should be underlined that one of the earth-based samples (sample 05) presented an unexpected high quantity of Calcium, namely 16.38%. Because the limestone is uncommon in this region of Portugal, it is concluded that this mortar sample has incorporated an important amount of lime.

Table 3 - Mineralogical compositions of the earth-based material samples

Samples	Mineralogical composition
Reference sample	Muscovite + Kaolinite
02	Muscovite
04	Muscovite + Kaolinite
05	Muscovite + Albite
06	Muscovite + Calcite
07	Muscovite + Kaolinite
08	Muscovite + Quartz

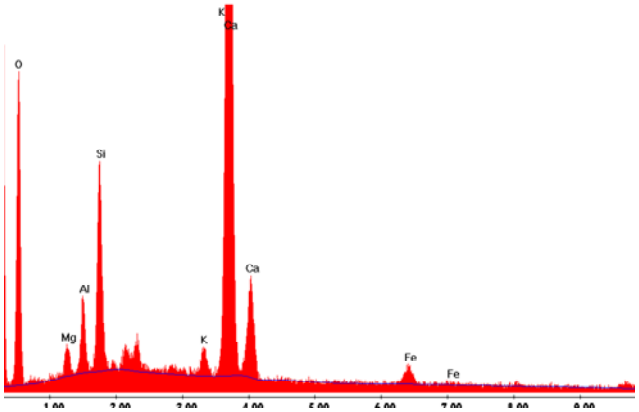


Legend: **a** -Muscovite, **b** – Calcium Carbonate, **c** - Kaolinite, **d** - Albite, **e** - Quartz, **f** - Calcite

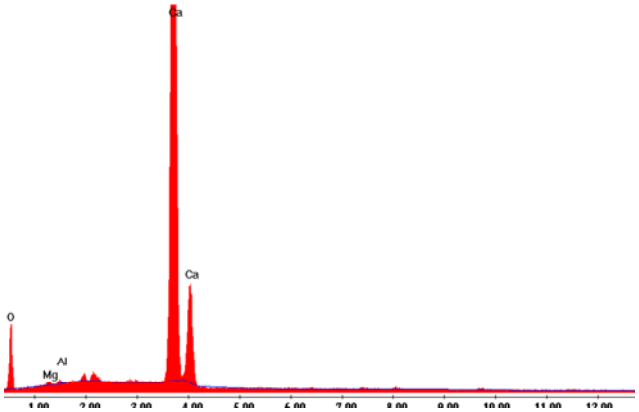
Fig.18 - Results of X-ray analysis of the sample

In addition, in order to complement and to guide this analysis, it is presented in Fig.19 the results of the X-ray diffraction test of the lime and of the hydraulic lime samples, which are the most used binder type used in this traditional building technique. It is noticed that both of them has a considerable percentage of calcium in their constitution.

Meanwhile, this test also indicates that the mineralogical elementary compositions of the lime and of the hydraulic lime tested are calcite and calcium oxide and calcite, quartz and plaster, respectively.



a) Lime



b) Hydraulic lime

Fig.19 - X-ray diffraction results

On the other hand, results of the SEM/EDS tests indicate as chemical elementary composition of these materials the values presented in Table 4.

Table 4 - Chemical elementary composition of lime and hydraulic lime

Chemical element (%)	Lime	Hydraulic lime
O	56.06	39.85
Mg	2.01	0.50
Al	3.40	0.38
Si	7.92	--
K	0.99	--
Ca	28.01	59.26
Fe	1.60	--

According to the information in Tables 2 and 3, and in Fig.18, the covering material of the timber structure is an earth-based material, generally without the addition of an agglutinant component like cement.

Only one tested sample collected from the construction 5 revealed the presence of agglutinating components in a quantity similar to the composition of the traditional mortars (1:4 to 1:5), and which could be lime or hydraulic lime.

The chemical and mineralogical elementary composition of the lime and of the hydraulic lime data presented here may also be very helpful as reference for others research works on the characterization of traditional constructions.

6.2 Timber

During the fieldwork, it was only possible to get timber samples related to the six of the twelve constructions analyzed. The designation of each timber sample (see Table 5, column 1) is related to the adopted designation for the constructions from where that sample was extracted.

The experimental identification and characterization process of the six timber samples was done at the Laboratory of the Forest Department of UTAD. Fig.20 shows examples of the tested timber samples, collected from the studied tabique constructions, and analyzed within this research project.

Fig.20 - Timber samples

The results of the classification are presented in Table 5.

Table 5 - Identification and characterization of timber samples

Sample	Specie
02	*Populus sp*
04	*Pinus pinaster*
05	*Pinus pinaster*
06	*Pinus pinaster / Castanea sativa*
07	*Pinus pinaster*
08	*Pinus pinaster*

It was concluded that the *Pinus pinaster* is the most common type of wood traditionally used in the timber structural components of the tabique elements. Moreover, *Pinus pinaster* is the most abundant type of tree in this region of Portugal.

6.3 Nails

The mechanical connection between the timber elements was usually made with nails. Hardness tests and reaction to chemical agent tests were done at the Materials Laboratory, of the Department of Mechanical Engineering, of the UTAD, for six nail samples, collected during the inspection works to the constructions. Fig.21 shows examples of the nail samples collected and tested.

Fig.21 - Nail samples tested

Table 6 summarizes data related to the geometry of these nails, as well as the results of the material characterization.

Table 6 - Dimensional and material characterization results of nail samples

Sample	Length (cm)	Diameter (cm)	Type of Cross section	Material
02	5.0 / 3.0	0.5	square	steel
04	3.5			
05	4.0			
06	4.0			
07	4.0			
08	5.0			

From the characterization tests of these connectors, the experimental results indicate that these nails are made of steel. This fact contradicts the information gotten during the fieldwork, when retired builders were interviewed about this subject. They said that normally the nails used to connect the horizontal timber elements to the vertical ones were zinc based material in order to avoid any oxidation process that could deteriorate the plasters or finishings of the walls.

7 Main Conclusions

Trás-os-Montes e Alto Douro is a region rich in tabique constructions. The sub-region Douro North Valley also confirms this fact.

Generally, these constructions are based on the use of natural materials and exhibit an advanced stage of deterioration. The owners should be stimulated to preserve this wonderful and invaluable heritage.

In general, the Douro North Valley constructions that have tabique elements are detached houses of two storeys and the tabique elements are more commonly used as interior partition walls. However, exterior tabique walls can also be frequently founded at the first floor level.

The most common structural materials used in the tabique elements are the *Pinus pinaster* timber, being the timber elements connected by steel nails. In addition, this structural support system is normally covered on both sides by an earth-based material instead of conventional mortars.

The dimensions traditionally adopted for the elements of the above-described system changes quiet sharply among the constructions analyzed. However, it was originated details for the timber structure of typical interior and exterior tabique walls, with average values for the dimensions of its wooden elements.

In this work, it was also proposed a conservation scale to evaluate the level of deterioration of typical tabique constructions, which was adopted in the evaluation of the construction analyzed within this project.

The results of this characterization work can assist the local authorities in the definition of a global strategy for the rehabilitation of this huge building heritage, arising the EU Sustainable Development Strategy and its key objectives, as is being developed in other European regions.

As stated in [11, 12], an innovation management culture should be developed, pushing the sustainable development. Requirements of environmental legislation, namely the EC eco-audit regulation, should be integrated in the environmental management actions [11].

The results of the research and the knowledge produced must be used in the processes of rehabilitation, helping to preserve the heritage, but also to save money, reducing resources and utility costs. Fortunately, many regions, authorities and associations has started to apply sustainable development strategies in their policies definition, for the environmental protection, restructuring their projects, with new strategic development planning approaches, but also by institutional and organizational adjustments [13]. In [14] and [15] can be found examples of good practices of restoration of traditional building heritage, adopting the re-use of materials and construction components.

Also, the results obtained within this research project on the characterization of tabique constructions will be a basic requirement for a future development of an empirical and numerical tool for the structural stability and safety analysis of these tabique constructions. In fact, in the structural analysis of existing masonry buildings, normally, tabique walls are disregarded, wrongly justified by their small stiffness and strength when compared with the load-bearing walls. But, they should be considered, specially for structural analysis under horizontal loadings, as the induced by earthquakes and wind.

A simplified numerical model for the traditional tabique walls, as the proposed in [16], is envisaged, for a more rigorous safety analysis of existing tabique constructions, a vast building heritage in many countries.

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