

## EXPERIMENTAL CAMPAIGN ON THE USE OF THE FLAT JACK TEST IN COB WALLS

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**Abstract.** *The flat jack test is one of the most used investigation techniques in the area of architectural heritage conservation. Unfortunately, there are no results available in the literature reporting the use of the flat jack technique in cob walls. This paper presents the first experimental campaign performed to validate the use of this Minor Destructive Technique (MDT) to determine the levels of stress in cob walls and their mechanical properties. Furthermore, three workshops organized and facilitated with the aim of increasing public engagement and awareness towards the conservation of earthen vernacular architecture are also presented.*

### 1 INTRODUCTION

The flat jack test was first developed and applied in the study of rock mechanics [1]. After its adoption in the years 1980s by Rossi for its use in masonry walls, the method has been used by several researchers to determine the level of stresses and the mechanical properties of ashlar, brick and stone masonry, as well as of, adobe and rammed earth walls [2].

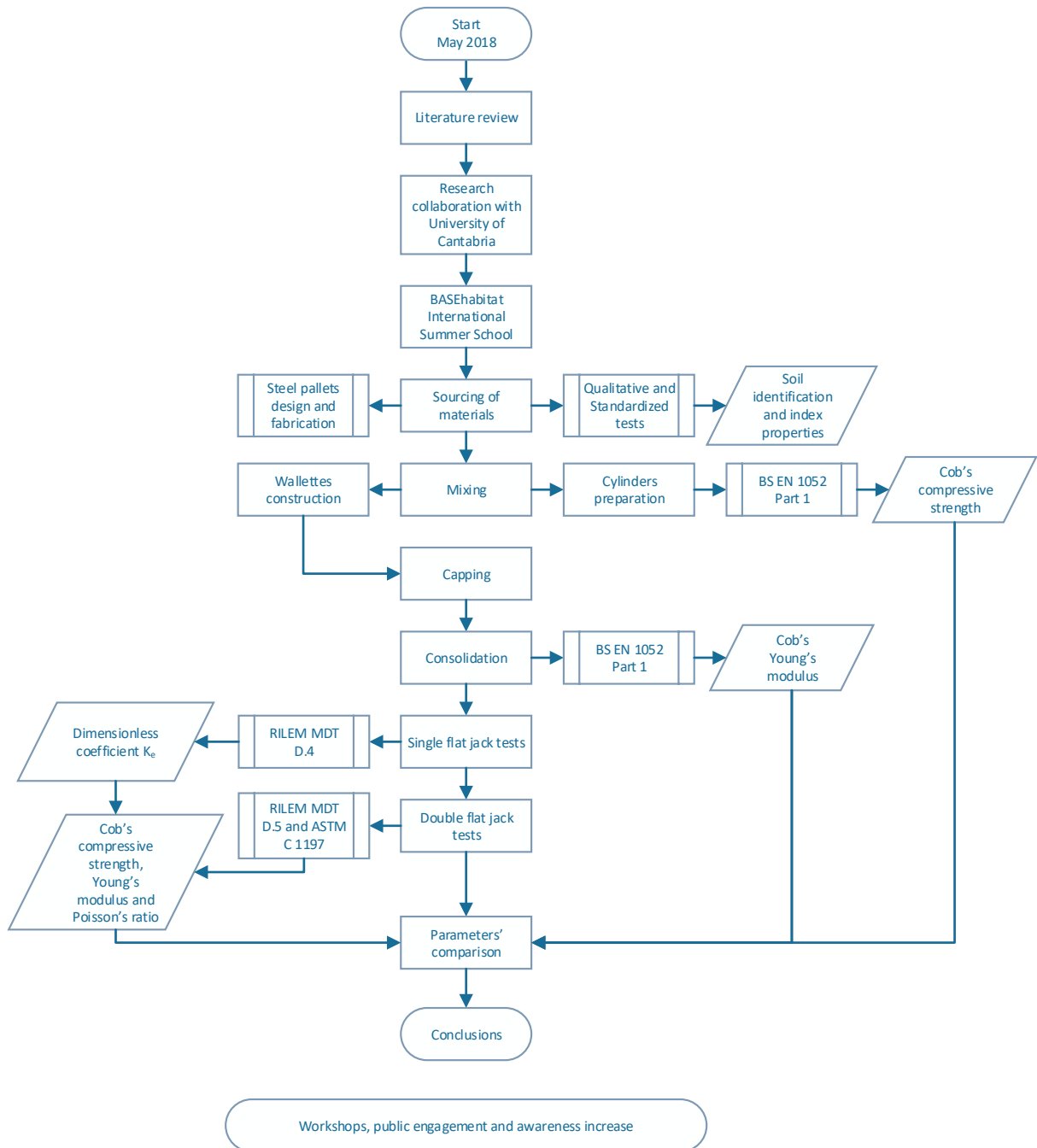
Cob is an earthen construction technique that was traditionally used in at least 18 European countries [3], and many others around the world [4], to build, mainly, dwellings and farming buildings. Cob elements are as well present in 29 UNESCO World Heritage Sites as highlighted by the World Heritage Inventory of Earthen Architecture [5].

Despite the widespread presence of cob buildings and the popularity of the flat jack test among conservation engineers, no results have ever been reported on the application of this Minor Destructive Technique (MDT) on such kind of wall typology.

This paper presents the description of the first laboratory experimental campaign to assess the feasibility of the application of the flat jack test to determine the stress levels and the mechanical properties of cob walls.

### 2 EXPERIMENTAL CAMPAIGN

The experimental campaign started in the spring of 2018 with the literature review of the topic (see Figure 1 where the followed methodology is presented in a diagram form).



**Figure 1:** Methodology's steps implemented during the experimental campaign.

The necessary technical knowledge to implement the flat jack test technique was acquired thanks to a research collaboration carried out at the University of Cantabria (UC) in Santander, Spain, during the months of June and July 2018. The expertise and know-how acquired during this period proved to be invaluable for the success of the flat jack tests performed in this experimental campaign.

The traditional cob construction technique was learned by the first author during his

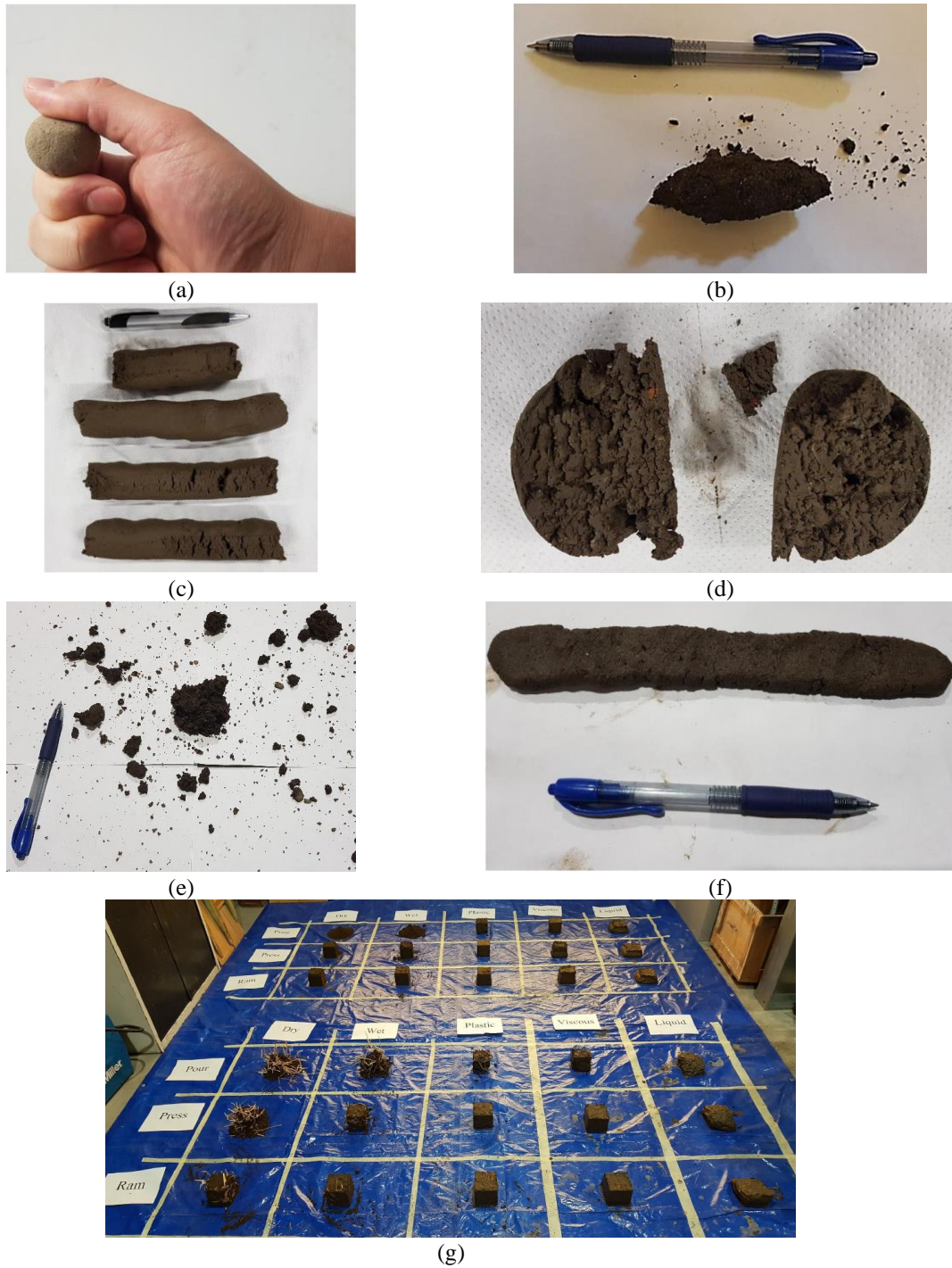
participation at the International BASEhabitat Summer School organized by the University of Linz, Austria. In this event, experienced earthen builders and researchers, taught the traditional skills used in France, UK and Ireland to build vernacular cob walls and these skills were used to build the wallettes at the laboratory of Civil Structural and Environmental Engineering (CSEE) in Trinity College Dublin (TCD).

The basic raw materials needed to build a cob wall are: straw, water and soil. It was intended to build the wallettes of this experimental campaign in a sustainable way and to try to reproduce the characteristics of a historical cob wall as closely as possible. Thus, materials were sourced locally, and traditional construction methods were used. The selection of the raw materials was based on recommendations provided by several authors [6–12]. Those recommendations are mainly concerned with the water quality, the type and the length of the straw, the clay content and the Particle Size Distribution (PSD) of the soil.

Qualitative soil tests have been traditionally used by vernacular builders, who had no access to complex equipment and laboratory facilities, to assess the suitability of the material for earthen construction purposes. These tests are highly related to the human senses and provide basic information about the constitution of the soil and of its behavior. The advantages of qualitative tests are their simplicity, easiness, low-cost and their relatively fast data obtainment. On the other hand, the interpretation of qualitative tests is subjective and depends on the experience and personal judgement of the test performer. Qualitative tests were performed on a sample of soil collected directly from the soil supplier yard. Those tests are shown in Figure 2.

To classify and determine the basic properties of the soil the standards followed in this experimental campaign were the BS 1377: Methods of test for soils for civil engineering purposes Part 1: General requirements and sample preparation [13], Part 2: Classification tests [14] and Part 3: Chemical and electrochemical tests [15]. Based on the data obtained from these standardized tests, the soil was identified and classified in accordance with BS EN ISO 14688 Geotechnical investigation and testing – Identification and classification of soil Part 1: Identification and description [16] and Part 2: Principles for a classification [17], respectively. Standardized tests were performed on a sample of soil obtained from the 1 m<sup>3</sup> bags delivered by the soil supplier.

The components' mixing proportions were based on recommendations given by several authors [11–12–18–19] and adopted to the physical constraints of the laboratory of CSEE in TCD. Thus, mixes of 80 kg of soil with 1.2 kg of straw and 12 kg of water were adopted. Each one of the mixes provided enough material to build a layer of approximately 10 cm height. Thus, in average, 10 mixes were necessary to build each one of the wallettes with approximate dimensions of 100 cm length by 100 cm height by 40 cm thickness.

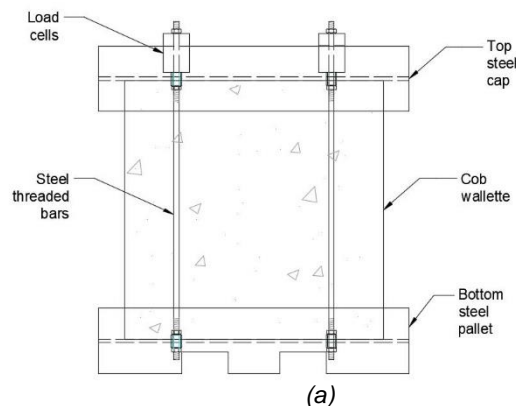


**Figure 2:** Qualitative tests performed, namely, (a) pressing ball, (b) touching, (c) cigar, (d) ball cutting, (e) ball dropping, (f) ribbon and (g) Carazas.

The cob wallettes were built on top of steel pallets to facilitate their transportation around the laboratory. Moreover, a top cap was also fabricated with the idea of connecting it with the

bottom pallet through threaded steel bars and applying low compression force during transportation of the wallettes in order to avoid damaging the walette due to vibrations that might have led to tensile stresses and therefore the opening of cracks. The steel bottom pallets and top cap were designed using a universal beam (UB) 533x210x82 section (this section was selected to accommodate the dimensions of the cob wallettes and of the pallet jack used in the laboratory). The bottom pallets were perforated at four locations of their flanges to allow the pallet jack to go beneath them. On the other hand, four C-channel section segments were welded to the web of the top cap to act as points of attachment and provide symmetric points of attachment for the crane's chains, thus allowing the lifting of the wallettes. Finally, four pieces of hollow steel tube were welded to both bottom and top UB flanges to provide the points of connection of the threaded bars.

Once the loam was readily mixed, it was divided into balls of approximately 20 to 30 cm in diameter. The balls were thrown to the steel pallet to build the first 10 cm layer of the first 30 cm lift of each one of the wallettes. Balls were thrown being careful to assure overlapping with previous balls and moulded with the fingers to try to fill all voids. The lifts were built a couple of cm bigger than the marked area of 0.4 by 1.0 m on the steel pallets with the aim of avoiding having any holes or cavities at the faces after the pairing of the surfaces. Once the bottom lifts achieved the desired height their top surface was marked with the fingers in order to create holes that would improve the interlocking with upper lifts. The pairing of each one of the wallettes' lifts was done four or five days after their construction and before adding the next lift on top of them. A timber saw was used to remove the extra material protruding from the faces and a bubble level was used as guidance to achieve verticality of the wallettes' faces. After the first lift was paired the second lift was added ensuring that extra material would protrude over the sawn faces. Furthermore, the top surface of the second lift was also finger-marked to ease the interlocking of the last lift. Again, after a short drying period (4 or 5 days) the second lift was paired using the timber saw and the bubble level. Next, the last lift was added and subsequently paired. They wallettes were built in three lifts, 30 cm, 30 cm and 40 cm height respectively. All dimensions varied by  $\pm 2$  cm due to the inherent variability traditional construction process adopted. The wallettes were stored indoors for a drying period of 4 months under uncontrolled environmental conditions. A diagram of the built specimens is presented in Figure 3.



**Figure 3.** Diagram of the built cob wallettes.

To ensure a horizontal top surface and consequently an even distribution of the compressive load the wallettes were capped with a layer of cement mortar. Timber formwork was clamped to the wallettes and levelled with the help of a bubble level. The cement mortar was placed on top of the wallette and levelled with a straight piece of timber. The finished surface was completely flattened and cured for several days with the application of a wet hessian cloth.

In a parallel process, six cylinders were prepared, using randomly sampled material from the cob wallettes' mixes, with the objective of performing compressive tests on them to estimate cob's compressive strength. This data would give a point of reference to establish the consolidation and test loads to be applied to the wallettes. The cylinders were prepared using 15 cm diameter by 30 cm length steel molds. The mold was filled with six or seven layers of cob. Every layer was tamped by hand, pressing with the fingers to try to fill all the voids. This preparation procedure is similar to the one implemented by Pullen and Scholz [20].

After a four-months drying period the pre-consolidation of the wallettes began. The pre-consolidation load applied to the wallettes was fixed taking as reference the mechanical properties obtained from the cob cylinders tested in this experimental campaign. It was decided not to exceed the apparent yield point of cob which corresponded approximately to 30 % of the computed average compressive strength of the cylinders (0.7 MPa). Therefore, the wallettes were subjected to a consolidation force of 84 kN +/- 1 kN.

The loading set-up consisted in 4 treaded bars fixed at the bottom and top steel pallets which were tensioned by tightening the nuts at the top. The tightening of the nuts was performed manually, in increments of approximately 2 kN per bar, and the initial loading process, going from 0 up to 85 kN took approximately 15 to 20 min for each wallette. The tension forces thus applied caused the shortening of the bars, deformation that subsequently translated into a compressive force applied to the cob wallettes. Therefore, loads were applied slightly eccentrically but in a symmetric way as the points of anchorage of the bars were located at the external faces of the steel pallets flanges. A load cell was installed between each point of support at the top steel pallet and the nut to measure the load transferred for each one of the bars to the wallette. The total load transferred to the wallette was calculated as the sum of the four bars' forces.

Four linear variable differential transformers (LVDT) were attached to the wallettes' faces, two in the front and two in the back, to measure the deformation caused by the compressive forces. The LVDT's were pinned through the material using stainless-steel pins of roughly 5 to 6 cm length by 2 mm diameter. The points of support were held in place at an initial distance of roughly 30 cm at the middle third of the specimens. This arrangement was in agreement with BS EN 1052 Part 1 [21].

The procedures described in ASTM C 1196 Standard test method for in-situ compressive stress within solid unit masonry estimated using flat jack measurements [22] and in RILEM LUM D2/MDT D4 In-situ stress tests on masonry based on the flat jack [23–24], specialized in masonry walls, were adopted and adapted to perform the single flat jack test in the cob wallettes of this experimental campaign. Similarly, the procedures described in ASTM C 1197 Standard test method for in situ measurement of masonry deformability properties using the flat jack method [25] and in RILEM LUM D3/MDT D5 In-situ stress/strain behavior tests based on the flat jack [26–27], were adopted and adapted to perform the double flat jack test.

The data obtained during the experimental campaign can be consulted elsewhere [28].



### 3 WORKSHOPS

As this experimental campaign aimed at increasing awareness regarding the importance of conservation of vernacular architecture, the experimental campaign was used to involve a great number of people and disseminate the acquired knowledge about the subject. Academics, technical staff, researchers, as well as undergraduate students and the general public participated in the different activities developed during this experimental campaign related to the conservation of earthen vernacular buildings and the use of natural materials for sustainable construction purposes.

Two one-day workshops were run. In the first one, undergraduate students were invited to attend a morning presentation on the conservation of earthen vernacular buildings in Ireland and to participate in the construction of the wallttes of the experimental campaign. The second workshop was organized within the framework of the Trinity Green Week 2019. The Trinity Green Week is an annual environmentally themed event with a multitude of events to stimulate the mind and engage the soul in creating better world citizens. Both students and the general public were invited to participate in this second workshop. Participants to both workshops are shown in Figure 4 (a) and Figure 4 (b), respectively.

Finally, students of architecture from University College Dublin (UCD) and from the Dublin Technical University (DTU) were invited to the laboratory of TCD. The students were given a presentation on the main aspects of the experimental campaign performed. After this, a tour around the laboratory facilities was conducted where they could see the specimens that were built and tested along with the flat jack tests' equipment that was used in the experimental campaign (Figure 4 (c)).



(a)



(b)



(c)

**Figure 4:** Cob workshops' participants.

### 4 CONCLUSIONS

The flat jack test is one of the most applied investigation techniques in the area of cultural heritage conservation, where the information obtained with this method is used, to assist in the structural safety evaluation of existent structures. The experimental campaign carried out and presented in this paper provided the first results of a flat jack test ever performed in a cob wall.

Another important part of this research comprised the series of public engagement and awareness increase activities performed around the experimental campaign presented in this work. The discussions that took place during and after the workshops proved to be extremely

rich, especially due to their multidisciplinary character and the different backgrounds and previous experiences of the participants of the events.

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