

EARTH BASED RENDER OF TABIQUE WALLS – AN EXPERIMENTAL WORK CONTRIBUTION

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Abstract:

A research work focused on studying earth render for *tabique* application purposes is presented. Initially, a brief description of the *tabique* building technique is provided. The relevance of the application of this traditional building technique is also highlighted. Different compositions of earth render are experimentally analysed and the respective performance is evaluated. Flexural and compressive strengths, workability, drying shrinkage cracking and water resistance are the material properties assessed. A simple earth render is selected as being adequate for *tabique* building applications and it is applied on the manufacturing of a *tabique* wall sample. This wall sample is monitored in terms of thermal insulation ability and its thermal transmission coefficient is estimated. Taking into account that there is still a lack of published technical information related to this topic, this paper may contribute to solve this limitation and to give some guidance in future repairing processes of *tabique* construction. The technological benefit of adding lime or cement with earth is researched. Real *tabique*

timber structure samples are applied in order to validate the obtained experimental results.

Keywords: *Tabique*, earth, raw material, render, traditional building techniques, wall, material properties, sustainability

1 – Introduction

In the building industry there is an increasing trend of choosing raw and organic building materials as an alternative to the application of industrialized materials. Sustainability and affordability are two attributes that justify this building option. For example, stone, timber, earth, sand, clay, cork and bamboo [1-8] are some traditional building materials that match these requirements. Taking into account that traditional building techniques apply these types of materials, focusing on their study may result in improving the knowledge related to the application of these building materials [9-10].

Adobe, rammed earth and *tabique* are traditional building techniques applied worldwide, which use earth as a building material [11-13]. Earth plays an important structural role in the adobe and the rammed earth contexts. On the other hand, it is extremely relevant as a finishing building element in the *tabique* building technique. In fact, it is applied as the major constituent of earth renders to cover the timber structural frames that characterize a *tabique* building element. An earth render protects the timber structure and gives technological attributes to the element. For instance, some of these technological attributes are water and fire resistance, as well as thermal and acoustic

insulation. Thus, an earth render plays a key role in the behaviour and in the durability of a *tabique* building element such as a wall.

Usually, *tabique* walls present a certain vulnerability to water. The impact of the rain on external *tabique* wall may generate a mechanical, physical and chemical deteriorating process of the earth render ending up causing damage. The degradation of the earth render may also affect the conservation of the timber structure, and consequently, the durability of the building may be put in risk. The penetration of rainwater and the humidity in the element will also influence its thermal conductivity. The latter scenario justifies the fact that it is common to coat externally *tabique* walls with water resistant solutions, such as metal corrugated sheets or schist tiles.

In the earth render context a hydraulic binder (e.g. lime or cement) is not considered necessarily as a constituent. Meanwhile, a soil with a certain plasticity is used instead of sand exclusively. Probably, these are the major technical aspects that differentiate an earth render from a cement based render.

According to research work performed in the *tabique* construction context [14] it has been concluded that this type of traditional construction is very likely to require measures of repairing, due to its age and also due to the lack of a proper maintenance policy. At the same time, there is still a lack of international design codes concerning earth construction and also of published technical information related to *tabique* construction. Thus, there are some technical constraints when actions of conservation or repairing of *tabique* construction are necessary.

Therefore, the main goal of this research work is to provide guidance in terms of earth renders for *tabique* building application purposes. In addition, a contribution to the knowledge of the thermal insulation properties of *tabique* walls is also given.

Although *tabique* is a Portuguese terminology, this traditional building technology has similarities with other techniques, with different designations, and which are from other parts of the world. For instance, in Brazil, *pau a pique*, *taipa de mão* and *taipa de sebe*, are three common designations of this building technique (or similar). On the other hand, in other South American countries such as Chile or Peru, *quincha*, is the terminology adopted. Meanwhile, the Anglo-Saxon terminology used is wattle and daub. Therefore, *tabique* construction may have a worldwide incidence. This fact may also justify the relevance of this research work.

This paper is structured as follows: firstly, a summary of the existing *tabique* construction in the north-east region of Portugal is provided; secondly, a summarised reviewing of traditional earth renders of *tabique* walls is also introduced; thirdly, some material properties of different earth renders are experimentally evaluated. Flexural and compressive strengths, workability, drying shrinkage cracking and water resistance are analysed for different six earth renders. At the same time, one of these earth render samples was selected for *tabique* building applications purposes and the thermal insulation behaviour of a *tabique* wall sample built with that selected render is also assessed in this section; finally, the main conclusions are drawn.

2 – Brief description of *tabique* construction

Tabique construction corresponds to a relevant Portuguese heritage. The *tabique* building technique was currently applied until the introduction and dissemination of the reinforced concrete construction technique. Therefore, the Portuguese urban city centres are very likely built according to *tabique* technique. Urban and rural *tabique* construction characteristics are differentiated in [15]. In general, a *tabique* construction corresponds to a dwelling. It tends to have several floors [14, 15]. A *tabique* bungalow is an uncommon typology solution. For instance, a two-floor dwelling and a *tabique* bungalow are presented in Figures 1.a and 1.b, respectively. Walls and chimneys are the main *tabique* building components. The walls may be exterior or partition. In the case of exterior *tabique* walls, these correspond to the main vertical structural elements of a building and they tend to be stiffer by presenting a more robust timber frame solution [15]. It has been reported [14] that the partition *tabique* walls are also relevant in terms of structural behaviour because they may work as a bracing solution of the main structural elements. Although, the timber frame of a partition wall tends to be lighter than the respective frame of exterior walls, they may have the same type of timber frame solution such as a set of vertical and horizontal timber boards connected to each other. Traditionally, a *tabique* dwelling presents stone (e.g. granite or schist) masonry walls at the cellar and ground floor, and *tabique* walls (e.g. exterior and/or interior) in the upper floors. In this type of building typology, the main horizontal structural elements are timber floors. In brief, a *tabique* building component is formed by a timber structural frame system covered with an earth render. There are different alternative solutions for the timber structural frame. Vertical timber boards linked to each other by a set of horizontal timber boards is a commonly applied timber structural frame solution. The horizontal timber boards are applied on both sides of the vertical timber boards. These horizontal elements also have an important function of improving the

adhesion of the earth render to the timber structure. The timber elements are nailed to each other.

At the present time, the Portuguese *tabique* construction tends to present signs of deterioration. The *tabique* buildings shown in Figure 1 are examples of this situation. A lack of a proper regular maintenance has been pointed out as being the main cause of this fact. Therefore, repairing actions are required. In order to carry out a proper repairing process it is required to know the specific technological aspects concerning this type of traditional building technique. This paper intends to give a contribution to this issue by studying earth renders. Earth render plays a key building functionality in the *tabique* context because it protects the timber structure by increasing its durability [14-15]. In fact, earth render increases the fire resistance of the wall and protects the timber structure from the biological attack of insects and fungus.

3 – Traditional earth render of *tabique* walls

More than three hundred *tabique* buildings existing in the north-east part of Portugal have already been studied [14-15] in order to contribute to the characterization of this valuable Portuguese heritage. The building typologies, the building materials (e.g. the filling of the *tabique* components, the species of the wood of the frame, the type of nails), the constructive solutions and the building details, the structural and non-structural defects and their causes and the possible rehabilitation solutions (structural and non-structural) are some of the technical aspects that have been under research concerning the *tabique* building technique [14]. In relation to the characterization of the commonly applied filling more than sixty filling samples of *tabique* walls were

collected and experimentally studied in terms of granulometry, elementary mineral composition and elementary chemical composition. Granulometric analysis, X-ray diffractometry test and scanning electron microscopy/energy dispersive spectroscopy analysis (SEM/EDS) were the experimental techniques performed in this study.

The granulometry results indicated that a ratio of 20% of thin particles (size smaller than 0.5 mm) and 80% of medium sized particles (in-between 0.5 mm and 2 mm) may be considered as being a traditional soil mixture for the filling material of *tabique* components. The earth has been characterised as being granite related. Additionally, a lime earth based render (incidence of 70%) and simple earthy render (incidence of 30%) were the identified render solutions currently applied as filling of *tabique* components. It was not possible to identify the amount of water and lime incorporated in the present research work. Therefore, this paper intends to give a contribution to this matter by studying six different mixes of earth render.

4 – Material properties of different earth renders

In order to prepare a *tabique* wall sample for thermal insulation behaviour analysis, an earth render had to be prepared. Therefore, it was necessary to collect a soil and a mix composition had to be chosen. Being local and having a similar granulometry to the earth render of the region's reference *tabique* wall were two of the main key conditions to select the soil. Considering that earth and a mixture of earth and lime are the main compositions of the traditional earth render applied in *tabique* building components [14-15], different mixes were studied. In this case, the flexural and the compressive strengths, the workability, the drying shrinkage cracking and the water resistance were

the material properties experimentally assessed to characterise the performance of each earth render. A description of the experimental work done, the presentation of the main results and the respective discussions are detailed in the following sections.

4.1 – Granulometry

A real partition *tabique* wall was used as reference in this research work, Figure 2.a. This wall was a building component of a traditional Portuguese dwelling that was demolished. During the demolishing and transportation processes most of the earth render of the wall was lost. Figure 2.b shows a detail of some of the remains of the earth render of the wall. In Figure 2, the traditional timber frame solution made of vertical and horizontal boards is also presented. This structural solution is currently applied in both exterior and partition walls [14].

The remains of the earth render of the *tabique* wall were collected (Figure 3.a) and ground. The granulometry of this material was assessed, Figure 4. In terms of particle size, this material seems to be formed by 10% of silt, 65% of sand and 25% of gravel. In terms of amount of thin particles (particle size smaller than 0.5 mm), it corresponds to 20%, approximately. These percentages are typical in the *tabique* context [14]. It is worth mentioning, that the colour of the material (greyish colour, Figures 2.b and 3.a), its high consistency and apparent strength are indicators that lime was applied in this earth render. This fact may have affected the results of the granulometric analysis. The amount of thin particles may have increased because of the existence of the lime particles. Moreover, the amount of thick particles (particle sized bigger than 2 mm) may have also increased because the agglutination of the soil particles which resulted from the addition of lime may have made the disintegration process difficult. Meanwhile, a

sample of local soil was picked up and its granulometry was also assessed, Figures 3.b and 4. Comparing the obtained granulometric curves, Figure 4, it is concluded that the earth render of the reference *tabique* wall and the picked soil have a similar granulometry. Therefore, the respective soil was assumed to be adequate for filling purposes of *tabique* building components.

4.2 – Earth render mixes

As it was previously stated, different mixes of earth render were studied in this research work. In fact, six mixes were considered. Three renders did not comprise any hydraulic binder, corresponding to having exclusively soil and different amount of water. These renders are designated as Mix 1, Mix 2 and Mix 3. Table 1 includes the mix composition for these renders. The respective soil:water ratio (in terms of weight) was 5:1, 5.7:1 and 6.7:1. On the other hand, two earth renders considered the addition of lime. These renders were Mix 5 and Mix 6, and the respective constituent soil:water:lime ratio was 20:3.8:1 and 12.5:2.5:1, Table 1. Finally, an earth render considering Portland cement as binder was also prepared according to the 40:6.5:1 ratio (soil:water:cement), designated as Mix 4 in Table 1. Among these renders, only Mix 4 is not traditional in the *tabique* context. However, its study seemed to be pertinent in order to assess its attributes.

4.3 – Flexural and compressive strengths

Ten samples of each earth render mix were prepared in order to be tested in terms of bending and compression at the age of 30 days and according to [16]. The curing process occurred under the controlled thermo-hygrometric conditions of a climate chamber (temperature of 20°C and a relative humidity of 40%). A Seydner Mega

10/250/15D testing rig was used to assess the mechanical properties, namely, its ultimate loading capacities, under bending (Figure 5.a) and compression (Figure 5.b). The tests were carried out in force control with a load rate of 5 and 24 N/s, respectively, for the bending and compressive tests. The flexural and compressive bearing capacity was 15 and 250 kN, respectively. The compression samples were obtained from the two halves of the prismatic samples tested in bending. Therefore, 60 samples were tested in bending (i.e. 10 per each earth render mix) and 120 samples were tested in compression (i.e. 20 per each earth render mix).

The obtained flexural (F) and compressive (C) strengths are plotted in Figure 6. The average flexural and compressive strength values are also featured in Figure 6. According to the data of Figure 6 some conclusions are ascertained in terms of the mechanical behaviour of the earth render of *tabique* building components. The inclusion of a hydraulic binder tends to increase the mechanical behaviour of the earth render, as also evidenced in other studies e.g. [9, 17]. In fact, Mixes 4, 5 and 6 have higher compressive and flexural strengths than Mixes 1, 2 and 3. Adding lime instead of cement seems to have a meaningful benefit in terms of the mechanical behaviour. At the same time, an increase in the amount of water also improves the strength of the material. Mixes 1, 2 and 3 are a clear example of this fact. Generally, an increase in the amount of a binder tends to be associated with an increase in the amount of water. Consequently, the respective expected strength improvement may not occur. This situation occurred between Mixes 5 and 6, in which an increasing of lime (from 300 g to 480 g, Table 1) resulted in a degradation of the mechanical behaviour of the render (average compressive strength varying from 1.53 MPa to 1.33 MPa and average bending strength varying from 0.49 MPa to 0.42 MPa, Figure 6). In addition, these

results also corroborate the fact that earth based building materials have a better behaviour in compression than in tension. In terms of failure modes, Figure 5.a indicates that a very well defined crack was formed approximately in the middle span of the earth render sample tested in bending. This type of failure mode occurred similarly in all the tested samples. Meanwhile, Figure 5.b features the typical failure mode observed in the uniaxial compressive test (i.e. underlined in red, Figure 6.b). It is worth referring that the occurring failure modes are similar to the ones occurred in currently applied building material (e.g. cement based render, concrete or stone) when they are tested in the same context.

4.4 - Workability

An adequate workability is an important expected attribute in an earth render of a *tabique* building component. Technical aspects such as mixing, adhesion, handling and finishing may influence this material property of an earth render. In order to evaluate the workability of the earth render of *tabique* building components a scale was defined as follows: very difficult (1 point); difficult (2 points); moderate (3 points); good (4 points); very good (5 points). On the other hand, a simple experimental set-up was adopted consisting of rendering a portion of a timber structure of a real *tabique* wall, Figure 7. The different mixes of earth render were applied on this structural element. Figure 7 gives some highlights of this experimental procedure in which a mix of an earth render is already applied (Mix 1) on the timber structure and another one (Mix 2) is in progress in terms of application. Through the latter figure it is also noticeable that the timber structure is rough or even furrowed, in order to facilitate the adhesion of the earth render on the timber structure. This is a traditional practice in the *tabique* context. Each earth render mix, Table 1, was applied in order to fill the existing gap between the

timber elements and also to form a layer of 1.5 cm of thickness. During the application process of each render, the above mentioned technological aspects were evaluated, and their classification is summarized in Table 2. Considering the specific technical particularities under research (earth based render and timber based wall), this expedite experimental set up was adopted instead of the slump flow test.

According to the proposed evaluation procedure, Mix 1 was the studied earth render that presented better workability because it obtained the higher rate (a rate of 16 points, Table 2). In fact, in the case of Mix 1, it was easy to mix the constituents, the render showed an adequate adhesion to the timber structure, it also was handled and it allowed a good finishing, Figure 7. Based on the data of Table 2, the adhesion seems to be the vulnerable technical aspect of Mix 1. At the same time, Mix 1 is followed by Mixes 5 and 6 in terms of workability. Mixes 5 and 6 obtained a rate of 14 points which represents a good workability. These mixes include lime as a constituent. The increase in the amount of lime was also followed by an increase in the amount of water and it may explain the fact that the workability was not affected. The addition of cement does not seem to benefit the workability of an earth render. In fact, it is necessary to increase the amount of water. The amount of water is a key factor for the workability performance of an earth render. This technical aspect is emphasized when Mixes 1, 2 and 3 are compared in terms of workability, Table 2. A reduction of the amount of water tends to reduce disproportionately the workability of the material. For instance, in Mixes 1 and 3 there was a 300 ml reduction (Table 1) of the water content and the respective workability performances dropped 9 points (from 16 to 7, Table 2).

4.5 – Drying shrinkage cracking

Another important material property of an earth render of a *tabique* building component is the drying shrinkage cracking tendency. Taking into account that it is expected to apply earth render on exterior *tabique* walls and that it is likely that this building component will not have any additional coating element, this material property is relevant in terms of durability. Apart from the quality of the render, the conditions of its application may also affect this cracking phenomenon. For instance, high temperature and dry timber support are some undesirable conditions. In order to analyse the susceptibility of each of the six earth renders under research in terms of this phenomenon, the samples processed for the workability assessment (previous section) were then dried naturally during 30 consecutive days and under the controlled thermo-hygrometric conditions of the laboratory. During this period of time the samples were visually monitored in order to check the drying shrinkage cracking appearance. The obtained experimental results are presented in Figure 8 in which the cracks due to drying shrinkage are identified in red for each earth render.

In general, the six different earth renders behaved adequately in terms of drying shrinkage because an impressive cracking pathology scenario did not occur in any case. Mixes 1 and 3 did not present any visible cracking, Figures 8.a and 8.c. It is worth underlining that these renders are processed exclusively with soil and water, Table 1. This building scenario corresponds to a traditional practise in the *tabique* construction. On the other hand, few cracks resulted from the natural drying of Mixes 2 and 4, Figure 8.b and 8.d, respectively. Mix 2 also corresponds to a render processed with soil and water and Mix 4 includes cement as a constituent, Table 1. However, these cracks are not expressive in terms of size. Meanwhile, Mixes 5 and 6 were more affected in terms of cracking appearance by the drying process, Figures 8.e and 8.f, respectively. In these

last two cases, the amount of cracks and their expressiveness were higher. In fact, in both cases, Figures 8.e and 8.f, there is a longitudinal crack. Mixes 5 and 6 include lime as a binder which is a traditional technique in this context. Probably, in these two cases, the amount of water added in the mixtures was excessive or indeed not adequate for cracking to appear. Generally, the cracks tend to be formed from the centre to the edge of the sample. Based on this information, it is possible to conclude that the inclusion of a hydraulic binder such as lime or cement does not seem to improve the quality of an earth render in terms of drying shrinkage cracking phenomenon. In fact, it tends to increase the susceptibility of the appearance of cracks due to the drying shrinkage, in particular, when lime is added. Aspects such as the number of the samples and the size of the adopted samples may limit the representativeness of these conclusions and it may justify further research in this matter.

4.6 – Water resistance

Another relevant material property that has to be considered in earth renders of *tabique* construction is the water resistance. Similarly to the other traditional earth building techniques such as adobe or rammed earth, a *tabique* building component is also vulnerable to water. This susceptibility is even higher if the component is placed in the exterior (e.g. an exterior *tabique* wall) and exposed to the rain. This fact justifies that these walls are currently coated with an additional element such as metal corrugated plates or schist tiles, among other possibilities. Therefore, the earth renders subjected to this research work were also tested in terms of water resistance. For this purpose, the samples used in the workability and in the drying shrinkage cracking studies were also applied in this context. In order to simulate in laboratory the mechanical impact of the rain on an exterior *tabique* wall an expedite set up was also specifically prepared to

perform the water resistance test. The adopted set up is schematically presented in Figure 9 and it consists of a device formed by a water tank, a pipe and a dropper. The water tank is placed at a height of 3.5 m in order to allow the water dropping by gravity. On the other hand, the drops fall at a distance of 1.0 m until reaching the earth render sample, which is positioned obliquely and forming an angle of 45° with the horizontal direction, Figure 9. The dropper allows controlling the intensity of drops falling on the sample.

Each earth render mix was tested in terms of water resistance. The duration of each water resistance test and the respective number of drops are shown in Table 3, and the respective damage due to the successive impact of the drops is presented in Figure 10. In this context, total damage of the sample corresponds to the complete loss of the material in the location where the drops fell. Therefore, it is a local total damage. When the duration of a test was 24:00:00 (hours:minutes:seconds) there was no total damage.

Thus, Mixes 5 and 6 had shown adequate water resistance ability because they did not face any damage for 1 day under the continuous mechanical effect of the impact of 172800 drops falling from a 1 m distance. These earth samples kept their integrity, Figures 10.e and 10.f. In contrast, Mixes 1, 2 and 3 showed a very vulnerable behaviour in terms of water resistance. In fact, they faced total damage in less than 01:00:00 h:m:s after being exposed to the impact of the falling of drops, Table 3. Figures 10.a, 10.b and 10.c show the extent of the occurred damage in these earth render mixes. Finally, Mix 4 also showed vulnerability in terms of water resistance because it reached total damage in less than 05:00:00 h:m:s, Figure 10.d and Table 3. Based on these results, we may conclude that the inclusion of a hydraulic binder tends to improve the water resistance

behaviour of an earth render of *tabique* construction, in particular, if that binder is lime. The fact that this improvement is not significant by adding cement as a binder may be related with material compatibility concerning the used soil and cement. Further research regarding this topic should be carried out.

4.7 – Thermal insulation behaviour

In order to estimate the thermal insulation ability of a *tabique* wall it was necessary to select a mix among the six mixes of earth renders studied. According to the results presented in the previous section, we may consider that Mix 5 obtained adequate quality in terms of earthy render showing, simultaneously, the best mechanical performance, a very good workability and proper water resistance. It only showed certain vulnerability in terms of the drying shrinkage cracking phenomenon. Meanwhile, Mix 1 also had shown acceptable achievement as an earth render of *tabique* construction. In spite of being extremely susceptible to water Mix 1 did not present any visible cracking due to drying shrinkage. This technical aspect may be relevant in terms of durability of the element and, in particular, in terms of thermal insulation performance. As it was stated earlier, coating this type of wall with a waterproof system is a traditional applied building solution thus, the water vulnerability of Mix 1 may be minimized. Therefore, at this stage, Mix 1 was the selected earth render to conduct the thermal insulation analysis. Being traditional and being simple (i.e. without the inclusion of a binder) were two additional attributes of Mix 1 that helped this decision.

4.7.1 – Sample preparation

In this research work, it was necessary to build a 0.75 m × 0.65 m (width × height) sample of a *tabique* wall, Figure 11. In this part, the used timber structure is also a portion of the timber structure of the real *tabique* wall depicted in Figure 2.a. *Pinus pinaster* was the identified species of the timber elements of the wall. The timber structural system of the wall is composed of vertical timber boards connected to each other by timber horizontal boards, which are nailed on the vertical boards on both sides. In terms of medium values, the vertical boards presented a width of 0.164 m, a thickness of 0.025 m and a gap between them of 0.003 m. Meanwhile, the horizontal boards had the following average dimensions, width of 0.026 m and thickness of 0.018 m, and they were separated from each other by 0.021 m. Mix 1 was the earth render applied on the timber structure, on both sides, in order to wrap completely the timber elements and to assure a 0.015 m thickness layer of covering. Thus, this wall system has a thickness of 0.091 m. After the application of this earth render on the timber structure, the drying process occurred during thirty consecutive days under the controlled thermal-hygrometric conditions of the laboratory. After this period of time, the *tabique* wall sample was ready to be thermally tested.

4.7.2 – Experimental set up

The experimental work was performed in a laboratory, where a thermal test room was used as an alternative solution of a thermal test cell. The thermal test room measures are 4.00 m × 3.00 m × 2.54 m (length × width × height) and it is thermally controlled. This experimental procedure has been successfully applied in previous research works such as [18]. To guarantee the validity of the experimental work it was necessary to ensure that the temperature of the internal environment remained stable and always higher than the temperature of the external environment. An approximately constant interior

temperature of the thermal test room was guaranteed by using a domestic heater in the room which was continuously switched on during the test performance. This control of the temperature allows the heat flux to occur always from inside to outside.

The sample of the *tabique* wall replaced an existing window in the northeast façade of the test room, Figure 12. The sample was carefully fixed to the wall of the test room by polyurethane foam (II, Figure 12). This fixation solution also avoided undesirable insulation voids, thermal bridges, non-insulated headers and other faults which may compromise the feasibility of the final thermal results.

According to ISO 9869 [19], the recommended equipment apparatus is composed by two heat flowmeters (1 and 2, Figure 12.a), four surface temperature sensors (III, Figure 12.a), two ambient temperature sensors, a data logger and a computer. Both heat flowmeters and surface temperature sensors were fixed in the middle of the inner face of the wall, Figure 12.a. The interior and the exterior temperatures ($T_i(n)$ and $T_e(n)$) were measured using thermo hygrometric equipment kept indoors and outdoors, respectively. In this research work, the temperatures ($T_i(n)$ and $T_e(n)$) and the heat flow across the wall model ($q1(n)$ and $q2(n)$) were measured continuously (in-between 10 minute intervals (n)). The heat flowmeters 1 and 2 (Figure 12.a) measured the heat flow occurring across the wall sample $q1(n)$ and $q2(n)$, respectively.

Although the values obtained from the four temperature sensors are not directly used for calculating the thermal transmission coefficient of the analysed sample, they allow verifying if the values obtained during the measurement period are reliable. If any of the acquired values fall outside the magnitude of the remaining values, it is necessary to identify the cause and remove those values from the measurement period. Similar

analysis is performed for the relative humidity values obtained using the thermo hygrometric equipment. The values of these parameters are therefore used to identify influencing variables of the experimental test, contributing to its validation.

There was no drying shrinkage cracking appearance due to drying of the *tabique* wall sample as Figure 12 shows.

4.7.3 - Methodology

The methodology used to analyse the thermal insulation performance of the *tabique* wall sample was based on an experimental work done according to ISO 9869 entitled Thermal Insulation: Building Elements – In Situ Measurement of Thermal Resistance and Thermal Transmittance [19]. According to the international standard [19], the thermal transmission coefficient (U) of a material or a building system can be quantified applying Equation 1.

$$U(ntotal) = \frac{\sum_{n=1}^{ntotal} q(n)}{\sum_{n=1}^{ntotal} (Ti(n) - Te(n))} \quad (1)$$

In which, $q(n)$ is the heat flow across the wall sample in the moment n ; $Ti(n)$ and $Te(n)$ are the interior and the exterior temperatures in the moment n , respectively; $ntotal$ is the total number of moments in which the data was collected.

Taking into account that two heat flowmeters were used corresponding to $q1(n)$ and $q2(n)$, it is possible to estimate two thermal transmission coefficients, $U1(ntotal)$ and $U2(ntotal)$, which are the thermal transmission coefficients related to the data registered by the heat flowmeters 1 and 2, respectively, by applying Equation 1. Thus, the thermal

transmission coefficient of the wall model ($U'(ntotal)$) is the average value of $U1(ntotal)$ and $U2(ntotal)$ and according to Equation 2.

$$U'(ntotal) = \frac{U1(ntotal) + U2(ntotal)}{2} \quad (2)$$

According to the standard [19], a minimum of three days test duration is required if the temperature is stable around the heat flowmeters. Otherwise, this duration may be more than seven days for precaution depending on the thermal inertia of the building component. Based on the above described constitution of the *tabique* wall sample, the respective thermal inertia of this type of traditional building element may be considered low and, consequently, a minimum of three days test duration is acceptable according to [19].

4.7.4 – Experimental results and discussion

The thermal insulation test was performed during April and May of 2012, having duration of fourteen days, Figure 13. Therefore, the three days recommended minimum test duration was guaranteed. In fact, three days was approximately the required time to stabilize the interior temperature (*At stabilizing*) of the room. As it was stated earlier, this interior thermal condition was achieved by using a domestic heater in the test room which was constantly switched on during the test. It was possible to stabilize the interior temperature of the test room around 35°C. In terms of exterior temperature, the collected data is in accordance with the expected temperature in the northeast part of Portugal and for the respective period of time of the year according to the Portuguese Institute of the Sea and Atmosphere [20]. For these conditions (region and time of the year), the data concerning the exterior temperature also express clearly the natural

variation of temperature in a day time (day and night periods), Figure 13. The interior temperature is more stable and higher than the exterior temperature. Therefore, the achieved thermal gradient between interior and exterior temperatures (ΔT) during the tests is adequate to apply the methodology already presented. These thermal conditions provided the occurrence of a desirable continuous heat flow across the wall sample from the inside to the outside. It is important to guarantee this thermal particularity in order to evaluate the thermal insulation performance of the analysed building systems.

The values of the heat flow, $q1(n)$ and $q2(n)$, are similar, which allows obtaining reliable values of the thermal transmission coefficient (U). Therefore, the thermal transmission coefficient of the wall sample (U') of $1.59 \text{ W/m}^2\text{°C}$ was estimated, by applying the data of Figure 13 in Equation 1, followed by the application of Equation 2.

Comparing this value with the other obtained for constructive solutions currently used in building construction, it can be concluded that the tested *tabique* wall has a good thermal performance taking into account its thickness. For example, a single exterior wall made by regular drywall concrete blocks with 20 cm has a U value of $1.9 \text{ W/m}^2\text{°C}$, which demonstrates a better performance in the case of the *tabique* wall.

The knowledge of the U value of this traditional solution can also be useful to define energy rehabilitation solutions to improve the thermal performance of this type of buildings and to achieve the current thermal requirements.

5 – Conclusions

A granite related earth formed by 20% of thin particles and 80% of medium sized particles is a commonly applied soil in the *tabique* context. Traditionally, a simple earth render is an applied solution of filling of the timber frame of *tabique* components.

A local soil sample was used to conduct the experimental work related to this research. Its selection was based on a granulometric analysis in which a real filling of a *tabique* wall was used as reference. Six different mixes of earth render were studied. The amount of water to incorporate, the inclusion of a hydraulic binder and the type of the hydraulic binder were the main parameters analysed. Traditionally, simple lime based earth renders are the building solutions applied in the *tabique* construction.

An evaluation procedure of the performance of earth renders for *tabique* application purposes is proposed and conducted in this research work. Mechanical properties (e.g. flexural and compressive strengths), workability, drying shrinkage cracking and water resistance were considered the main material properties of the characterization of the performance of this type of render.

The mechanical behaviour of an earth render, in particular the bending and the compressive strengths, tends to improve when the water content is reduced or when a hydraulic binder is considered. The inclusion of lime rather than cement seems to be a better option. It is also a traditional building practice. A methodology of evaluating the workability of earth render for *tabique* building applications is proposed. An earth render process according the ratio of 5:1 (soil:water) has shown a proper workability in this building context. Alternatively, the ratios of 20:3.8:1 and 12.5:2.5:1 (soil:water:lime) have also behaved adequately in terms of workability.

In this case, an inclusion of a hydraulic binder such as lime or cement did not seem to improve the behaviour of an earth render in terms of the susceptibility of appearance of cracks due to the drying shrinkage phenomenon. In contrast, simple earth render behaved adequately and independently of the amount of water considered in the mixture.

An earth render of *tabique* construction tends to be susceptible to water. A water resistance test was performed in order to simulate in laboratory the mechanical effect of the rain falling on a *tabique* wall. The obtained results indicate that the inclusion of a hydraulic binder as a constituent may improve significantly the water resistance of a *tabique* wall. In particular, if the hydraulic binder is lime.

A simple earth render having a composition (ratio in terms of weight) of 5:1 (soil:water) was selected to be applied in the process of a traditional *tabique* wall sample to be tested in terms of thermal insulation behaviour. This type of earth render proved to be adequate for this application. The thermal transmission coefficient (U') of a typical traditional *tabique* wall sample has been estimated as 1.59 W/m²°C. In this case, the thermal behaviour of a system (timber structure and earth filling) was assessed in spite of the thermal behaviour of a single material. It is important that future research work consider different types of renders and timber structures of *tabique* wall systems.

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Tables

Table 1: Analysed earthy render mixes

Mix	Amount of the constituents			
	Soil (g)	Water (ml)	Lime (g)	Portland cement(g)
1	6000	1200	0	0
2	6000	1050	0	0
3	6000	900	0	0
4	6000	975	0	150
5	6000	1150	300	0
6	6000	1200	480	0

Table 2: Qualitative assessment of the technological parameters (scale 0 to 5 being 0 worst and 5 the best)

Technical characteristic	Mix 1	Mix 2	Mix 3	Mix 4	Mix 5	Mix 6
Mixing	5	3	2	2	3	3
Adhesion	3	3	1	3	4	4
Handling	4	4	2	3	3	3
Finishing	4	3	2	4	4	4
Rate	16	13	7	12	14	14

Table 3: Water resistance testing results (h - hours; min - minutes; s - seconds)

	Duration (h:min:s)	Number of drops
Mix 1	0:38:15	4590
Mix 2	0:44:32	5344
Mix 3	0:51:47	6214
Mix 4	4:27:17	32074
Mix 5	24:00:00	172800
Mix 6	24:00:00	172800

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a)

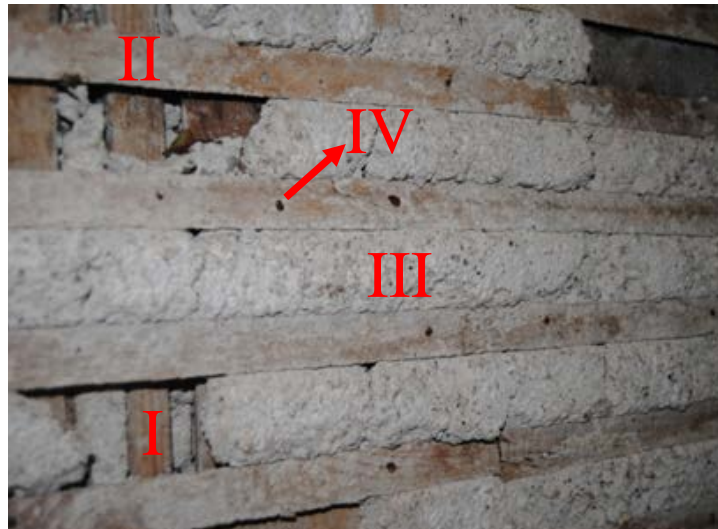


b)

Figure 1: Examples of *tabique* dwellings



a)



b)

Key: I – vertical board; II – horizontal board; III – earthy render; IV – nail

Figure 2: Used *tabique* wall: a) wall and b) detail



Figure 3: Studied materials in terms of granulometry: a) earth render of the reference tabique wall sample and b) collected soil

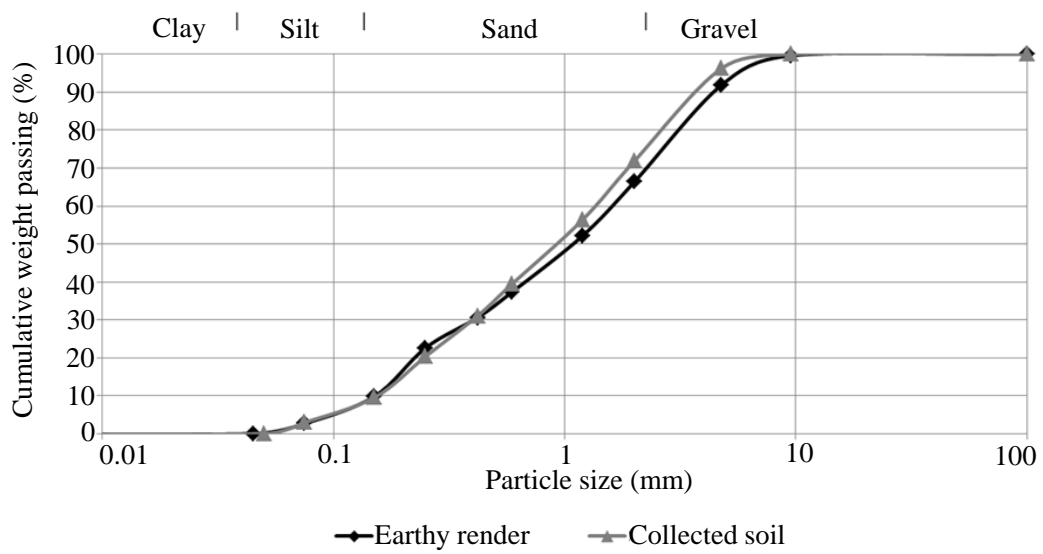


Figure 4: Granulometric curves

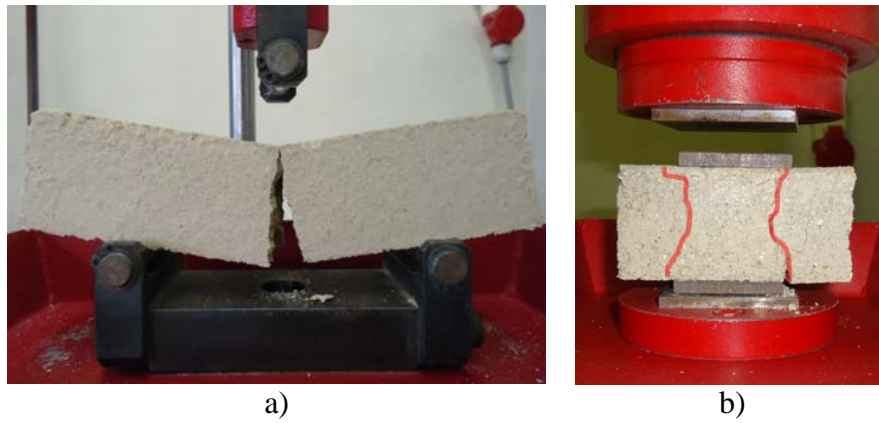


Figure 5: a) Bending test (Mix 5) and b) compression test (Mix 1)

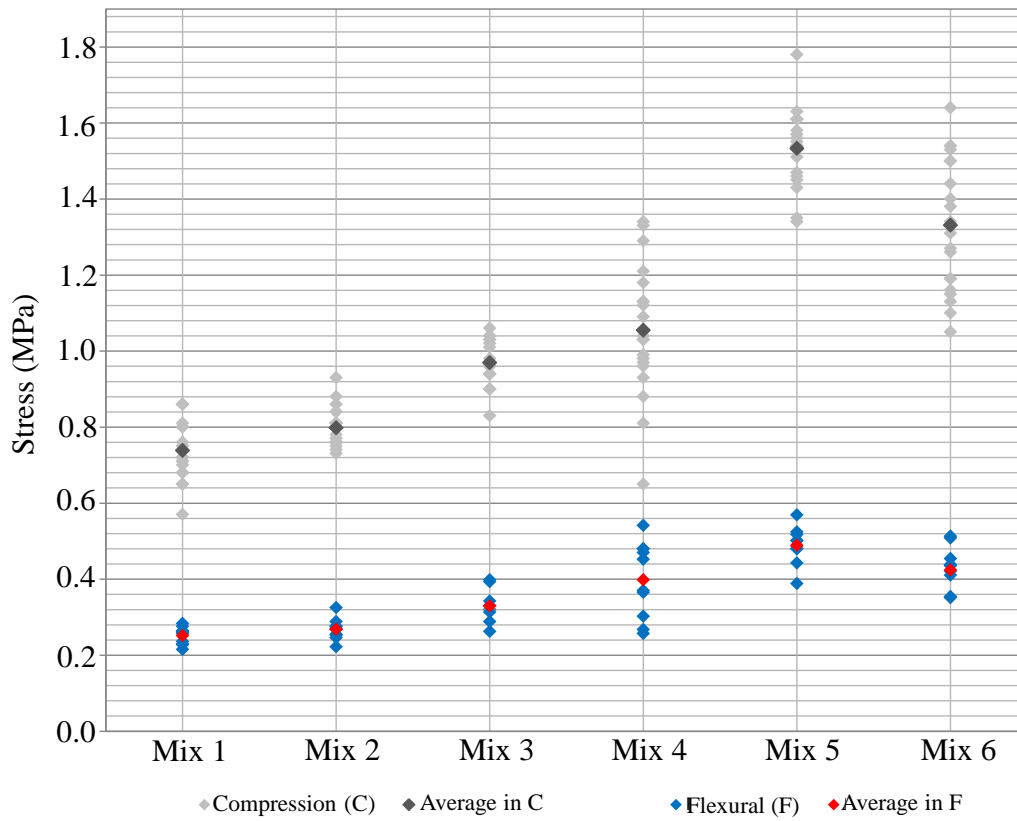
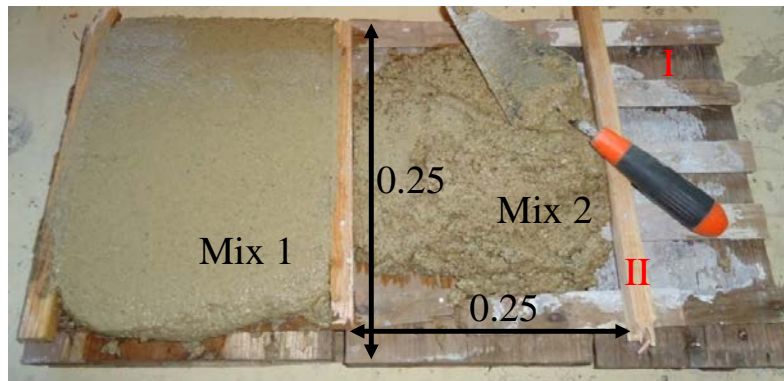


Figure 6: Flexural (F) and compressive (C) strengths



Key: I – portion of a timber structure of a *tabique* wall; II – auxiliary timber board
Figure 7: Workability assessment (units in metres)

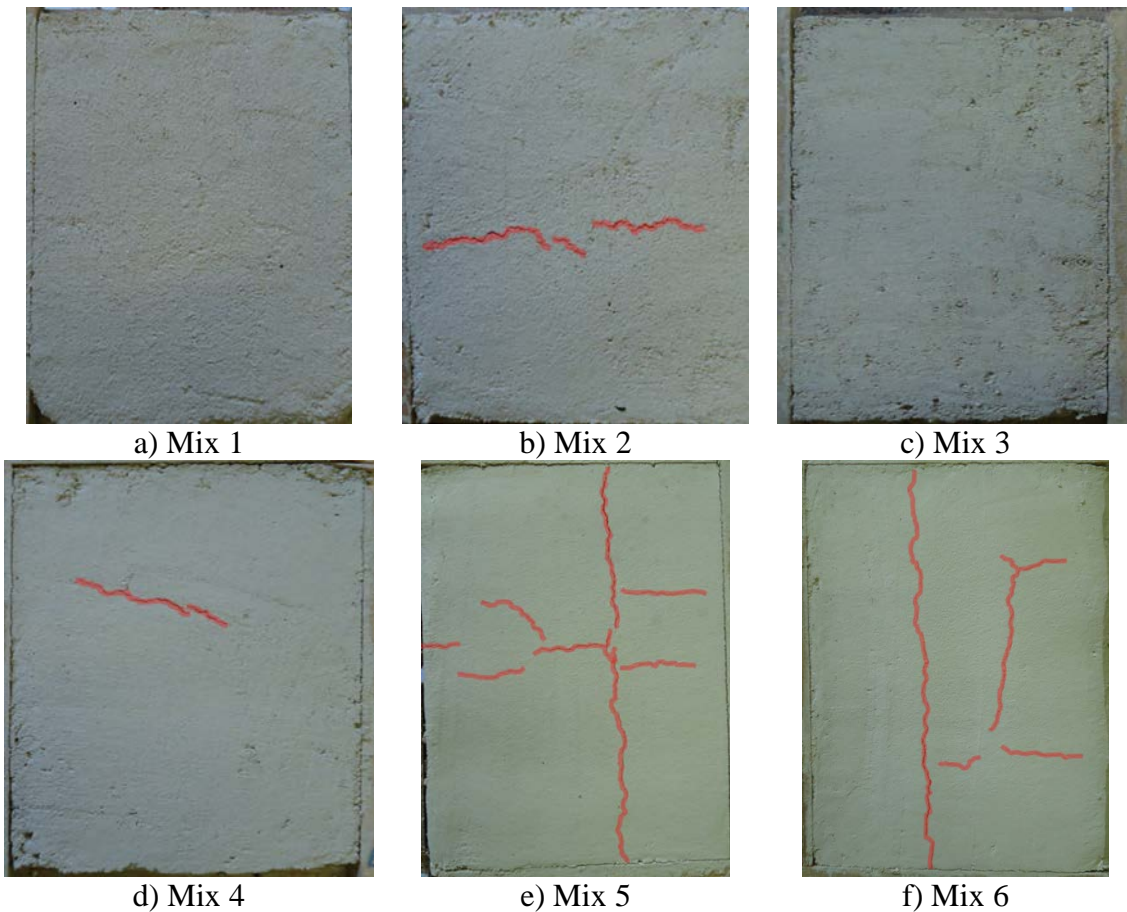
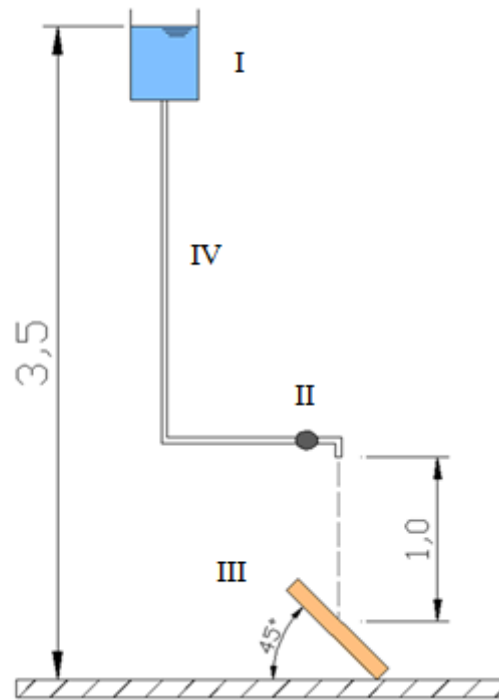


Figure 8: Drying shrinkage cracking (samples aged of 30 days)



Key: I – water tank; II – dropper device; III – earthy filling sample; IV - pipe
Figure 9: Adopted water resistance testing set up (units in metres)

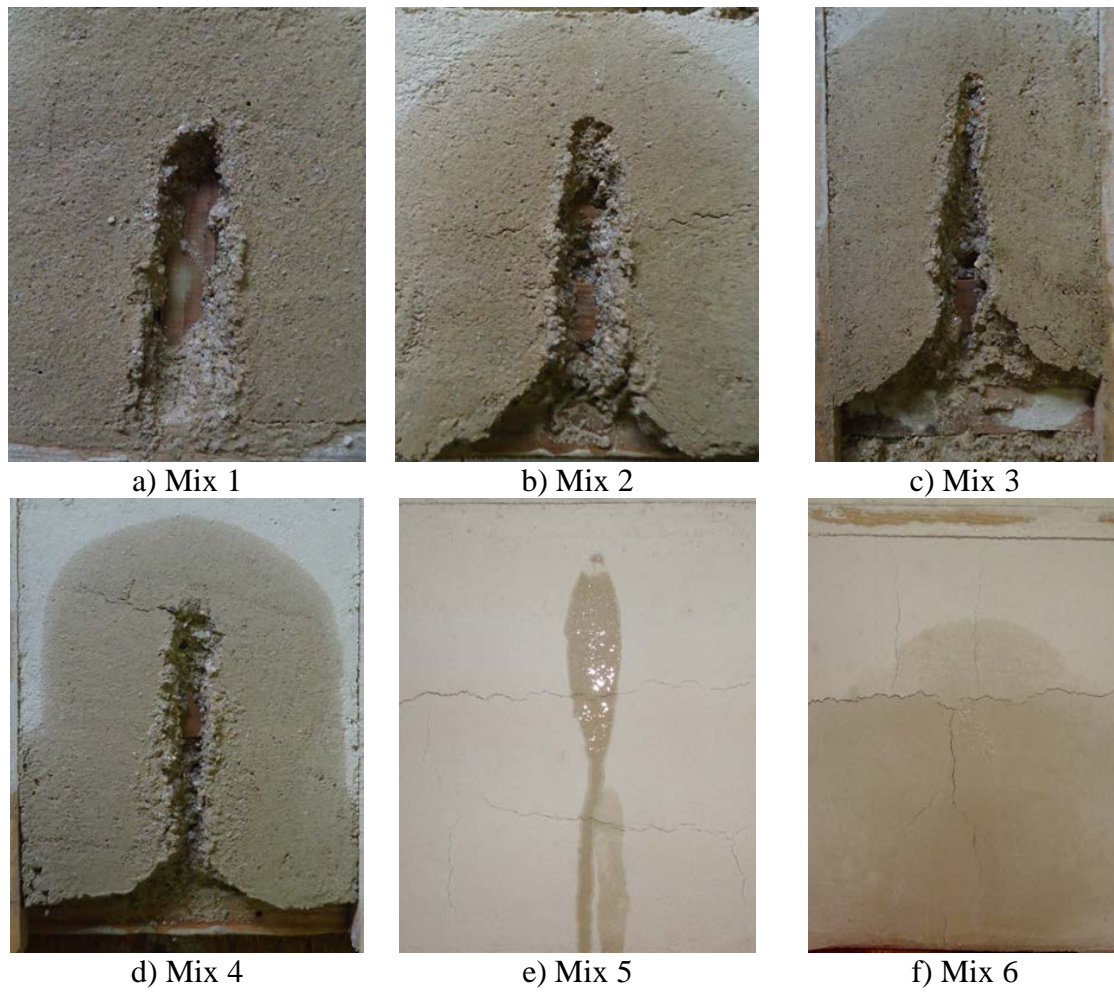
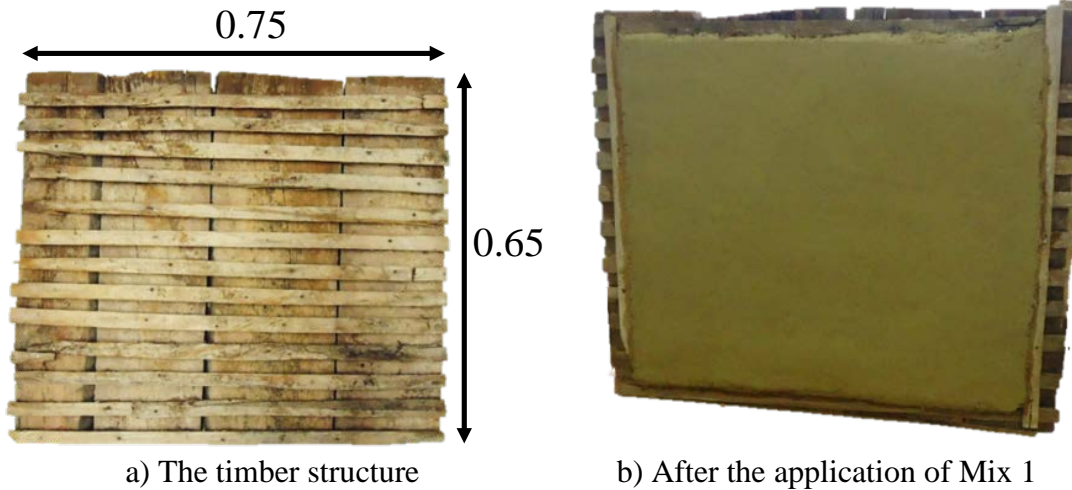
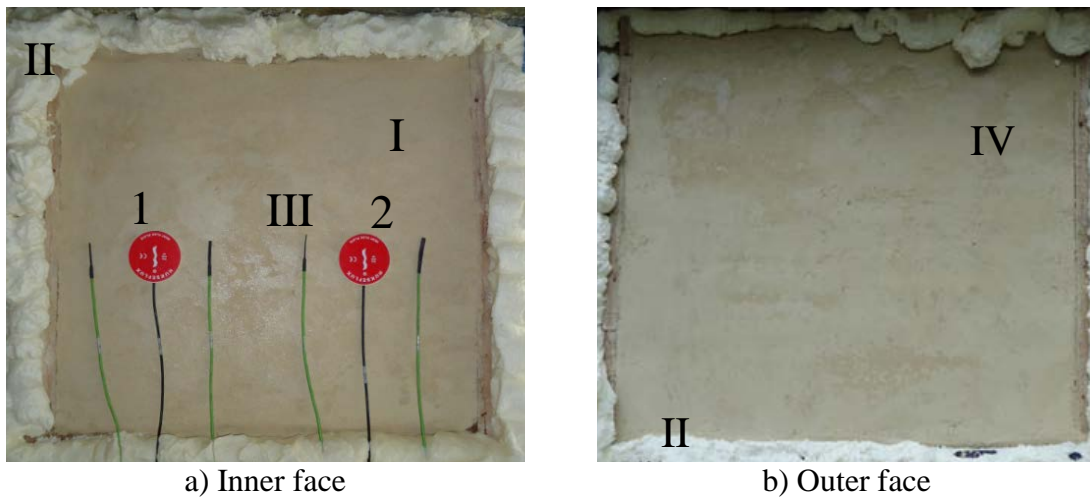


Figure 10: Results of the water resistance test

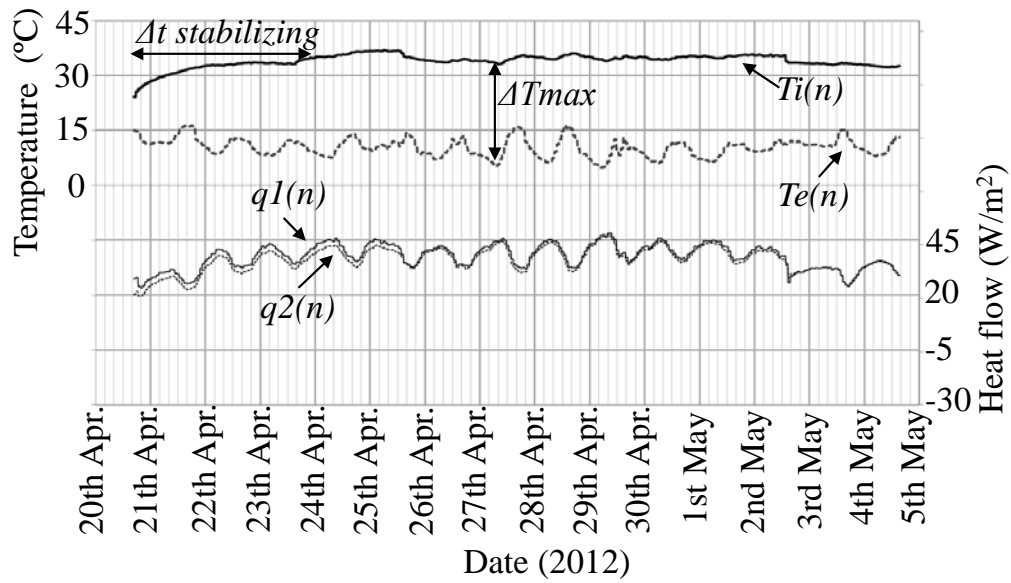


a) The timber structure b) After the application of Mix 1
Figure 11: Building systems of the *tabique* wall sample for thermal insulation testing purposes



a) Inner face b) Outer face
Key: I – Inner face of the wall sample, earthy render finishing; II - Polyurethane foam; III – Temperature sensors; IV – Outer face of the wall sample; 1 and 2 – Heat flowmeters.

Figure 12: Thermal insulation test in progress



Key: $Ti(n)$ – Interior temperature; $Te(n)$ – Exterior temperature; $q1(n)$ and $q2(n)$ – Heat flow measured by the heat flowmeters 1 and 2, respectively; ΔT_{max} – Maximum thermal gradient; $\Delta t_{stabilizing}$ - required time to stabilize the interior temperature of the test room.

Figure 13: Data from the thermal insulation test of the *tabique* wall specimen